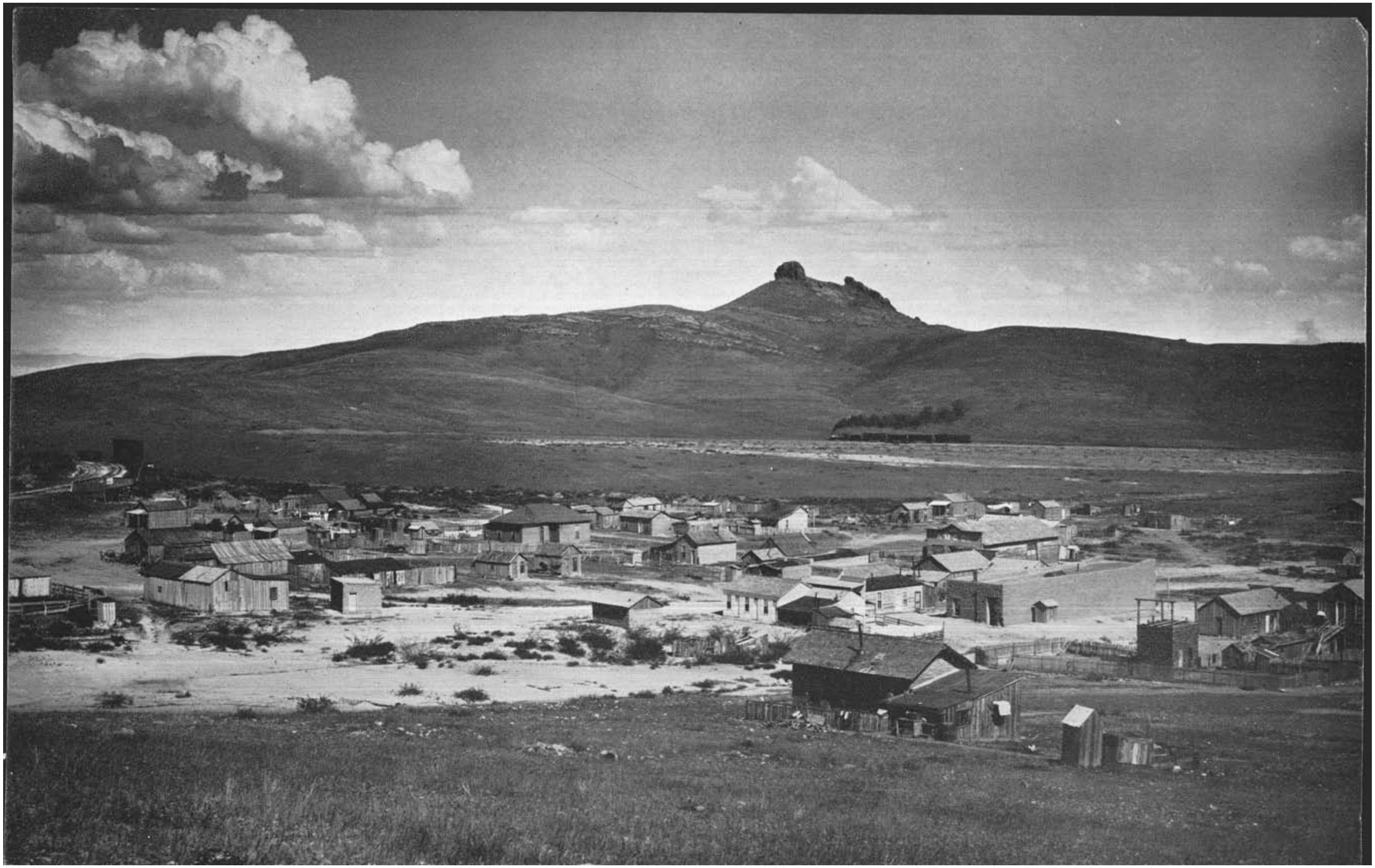

BULLETIN 37

Geology and Mineral Deposits of Lake Valley Quadrangle, Grant, Luna, and Sierra Counties, New Mexico

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Stratigraphy and structure of sedimentary and volcanic rocks and descriptions of mining districts

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STATE BUREAU OF MINES AND MINERAL RESOURCES
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FRONTISPIECE
VIEW OF LAKE VALLEY (circa 1905).

TOWN OF LAKE VALLEY IN THE LAST DAYS OF THE SILVER BOOM. COMPARE WITH PLATE 2-A. *Picture by Henry Schmidt, from the collection of Raymond Schmidt.*

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Abstract

Lake Valley quadrangle is located about 15 miles north of Deming, in southwestern New Mexico. The area is nearly flat in the southeast, but becomes increasingly rugged in the northwest and southwest, where locally the relief exceeds 1,000 feet.

One of the main structural features is the north-south trending Mimbres Range, a faulted anticlinal "high" which extends along the west side of the quadrangle as an extension from the Black Range anticline to the north. The Mimbres Mountains terminate at a regional fault which separates them from Cooks Range, a large faulted mass of Precambrian, Paleozoic, and Mesozoic rocks cut by intrusions, in the southwestern corner of the area. A third large structural feature is the Lake Valley fault block in the northeast, in which early and middle Paleozoic limestones and shales have been raised to the level of the surrounding Tertiary volcanics. Lesser faults of general north-south and east-west trend are found in many areas, but are difficult to trace for any distance in the volcanic rocks.

Every geologic period, with the exception of the Triassic and Jurassic, is represented by at least one formation. Above the granitic Precambrian basement lies a series of Paleozoic and Mesozoic limestones, sandstones, and shales, represented completely only in Cooks Range. The Tertiary system is represented largely by volcanics, which cover about two-thirds of the area. The earliest series, made up of pyroxene andesites, is followed by pyroxene andesites and lathes, which have been intruded by northeast-trending porphyry dikes. Later, quartz latite tuffs and rhyolitic flows were deposited on an erosion surface on the pyroxene andesites and latites. The rhyolites were succeeded by pyroxene andesites and basalts. During Tertiary time there were several periods of erosion and at least one period of faulting. A thick series of fanglomerates, the Santa Fe (?) formation, which covers a large part of the southern and western area of the quadrangle, was laid down probably in Pliocene or Pleistocene time. Uplift and erosion in Pleistocene and Recent time have yielded the present topography. Late gravels and alluvium were formed during the last erosion cycle.

The five mineralized areas in Lake Valley quadrangle are: the Lake Valley mining district, characterized by oxidized silver-manganese replacement deposits in the Lake Valley limestone; the Macho mining district, which contains lead-silver vein deposits in pyroxene andesites; the Old Hadley-Graphic district, characterized by copper-lead-zinc-silver veins in pyroxene andesites; and the Cooks Peak and Jose districts, where lead-zinc-silver replacement deposits occur in the Silurian Fusselman limestone. Lead-zinc deposits were being mined in the Cooks Peak district in 1951. Late in 1953 the Cooks Peak district was inactive, but preparations were being made to mine and concentrate manganese ores in the Lake Valley district, where manganese mining began again early in 1954. Several other smaller prospects also are known. The mineralization is believed to be of Tertiary age, since it occurs both in pyroxene andesites and in Paleozoic rocks.

Masses of perlite have been found in the rhyolite flows.

Introduction

GEOGRAPHY AND PHYSIOGRAPHY

Lake Valley quadrangle forms a part of Sierra, Grant, and Luna Counties in southwestern New Mexico. It lies about 15 miles north of Deming, and about 80 miles northwest of El Paso, Texas. The area is bounded by longitudes 107°30' and 107°45' west and latitudes 32°30' and 32°45' north.

The southeastern part of the qaadrangle includes a part of Lake Valley, a region of low relief between 4,600 and 5,000 feet in altitude, with local relief generally less than 50 feet. To the north and west the terrain becomes more rugged; altitudes of 7,000 feet are common in the Mimbres Range, which forms the western border of the quadrangle, and local relief in this area exceeds 500 feet. The rugged, but short, southeast-trending Cooks Range, marked by deep canyons and steep slopes, lies in the southwest corner of the quadrangle, and may be regarded as the southernmost part of the Mimbres Mountains. Cooks Peak, the highest point in Cooks Range—and a regional landmark, has an altitude of 8,404 feet, or 3,800 feet above the surrounding plains. Drainage in the quadrangle is mostly to the south and east; only a narrow strip on the west drains westward into Mimbres Valley.

The climate is typical of the more moderate, semiarid conditions common to intermediate elevations throughout the southwestern United States. Summers are hot; however, though temperatures above 100°F are common, they are not the general rule. During the winter the temperature seldom drops below 0°F. Annual rainfall averages 10-12 inches, most of it occurring during the summer and winter. In the winter there is an average fall of 12-14 inches of snow. Summer rains are of the intermittent torrential type. Thundershowers, which may provide one or more inches of rain locally in a few hours, cover limited areas during the period from July 1 to September 15.

The flora is as varied as the topography. The highest mountains are covered by pillion and juniper. The lower slopes are sparsely covered by thickets of live oak, hackberry, greasewood, and mesquite. The vegetation on the plains and low, rolling hills is mostly grass, greasewood, and numerous flowering plants, which bloom after the summer rains. Cacti of many species, and several varieties of yucca, occur at all altitudes, but are most common on the lower slopes and plains.

The area is populated only sparsely. The main industry is cattle-raising, and most of the people live on small scattered ranches. During the latter part of the 19th and the early part of the 20th century, mining was an important industry. The rich bodies of oxidized lead, zinc, and silver ore are now for the most part worked out or not minable on an economic basis. Among these was the famous "Bridal Chamber" of the Lake Valley district, a fabulously rich pocket of cerargyrite ore. However, new exploration has led to the reopening and operation of some of the lead-zinc mines of the Cooks Peak mining district on a small scale. The mining of manganese ores in the Lake Valley district is in progress (since early in 1954) in conjunction with the current government program of strategic minerals procurement.

NATURE OF INVESTIGATION

The author spent about 120 days in the field within Lake Valley quadrangle. As the area of the quadrangle is about 251 square miles, it may be seen that most of the work was on a detailed reconnaissance basis only, since it was necessary to cover 1-2 square miles a day. Regional mapping was done on aerial photographs on a scale of about 2 inches to a mile and transferred to a Soil Conservation Service plat. In addition, more detailed studies in important selected areas and examinations of some mines have been made. Therefore, it should be stressed that more detailed work may lead possibly to somewhat different interpretations from those presented here.

ACKNOWLEDGMENTS

Grateful acknowledgment is accorded to Dr. Eugene Callaghan, Director of the New Mexico Bureau of Mines and Mineral Resources, for constructive comments in the field and office, and for extending financial assistance without which this study would not have been possible. To the staffs of the Bureau and of the New Mexico Institute of Mining and Technology appreciation is expressed for their generous advice on some of the field problems. Dr. Robert Balk, of the Bureau, kindly read the paper critically and offered many valuable suggestions. Thanks are due to Prof. C. H. Behre, Jr., of Columbia University, for his encouragement and assistance, and to Messrs. F. D. Eckelmann and Charles P. Valentine, of Columbia University, for their very good work as assistants in the field in 1950 and 1951, respectively. Part of this work has been accomplished with the aid of a grant from the Kemp Memorial Fund of Columbia University. The author wishes also to express his gratitude to the many persons in the region who assisted him in his work by providing information which aided materially in the furtherance of this study.

PREVIOUS GEOLOGIC WORK

Prior to the present investigation no detailed geologic mapping had been done in Lake Valley quadrangle, except for the mapping of the Lake Valley mining district. Darton (1916) published a map of the part of the quadrangle included in Luna County on a scale of 4 miles to one inch. His map was found to be an excellent basis for more detailed work in that part of the quadrangle. The only other map of the area is the state geologic map, published in 1928.

The stratigraphy of the Cooks Range and Lake Valley areas was investigated first by Darton (1916, 1917, 1928) . Detailed stratigraphy of the Lake Valley formation in those areas was discussed by Laudon and Bowsher (1949) . Dr. R. H. Flower, of the New Mexico Bureau of Mines and Mineral Resources, has kindly added to this report stratigraphic analyses of the El Paso and Montoya groups.

Clark (1894) , Keyes (1908) , MacDonald (1908) , Lindgren and Gordon (1910) , Harley (1934) , and Creasey and Granger (1953) have published maps and reports on the Lake Valley district which proved very helpful in the author's description of the area. Harley (1934) also described the Macho district. The Cooks Peak district was described by Lindgren and Gordon (1910) . The latter two reports were useful largely on a historical basis.

Geology

Most of the bedrock areas in the quadrangle are underlain by volcanic rocks of Tertiary age. These include pyroxene andesites, latites, and rhyolites, and their fragmental equivalents. Paleozoic and Mesozoic rocks, mainly limestones, with some sandstones and shales, are exposed only in the northeast and southwest corners of the area. In the southwest, Cooks Range, a large intruded and faulted mass, rises above the general level of the Tertiary flows and pyroclastics, whereas in the northeast, at Lake Valley, a large fault has raised the Paleozoic sediments up to the level of the surrounding volcanics. The southeast is a large area of bolson plains. A wide belt of Tertiary fanglomerates extends from the south-center to the northwest part of the quadrangle. A general stratigraphic section is given in Table 1.

The major regional structural features in the quadrangle are the Mimbres Range, Cooks Range (a southern extension of the Mimbres Mountains) , and the Lake Valley fault block. The Mimbres Range is essentially a much-faulted anticline of Paleozoic limestones, sandstones, and shale, and Tertiary and Quaternary volcanics and gravels, with

TABLE 1. GENERALIZED STRATIGRAPHIC SECTION OF LAKE VALLEY QUADRANGLE*

Modified from Darton (1916, p 19)

SYSTEM	SERIES	FORMATION	THICKNESS (FEET)	CHARACTER
Quaternary	Recent	Alluvium	0-100	Soil, sand, clay, gravel
		Terrace gravels	0-50	Sand, clay, and gravel forming stream terraces
	Recent and Pleistocene	Bolson deposits	0-1000	Sand, clay, and gravel
		Pleistocene (?) gravels	0-200	Soil, sand, and gravel underlying the surface of Pleistocene (?) pediment
Unconformity				
Tertiary	Pliocene-Pleistocene (?)	Santa Fe (?) formation	0-1500	Fanglomerate, fragmental volcanic material, water laid; consolidated sands and gravel
	Oligocene-Miocene (?)	Volcanics*	5000±	Rhyolites, quartz latites, pyroxene andesites, basalts, and some of their fragmental equivalents
Unconformity				
Cretaceous	U. Cretaceous (Benton-Niobrara)	Colorado shale	300	Dark-gray, blocky shale with impure, thin, dirty, buff limestone and sandstone members
	Comanche	Sarten sandstone	300	Massive gray sandstone, in part quartzitic

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* A more complete section of the volcanic rocks is given in Table 3.

TABLE 1 (continued). GENERALIZED STRATIGRAPHIC SECTION OF LAKE VALLEY QUADRANGLE*

Modified from Darton (1916, p 19)

Unconformity				
Permian (?)	Wolfcamp-Leonard (?)	Lobo formation	80-180	Reddish shales and sandstones, impure limestone, and cherty limestone conglomerate
Unconformity				
Pennsylvanian	Des Moinesian-Missourian	Magdalena group	30-160	Gray and dark limestone, cherty limestone, white to buff chert, cherty limestone conglomerate
Unconformity				
Mississippian	Osagian	Lake Valley formation	200-500	Light-gray limestone with shale members; cherty at top and base; very fossiliferous
	Unconformity			
	Kinderhookian	Caballero formation	0-50	Interbedded green-gray shale and buff limestone; massive 6- to 10-ft limestone layer at base
Unconformity				
Devonian	Upper Devonian	Percha shale	150-175	Black fissile shale grading to green shale, with limestone lenses near top
Unconformity				
Silurian	Niagaran	Fusselman limestone	200-300	Massive, gray dolomitic limestone, pink at top
Unconformity				
Ordovician	Richmond-Trenton	Montoya group	50-300	Gray limestone with thick cherty members; dark sandstone at base
Unconformity				
Ordovician	Canadian	El Paso group	500-850	Light-gray limestone, mostly slabby, some massive algal beds
Cambrian and Ordovician	Upper Cambrian & Lower Ordovician	Bliss sandstone	100-150	Sandstone and sandy shale, hematitic and glauconitic
Unconformity				
Precambrian	——	Granite	——	Reddish, coarse-grained granite

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* A more complete section of the volcanic rocks is given in Table 3.

minor intrusions, whose north-south axis coincides with that of the higher and much broader, but more complex, Black Range anticline. Cooks Range is a large fault block of Precambrian, Paleozoic, and Mesozoic rocks which have been intruded by a late Cretaceous or early Tertiary granodiorite plug. It is cut off from the Mimbres Mountains on the north by a regional fault. The Lake Valley fault block is a large southeastward-dipping mass of Paleozoic limestones and shale which has been broken by minor faulting. The major faults of the region follow a general northwest strike, but some northeast-striking crossfaults are also present. Minor structural features do not appear to be distinctly related to the major structural trends.

Structurally, the Lake Valley quadrangle lies on the border between the Colorado Plateau and Basin and Range structural and physiographic provinces, in what has been described as a transitional zone between the two. In the words of Fenneman (1931, p 381) :

> It [the structure of the region] does not in the least conform to the simple conception of the basin ranges, but in its complicated history of intrusion, faulting, lava flows, and various erosion cycles it resembles still less the horizontal plateau to the north.

However, some of the Basin and Range features still prevail in the southern part of the quadrangle, especially in the major faults of Cooks Range. The northern part of the quadrangle conforms more to the structural pattern of complex faulting and folding of the Southern Rocky Mountain province to the northeast, but since it has only one gentle overall anticlinal structure, it cannot be classified as anything but a transitional zone which bears resemblances to all three provinces.

THE ROCKS

PRECAMBRIAN SYSTEM

The Precambrian basement of Lake Valley quadrangle is exposed only in a small area at the extreme northern end of Cooks Range, where it consists wholly of granite. The massive, coarse-grained, pale reddish- to light greenish-gray rock is gneissic at places. It consists mainly of feldspar, quartz, chlorite, and iron oxides. Locally the rock is epidotized. Several rhyolite dikes of uncertain age cut the granite, and at places the coarseness of the rocks suggests that there was some formation of pegmatites, probably in Precambrian times. Beyond the fact that it is Precambrian, the age relations of the granite are unknown.

Microscopically, the granite consists of coarse, anhedral quartz, with subhedral microcline, orthoclase, and chlorite in an interlocked mass also containing minor epidote, apatite, and magnetite. Some of the feldspar crystals have been sericitized, leaving small grains of unaltered feldspar in large masses of sericite. Small masses and veinlets of sericite occur in other feldspar crystals. Some large microcline crystals have inclusions of quartz and chlorite.

CAMBRO-ORDOVICIAN

Bliss Sandstone

Sandstone and quartzite beds which lie unconformably on Precambrian granite were correlated by Darton (1917-b, pp 24-35; 1928, pp 9-10) with the Bliss sandstone of the Franklin Mountains, on the basis of lithologic similarity and position in the section.

Flower (1953) has shown that the Bliss sandstone of New Mexico contains a lower unit of Upper Cambrian age and an upper unit of lowermost Ordovician age. Up to the present time investigations of the Bliss sandstone in Cooks Range have supplied no evidence of the age of the formation there.

The Bliss sandstone can be recognized readily by the characteristic dark weathering surface. Because of this feature it appears, when seen at a distance, as a broad black band, with the reddish Precambrian below, and the light brown to grey weathering El Paso limestone above.

In Lake Valley quadrangle the Bliss sandstone crops out only in the northern part of Cooks Range, where it consists of about 90 feet of gray and purplish-black quartzitic sandstone. Bedding planes are lined with epidote. About 6 inches of arkosic grit lie directly on the Precambrian granite. A cream-colored 40-ft rhyolite sill occurs about 60 feet above the base. A rock closely resembling that in the sill also forms dikes in the Montoya group (Ordovician) and in the Precambrian granite. Flow structure is prominent at the base and top of the sill (see pl 3-A) .

A typical section of the Bliss sandstone in Cooks Range is as follows:

SECTION OF BLISS SANDSTONE (NE¼NW¼ sec. 11, T. 20 S., R. 9 W.)

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	Base Sierrite limestone (El Paso group)	
10.	Quartzite, purplish-black, fine-grained, hematitic, grading up into quartzite, gray, with streaks of hematitic material, grading back into purplish-black quartzite as at base	35.0
9.	Sandstone, pale creamy-buff, fine-grained	11.0
8.	Quartzite, purplish-gray, coarse-grained, hematitic, weathers dark brownish-purple	2.5
7.	Rhyolite sill, pale-cream, fine-textured, weathers pale grayish-buff. Basal 2 feet show lamination, green banding, spherulites, crumpled flow structure	(37.8)
6.	Quartzite, purplish-black, coarse-grained, hematitic; in beds up to 2 feet thick, interbedded with silty sandstone, very fine-grained, weathers greenish buff. Some epidotization on joint planes bedding surfaces	24.3
5.	Quartzite, purplish-black, coarse-grained, hematitic; bedding surfaces epidotized	7.1
4.	Quartzite, dark-green, coarse-grained, glauconitic	1.8
3.	Quartzite, purplish-black, coarse-grained, hematitic	3.4
2.	Quartzite, dark gray-green, coarse-grained, glauconitic; ripple marks at top	1.0
1.	Sandstone, gray, medium-grained, quartzitic; weathers brownish gray; about 0.5 feet of arkosic grit at base	7.9
	Unconformity	
	Precambrian granite	
	Total (less sill)	94.0

ORDOVICIAN SYSTEM

El Paso Group*

The El Paso group of lower Ordovician (Canadian) age lies conformably on the Bliss sandstone. It was first defined as a formation by Richardson (1908) , but has been raised to group status by Kelley and Silver (1952) .

The El Paso limestone of New Mexico appears as a fairly homogeneous unit lithologically, though in any short interval limestones and dolomites of almost bewildering variety can be found. The lower part consists in general of thin-bedded lime muds, with a few lenses of lime sand. Many of the lime muds incorporated reworked algal fragments, pebbles from reworked beds, or both.

In general, the upper portion is characterized by stromatolite reefs. Red weathering nodular chert is present at some horizons. Limestone pebbles in a lime-mud matrix, and occasional lenses of calcarenite containing both pebbles and fossils, are common. There may be thin-bedded lime muds and layers with a fine detrital sand of fossil fragments upon their surfaces. But these lithological types recur and intermingle so freely, that previous attempts to divide the El Paso on the basis of the physical features of the strata have not met with any great success.

Cloud and Barnes (1948) divided the El Paso of the Franklin Mountains and indicated the correlation of the various units in terms of the Llano uplift and the Ozark region. The Cooks Range section differs from that of the Franklins in several important respects. First, it is possible to recognize a lower Canadian interval, comprising the five lowermost units. Second, the prominent horizons of dolomite and sand separating the major division in the Franklin Mountains are absent here. Third, the most conspicuous interval in the El Paso section of Cooks Range is a black oolitic limestone (unit 7) , which is not developed in the Franklin Mountains. The Cooks Range section is the thickest so far studied in New Mexico, containing 831 feet in contrast to the 300-400 *feet* of most other sections. The thickness of the El Paso limestone is controlled largely by the extent of post-Canadian pre-Montoya erosion, which varies considerably among the New Mexico sections. In general, however, the El Paso is eroded to a point either shortly below or, at the most,just above the second *Piloceras* zone; in Cooks Range there are roughly 260 feet not found in other sections.

Kelley and Silver (1952) differentiated two formations, the lower Sierrite limestone, and an upper Bat Cave limestone. These divisions, at first accepted by the writer, have proved to be no more than approximate. In the main, the Sierrite limestone embraces a thick interval of Gasconade (lower Canadian) age, but Kelley and Silver themselves have not been altogether consistent in drawing a boundary between these two units. This is shown plainly by the reported *"Endoceras"* in the Sierrite limestone, which indicates that they have included therein beds properly assigned to the lower Bat Cave limestone, but which resemble

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•Large portions of this and the following. (Montoya group) sections, particularly those dealing with paleontology and correlation, have been supplied by Dr. R. H. Flower.

the underlying Sierrite limestone lithologically, where obvious beds of stromatolites are lacking.

The position of these divisions is indicated in the accompanying section. The precise position of the 198 feet of El Paso exposed at Lake Valley is uncertain. Its base lies clearly above the black oolite, but its top presumably is below the second *Piloceras* zone, unit 11 of the Cooks Range section.

EL PASO GROUP—COOKS RANGE SECTION (S½ sec. 17, T. 19 S., R. 9 W.)

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	Montoya group (Cable Canyon sandstone)	
	Unconformity	
	Bat Cave formation	
14.	Limestones, fine-grained, gray, stromatolitic, weathering light blue-gray, with interspersed beds of medium-grained, yellowish weathering gray dolomite and thin dark-gray to black, fine-grained blue gray weathering limestone near top. Piloceroids, endoceroids, brachiopods, large, low-spired gastropods, trilobite fragments, and abundant echinoderm fragments (upper *Piloceras* bed)	35.0
13.	Limestone, fine-grained, dark-gray to black, dominantly thin-bedded, some fucoidal chert, weathers bluish gray. Algal nodules make up about a quarter of this limestone	80.0
12.	Limestone, fine-grained, dark-gray to black, with numerous detrital fossil fragments, dominantly thick-bedded, 3- to 6-foot beds, weathers blue gray, some chert nodules; fauna poor, but in addition to algal fragments, gastropods, and small endoceroid siphuncles, there are trilobite fragments and small brachiopods. Trilobites include *Jeffersonia*	70.0
11.	Limestone, fine-grained, dark-gray to black, with scattered grains of black crystalline calcite, thick-bedded, 3- to 6-foot beds, weathers light gray to light blue-gray, some chert nodules. Thin black oolite near top. Algal fragments, numerous sponges, piloceroid and endoceroid siphuncles, small gastropods (second *Piloceras* bed)	30.0
10.	Limestone, fine-grained, dark-gray, thick-bedded, 3- to 6-foot beds, weathers light gray to light bluish-gray. Algal fragments, rare sponges, small slender calcite-filled endoceroid siphuncles, gastropods	55.0
9.	Limestone and dolomitic limestone similar to unit 8, without reefy masses. Some 4-foot layers of thin-bedded black oolitic limestone similar to unit 7. Beds become thicker, more massive than in unit 8. A few beds of nodular algal material in shaly matrix	40.0
8.	Limestone and dolomitic limestone, alternating cherty fucoidal and detrital calcarenite, with some stromatolitic reef beds 3-4 feet thick and associated pebble-filled fine-grained limestone. Cherty fucoidal limestones dominantly fine-grained, dark-gray to black, in layers 1-4 inches thick, weather light bluish-gray, with orange-brown weathering chert; calcarenite dominantly light-gray, coarse-grained, crystalline, in beds 6 inches to 2 feet thick, weathers pale gray-buff; reefy beds medium-gray, weather light blue-gray. Fossils in fucoidal beds are generally numerous tiny gastropods, flat-spired and low-whorled conical forms. Reef beds contain numerous algae and sponges	80.0
7.	Limestone, dark-gray to black, medium- to coarse-grained, sandy, oolitic, with scattered algal nodules and some pebbles. Weathers black to purplish black with reddish spots. Bedding 2 inches to 1 foot. Grades laterally into algal reef at base. *Isoteloides* (?), *"Lophospira," Wolungoceras* (?), *Protocycloceras*, and euomphaloid brachiopods resembling *Lytospira*	18.4

6-b.	Similar in lithological aspects to unit 6-a, but with more massive algal reefs, in which a variety of sponges (*Archeoscyphia* and *Calathium*) are abundant and conspicuous. Rare *Diaphelasma, Jeffersonia,* endoceroid and piloceroid siphuncles abundant, including *Piloceras* spp., *Allopiloceras,* a new genus homeomorphic with *Cyrtendoceras, Clitendoceras,* also *Protocycloceras* and *Bassleroceras* (first *Piloceras* bed)	55.1
6-a.	Limestone and dolomitic limestone, typically light-gray, weathering light bluish-gray with bright-orange fucoidal markings in many beds, in layers 6 inches to 2 feet thick, mainly less than 1 foot thick; occasional 1- to 3-foot layers of stromatolitic reef material, with coarse lime sand and pebble breccia in the interstices. Some of the stromatolitic masses are sufficiently intermittent that only lime sands and breccias will be encountered over considerable lateral intervals. The basal beds, particularly these lime sands, contain a large fauna, the conspicuous and largest elements of which are endoceroid siphuncles. Other fossils include *Diaphelasma pennsylvanicum, Hormotoma* sp., *"Rhaphistoma trochiscus"* Meek, *Ophileta, Ozarkispira* (?), *Hystricurus.* Fragments suggest a considerable variety of trilobites, of which identifiable specimens have not been found. Natural sections of large trilobites are frequently encountered in the thin calcilutites of this interval	186.3
	Total Bat Cave formation	649.8
	Sierrite limestone	
5.	Dolomitic limestone, medium-grained, light-gray, with some fine-grained and coarse-grained beds. Bedding 1 inch to 1 foot thick. Chert bands irregular, vermicular. Chert becomes nodular and fucoidal at top. Some beds sandy. Beds weather medium to light gray with bluish tinge. Fine-grained limestones contain conspicuous fragments of large trilobites. Uppermost 10 feet contain thin, irregular lenses of algal limestone. *Schizopea, Litospira*	62.3
4.	Limestone similar to unit 2 lies directly above sill, lowest layers somewhat baked. Contains *Symphysurina.* These beds grade upward into beds similar to unit 3	45.9
	Granodiorite sill	(40.0)
3.	Limestone, mostly fine-grained, medium-gray to light-gray, crystalline, in beds 3-6 inches thick. Chert (i. e., siliceous seams) decreases, and finally disappears at top. Weathers light bluish-gray to gray buff, surface features vary; near base smooth, rounded, with chert reticulations, upper parts rough, pockmarked. Occasional beds of calcarenite, coarse-grained, light-gray, and lenses of limestone pebbles and algal nodules. Algae, including *Girvanella* types, and also others which form large hollow and sometimes branching tubes, increase in prominence near top. *Ectenoceras*	28.4
2.	Limestone, fine-grained, light bluish-gray to almost white, bedding 1-3 inches thick, with numerous siliceous bands on bedding planes. Occasional well-dolomitized layers. Weathers light gray to grayish buff. Limestones contain abundant fragments of *Symphysurina*	24.7
1-c.	Similar to unit 1-a, more massive, with poorly developed siliceous seams, *Lytospira, Ophileta, Clarkeoceras* (?)	4.0
1-b.	Similar to 1-a, siliceous seams poorly developed, ovoid algal nodules in upper part	3.0
1-a.	Limestone, fine-grained, light-gray to pinkish-gray locally, weathers light gray to tan or buff, massive. Actually thin-bedded, with numerous irregular siliceous seams, partly stylolitic, on bedding planes	13.0
Top Bliss sandstone		
	Total Sierrite limestone (less sill)	181.3
	Total El Paso group (less sill)	831.1

EL PASO GROUP—LAKE VALLEY AREA (NW¼ sec. 11, T. 18 S., R. 7 W.)

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	Montoya group	
	Unconformity	
	Bat Cave formation	
2.	Limestone, fine- to medium-grained gray, beds 3 inches to 3 feet thick, chert layers and nodules; nodules up to 12 inches long, ½ inch thick, layers up to ½ inch thick, reticulate. Chert is gray. Limestone weathers gray with rounded, fairly rough surface, forms ledgy slope. Some beds are stromatolitic with some associated coarse-grained detrital calcarenite. Contains endoceroid siphuncles. Many thin beds of dark-gray calcilutite with a fauna of small gastropods and brachiopods	99.0
1.	Dolomite, coarse-grained, olive-gray with red mottling, weathers olive buff to medium gray, with crackled appearance. Dolomitized. Surface weathers rough, with pockmarks, solution channels, holes, etc. Beds 1-3 feet thick	99.0
	Base not exposed; formation in fault contact with Tertiary volcanics	
	Total Bat Cave formation	198.0

Montoya group

The Montoya group of late Middle and Upper Ordovician age was defined first as a formation by Richardson (1908) , and raised subsequently to group status by Kelley and Silver (1952) . Though the contact with the El Paso group beneath may appear locally conformable, an unconformity is evident from regional study; indeed, the upper part of the El Paso has been removed by post-Canadian pre-Montoya erosion to varying depths in different sections.

The Montoya group consists of four formations: the Cable Canyon sandstone at the base, the Upham dolomite, the Aleman formation, and the Cutter formation at the top. The Cable Canyon formation consists typically of only a few feet of white quartzose sandstone, and is not present in all sections. The Upham dolomite consists of massive dark weathering dolomites, in the lower part of which there may be abundant scattered sand grains. Advanced dolomitization is responsible probably for the absence of a clear division between the Upham dolomite and the overlying Aleman dolomite at many places. The Aleman dolomite is characterized, however, by abundant chert, which occurs in bands or in nodular masses. Associated with the chert is an abundant silicified fauna, mainly of brachiopods. The overlying Cutter formation is, in this area, a thin-bedded very fine-grained light-gray dolomite, in contrast with the coarse-grained dark-gray to black dolomites of the two underlying members.

The customary assignment of the Montoya group to the Richmond division of the Ordovician rests primarily upon the silicified brachiopod fauna of the Aleman dolomite. Richardson (1908) , however, pointed out that the lower Montoya (the present Upham dolomite) contains a fauna of quite different aspect. These beds he correlated with the Galena limestone (Trenton) of the Mississippi Valley. It is evident that the Richmondian age of this division is highly dubious.

The section of the Montoya group exposed in Cooks Range is anomalous, particularly in its lower portion.

The Cable Canyon sandstone consists of 30 feet of coarse-grained thick-bedded pale-gray sandstone with a dolomite matrix, weathering orange brown, underlain by 3-4 feet of fine-grained sandy limestone interpreted by Dr. Flower as derived from the underlying El Paso group. In the upper unit, the sand grains range from ½ mm to 2 mm in diameter, and are strongly rounded. Many, however, show an angular appearance as the result of the development of secondary terminations. The percentage of dolomite matrix varies from 15 to 25 percent near the bottom, to almost 50 percent at the top. The upper contact is conspicuously marked by an abrupt decrease in the percentage of sand. The lower unit of the Cable Canyon sandstone is typical; the upper is noteworthy for having yielded a *Receptaculites* and a *Maclurites* (or *Maclurina).* Both fossils are characteristic of the typical Upham dolomite. They indicate that the Cable Canyon sandstone is only a basal sand of the Upham dolomite, and not a markedly older formation.

In most sections of the Montoya group in New Mexico the overlying Upham formation is a massive dolomite, chert-free, with large scattered sand grains in the lower part. The section in Cooks Range is atypical. A peculiar feature of the lower part of the Upham in this area is the presence of beds of coarse granular calcitic limestone with a fauna of large isotelid trilobites and brachiopods, including *Rafinesquina, Sowerbyella,* and a *Rhynchotrema* very different from that found in the overlying Aleman formation. These are followed by an intervening coarse, medium-gray, crystalline dolomite with crinoid plates, and a sugary-white to light-gray crystalline limestone, in the upper part of which calcite has replaced the shells of *Zygospira* and large convex *Rafinesquina.* Faunally and lithologically, this is unlike the typical Upham dolomite of most of New Mexico and western Texas, and has, therefore, been designated Upham (?) dolomite.

In general, the Aleman consists of thin-bedded gray to black fine-grained dolomite, weathering to various shades of gray, and locally to tan. There are lenses and occasional thin beds of gray chert in layers 2-6 inches thick. In most parts of the section the chert occurs as discontinuous layers of nodules, but layering is particularly characteristic of the lower beds with the *Dalmanella* and *Zygospira.* The interlayering of chert and dolomite gives rock surfaces a striped appearance, the dolomite weathering medium gray, the chert variably white, dark gray, and brown.

The lower beds of the Aleman of Cooks Range have yielded only *Dalmanella.* In other sections in New Mexico abundant *Zygospira* and *Cornulites* are found in this same association. Higher beds contain a larger association of brachiopods, in which *Platystrophia, Rafinesquina,* and *Rhynchotrema* cf. *capax* are found, usually with a variety of other orthoid brachiopods and *Streptelasma.* The Cooks Range section is again anomalous in that, in unit 8, there are beds which are remarkably free from dolomite, and in which bryozoa and brachiopods are preserved in calcite, without the usual silicification. Unit 10 contains an exceptionally rich, but otherwise typical, association of silicified brachiopods, in which *Hebertella, Rhynchotreta,* and *Streptelasma* are extremely abundant.

The Cutter formation consists dominantly of light-gray, sublithographic dolomite, with scattered nodular chert. Its color and texture are characteristic and are not repeated in any other part of the lower Paleozoic section. Bedding is 6 inches to 1 foot thick and may be obscure locally. White chert occurs in nodules 3-4 inches thick and 6-10 inches long. No fossils have been found within this formation in Cooks Range, but elsewhere the nodules have yielded silicified fossils. The Cutter is 50 feet thick, and its contact with the overlying Fusselman is sharp. The formation crops out as a series of rounded ledges on a fairly steep slope.

A fauna of Ordovician aspect discovered by Flower (Kelley and Silver, 1952) is the basis for assigning the Cutter formation to the Ordovician. This fauna is as yet largely unstudied, but contains certain elements (Flower, 1953-b, p 109) indicating a correlation within the Whitewater-Elkhorn portion of the Richmond.

In contrast, the Lake Valley section of the Montoya group is more typical of the other New Mexico sections, and is also much thinner than that of nearby Cooks Range. Secondary silicification has attacked the Cable Canyon and Upham members to varying and erratic degrees. The silicified portions form broken and prominent ledges. A casual inspection of such sections gives the impression that extensive faulting has occurred, an impression which is found to be completely false upon closer examination. The Aleman division in this section is relatively thin and the faunas meager, but it can be recognized by the characteristic chert. The light-gray Cutter formation is typical. Anomalously, its contact with the overlying Fusselman dolomite is not clearly defined in the Lake Valley section.

SECTION OF MONTOYA GROUP IN COOKS RANGE
(SE¼ sec. 11, T. 20 S., R. 9 W.)

Unit No.	Description	Thickness in feet
	Fusselman limestone	
	Unconformity	
	Cutter formation	
13.	Dolomite, very fine-grained to sublithographic, in beds 6 inches to 1 foot thick. Weathers pale gray to almost white, crackled	50.6
	Total Cutter formation	50.6
	Aleman formation	
12.	Dolomite, fine-grained, dark-gray beds 3 inches to 1.5 feet thick, weathers light gray to medium gray. Scattered nodules of dark-gray chert. Bedding planes show some worm markings	59.0
11.	Dolomitic limestone, medium-grained, medium-gray, thin-bedded, weathers light gray, massive, with a few chert nodules. Numerous silicified brachiopods weather out on bedding surfaces. *Hebertella* conspicuous, *Platystrophia, Rhynchotrema, Streptelasma*	10.8
10.	Dolomitic limestone, fine-grained, black, thin-bedded, weathers brownish gray, massive, fossiliferous. *Rhynchotreta* cf. *dentata* at top	3.0
9.	Covered, probably similar to unit 10	12.8
8.	Dolomitic to fairly pure limestone, fine-grained, black cherty, weathers brownish gray, thin-bedded, highly fossiliferous; abundant bryozoa and brachiopods, poorly silicified	2.0
7.	Covered, probably similar to unit 8	10.8

6.	Dolomite, fine-grained, dark-gray, weathers medium gray, in beds 3-6 inches thick interbedded with layers of dark-gray chert 1-3 inches thick with scattered chert nodules. Uppermost beds contain *Dalmanella*	91.8
	Total Aleman formation	190.2
	Upham (?) dolomite	
5.	Limestone, coarse-grained, crystalline, pale-gray to cream, weathers pale gray to creamy gray, bedding 6 inches to 1 foot thick. *Zygospira* and large convex *Rafinesquina*	6.4
4.	Dolomite, coarse-grained, medium gray, crystalline, in beds 1-3 feet thick, weathers light gray, contains some crinoid plates, some stylolites in lower beds	24.6
3.	Limestone with some dolomite, fine-grained, dark-gray to purplish-gray, but with beds of coarse granular limestone. Fine-grained beds contain black calcite crystals resulting from partial recrystallization. Thin- to medium-bedded (beds 6 inches to 2 feet thick). Weathers dark gray with pockmarked surface and numerous solution holes. Lowest 6 inches is reworked sandstone. Dolomite is slightly sandy for 10 feet above base. *Rhynchotrema* n. sp., *Sowerbyella,* large convex *Rafinesquina,* and isotelid trilobites	16.2
	Total Upham (?) dolomite	47.2
	Cable Canyon sandstone	
2.	Sandstone with dolomitic matrix, coarse-grained, pale-gray to light-gray, weathers brownish gray to orange brown. Thick-bedded (beds 2-3 feet thick). Most quartz grains are highly rounded, but may appear angular owing to secondary enlargement. Matrix makes up to 20-50 percent of the mass. Uppermost beds contain scattered *Receptaculites*	29.0
1.	Dolomite, sandy, fine-grained, lavender-gray, weathers medium to light gray, pitted, in beds 6 inches to 1 foot thick, sand grains subangular to rounded, with many secondary terminations. Dolomite consists mainly of reworked material from immediately underlying beds. Becomes more sandy at top and grades into unit 2	4.0
	Unconformity	
	Bat Cave formation (El Paso group)	
	Total Cable Canyon sandstone	33.0
	Total Montoya group	321.0

SECTION OF MONTOYA GROUP—LAKE VALLEY AREA
(SW¼ sec. 17, T. 18 S., R. 7 W.)

UNIT No.	DESCRIPTION	THICKNESS IN FEET
	Fusselman limestone	
	Unconformity	
	Cutter formation	
5.	Dolomite, very fine-grained to sublithographic, pale-gray to pale-brown, weathers creamy white and crackly. Upper 20-30 feet consist of an alternation of sublithographic dolomite with intergrading dolomite, medium- to coarse-grained, dark-gray. Bedding in both lithologic types 6-18 inches thick	77.0
	Aleman formation	
4.	Dolomitic limestone, fine- to medium-grained, light-gray, thin-bedded, weathers light olive-gray, some dark-gray chert on bedding planes, sparse brachiopods, including *Hebertella, Platystrophia, Rhynchotrema,* and *"Streptelasma"*	40.0
	Upham dolomite	
3.	Dolomite, coarse-grained, light blue-gray, in beds 3-6 inches thick,	

	with some dark-gray chert nodules, weathers olive gray, contains scattered *Rhynchotrema*	**33.0**
2.	**Dolomite, medium-grained, dark-gray, in beds 1-3 feet thick, weathers dark gray**	**22.0**
	Cable Canyon sandstone	
1.	**Sandstone with dolomitic matrix, coarse-grained, pale-gray, weathers light gray, thick-bedded. Quartz grains subangular to highly rounded, but may appear highly angular as the result of formation of secondary terminations. Matrix makes up 20-50 percent of the mass. Irregularly silicified to form a rock similar to quartzite in appearance**	**33.0**
	Unconformity	
	Bat Cave formation (El Paso group)	**——**
	Total Montoya group	**205.0**

SILURIAN SYSTEM

Fusselman Limestone

Lying unconformably on the Montoya group is 200-225 feet of massive gray, hard, compact dolomitic limestone of Silurian (Niagaran) age, called the Fusselman limestone. At Lake Valley the upper beds of this formation are silicified and form the top and back slope of Quartzite Ridge, which is the northwest boundary of the main fault block. The section in this area, as given by Darton (1917-a, p 42) is as follows:

Unit No.	**Description**	**Thickness in feet**
4.	**Limestone, pink**	**12**
3.	**Limestone, light-gray, massive**	**80**
2.	**Limestone, light-gray, with nodules of black and gray chert**	**40**
1.	**Limestone, light-gray, massive**	**80**
	Total Fusselman limestone	**212**

In Cooks Range the Fusselman limestone is the principal host rock to ores of lead, zinc, and silver. It crops out extensively along the road from Cooks to the top of the divide and along the slopes 2 miles to the north. The massive gray limestone is dolomitic, and generally hard and compact, though cavernous in places. The ore bodies occur in cavities a short distance below the overlying Percha shale. Silicification accompanied ore deposition; an earlier period of silicification, which formed a thick, fairly continuous layer of chert at the limestone-shale contact, is also in evidence.

A few fossils were found in the Fusselman in Cooks Range, Near the base traces of large pentameroid brachiopods were found, which apparently are related closely to *Pentamerus oblongus.* These same large pentameroids were found to be highly silicified in a fault block just east of the north-trending ridge which forms the north end of the range. Near the top of the formation occur smaller pentameroids, and the corals *Heliolites* sp. and *Halysites* sp.

DEVONIAN SYSTEM

Percha Shale

In both the Lake Valley and Cooks Peak areas the Percha shale, of Upper Devonian age, lies unconformably upon the Fusselman limestone. In the Lake Valley area it is about 200 feet thick and consists of approximately 150 feet of black, fissile shale with some thin, dark-brown, shaly limestone partings (Ready Pay member) , which grades upward into 50 feet of greenish-gray shale with limestone nodules up to 6 inches in diameter at the top (Box member) . At Lake Valley the Percha forms a broad valley on the back slope of the fault block. In Cooks Range it crops out at Cooks, on the northwest side of the peak, and at the base of the high ridge of Sarten sandstone to the south of the intrusive mass. In the valley north of Cooks Peak the limestone lenses which mark the Box member appear to be missing. However, outcrops are poor in this area, and the limestone lenses may be obscured by talus.

The Percha in this region is Upper Devonian in age. Both in the Cooks Peak area and about 2 miles north of Lake Valley, 3-6 feet of reddish-brown and greenish siltstones occur at the base of the Percha. At one locality, north of Cooks Peak, Dr. A. L. Bowsher and the author discovered a conodont fauna in these siltstones. Dr. Otto Haas, of the U. S. Geological Survey, has identified these as Upper Devonian (Sly Gap) in age (Bowsher, personal communication, December 1951) . In this particular area megafossils in the Percha proper seem to be lacking, so that no further light can be shed on the age of this formation there. However, Bowsher (personal communication, January 1952) has commented that much of the fauna of the Box member of the Percha is found in the Upper Devonian of the western United States and Europe. A clymenoid ammonoid fauna in the Percha near Wilson's ranch is said by Miller and Collinson (1951) to indicate that the Percha is late Upper Devonian in age. Clymenoids are unknown in the Mississippian, unless the boundary between the Mississippian and Upper Devonian in Germany is changed. This can be accepted as evidence of the Devonian age of the Box member.

In Lake Valley quadrangle, the Percha is relatively unfossiliferous. Laudon and Bowsher (1949, pp 60, 76-80) have reported the following fauna from the Percha in the Lake Valley and Cooks Range areas:

Lake Valley area:

READY PAY MEMBER	BOX MEMBER
Pugnoides	*Paurorhynca cooperi*
	Pugnoides pugnus
	Syringopora prima

Cooks Range:

READY PAY MEMBER	BOX MEMBER
No fossils found	*Paurorhyncha cooperi*
	Pugnoides
	Syringospira
	Spirifer
	Reticularia

Much more extensive Percha faunas have been found in the Hillsboro area, 17 miles north of Lake Valley (Darton, 1928; Stainbrook, 1947).

MISSISSIPPIAN SYSTEM

Caballero Formation

In the Lake Valley area the Mississippian system is represented by two formations, the Lake Valley formation (Osagian) and the Caballero formation (Kinderhookian) (Laudon and Bowsher, 1949). About 1 ¼ miles north of Lake Valley the Caballero formation reaches a maximum thickness of 48 feet. This diminishes rapidly to the north and south, and the Caballero formation is absent at Lake Valley and at Wilson's ranch, 2 ½ miles north of Lake Valley. The presence of the Caballero formation in Cooks Range was reported by Laudon and Bowsher in Bates, et al. (1942, pp 25) ; later the rocks there called Caballero were included by them in the Andrecito member of the Lake Valley formation, because "the fauna indicates closer affinities with the Lake Valley formation" (Laudon and Bowsher, 1949, p 74) .

The Caballero formation in the Lake Valley area consists of about 6 feet of thin-bedded, crosslaminated sandy limestone overlain by 30-40 feet of soft, gray, nodular limestone interbedded with soft gray shale. The Caballero is easily distinguished from the Percha, as the basal sandy limestone forms a prominent low scarp. A section of the Caballero formation follows:

CABALLERO FORMATION (SW¼NW¼ sec. 20, T. 18 S., R. 7 W.)

Unit No.	Description	Thickness in feet
	Lake Valley formation	
	Unconformity	
4.	**Shale, limy, greenish-brown, weathers gray green to greenish buff; some limy layers up to 0.2 feet thick**	**8.0**
3.	**Covered; apparently similar to unit 2, with more numerous shaly layers**	**17.4**
2.	**Calcilutite, dark-gray, slightly shaly, in ledges 0.5-1.0 foot thick interbedded with green-gray to greenish-buff limy shale in layers up to 0.5 foot thick**	**5.0**
1.	**Calcarenite, medium gray-green to brownish, very sandy, shows crosslamination on a fine scale (2-3 inches) at base. Bedding is 2-3 mm thick, some limonite stain on bedding planes near base; weathers green gray to brownish buff**	**6.3**
	Unconformity	
	Percha formation	
	Total Caballero formation	**36.7**

The fauna of the Caballero formation near Lake Valley is given by Laudon and Bowsher (1949, pp 58-59) as follows:

Rhipidomella missouriensis
Productina sampsoni
Chonetes glenparkensis
Schizophoria chouteauensis
Dielasma sp.
Camarotoechia sp.
Rhynchopora hamburgensis
Spirit er platynotus
S. gregert
S. louisianensis
Cliothyridina tenuilineata
Ambocoelia minuta
Nucleospira rowleyi

The formation has been dated by brachiopods and, in a locality in the Sacramento Mountains, by cephalopods (Miller and Youngquist, 1947), both of definite Kinderhookian age.

Lake Valley Formation

At the type locality near the Lake Valley mining district the Lower Mississippian (Osagian) Lake Valley limestone is 200-225 feet thick.

In early reports it was divided into three main layers (from top to bottom): the Crinoidal or "Hanging Wall" limestone, the Blue or "Footwall" limestone, and the Nodular limestone. Ore deposits lie at the contact between the Blue and the overlying Crinoidal limestone. More recently, Laudon and Bowsher (1949) have studied the Lake Valley formation in detail. At this locality they have divided it into four members (from base to top): the Andrecito, Alamogordo, Nunn, and Tierra Blanca.

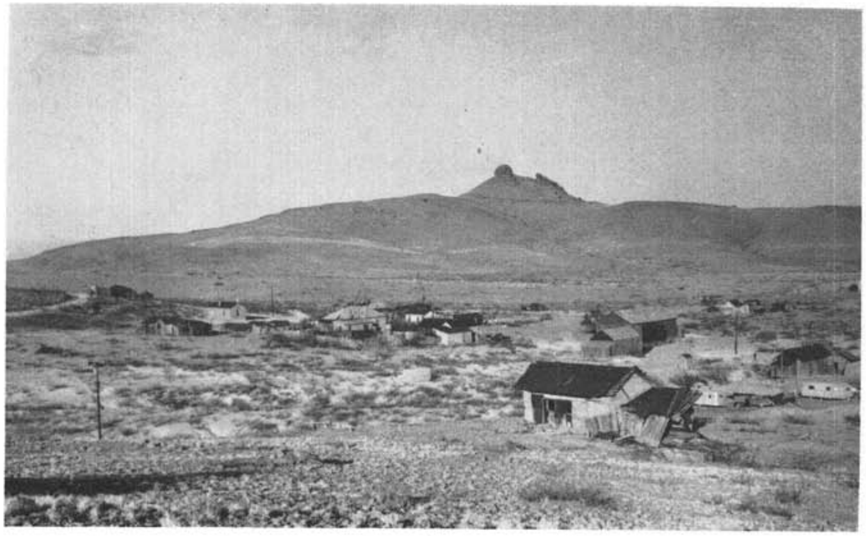
Near Lake Valley the Andrecito, which overlies the Caballero formation unconformably, consists of 50-75 feet of thin-bedded, gray, cherty limestone with shaly partings. The Andrecito grades into 20-35 feet of massive, hard, black, *Zaphrentisbearing,* cherty limestone, which weathers pale blue-gray, the Alamogordo member. The Nunn member, 65-100 feet thick, consists of somewhat nodular, blue-gray to greenish-gray crinoidal limestone (criquina) and soft, similarly colored crinoidal marls. Wachsmuth and Springer (1899) have described a large fauna of crinoids from these beds. The upper part is more massive and is interbedded with thin layers of brown and gray crinoidal limestone. Crinoids from these layers have been identified as early Osagian (Laudon and Bowsher, 1949). The Nunn lies conformably upon the Alamogordo, and grades upward into the medium-bedded, hard, gray to brown, coarse-grained, cherty, crinoidal limestone of the Tierra Blanca member. Though the transition between the members is gradational, the author has been able to place the contact within a three-foot "transitional zone," where the beds still resemble the Nunn in aspect, but contain cherty layers. The chert is white and occurs in small lenses, 0.5-5.0 feet long and 0.1-0.7 foot thick. This member is 50-55 feet thick. In the locality where the author measured a section, the Tierra Blanca is overlain unconformably by 2-3 feet of limestone-chert conglomerate, presumably the base of the Pennsylvanian. In other areas the top of the member is not exposed, as the beds dip eastward under Tertiary lavas.

In Cooks Range the Lake Valley formation is much thicker than at Lake Valley, totaling up to 450 feet as contrasted with 245 feet of section at Lake Valley. Table 2 gives the thicknesses of the various members in the three sections measured by Laudon and Bowsher in Cooks Range, and in two sections in the Lake Valley area, one measured by Laudon and Bowsher and the other by the author. It should be noted that the members of the Lake Valley formation vary in thickness over short dis-

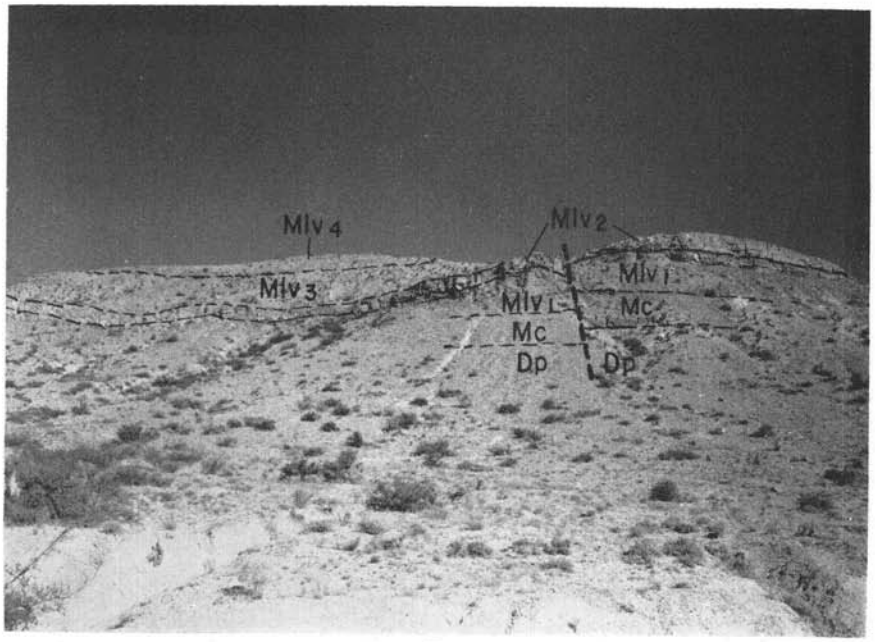
PLATE 2.

A. TOWN OF LAKE VALLEY IN 1954. COMPARE WITH FRONTISPIECE. Nom THAT RAILROAD TRACKS HAVE BEEN REMOVED AND MANY BUILDINGS ARE GONE OR IN DISREPAIR. TRAILERS IN RIGHT CENTER ARE LIVING QUARTERS FOR MINERS IN NEWLY DEVELOPED MANGANESE MINING VENTURE. *Picture by **F.** Kuellmer.*

B. THE LAKE VALLEY ESCARPMENT ONE MILE NORTH OF THE TOWN OF LAKE VALLEY. PERCHA SHALE (DP), CABALLERO FORMATION (MC), AND THE FOUR MEMBERS OF THE LAKE VALLEY FORMATION: MLV1, THE ANDRECITO MEMBER; MLV2, THE ALAMOGORDO MEMBER; MLV2, THE NUNN MEMBER; AND MLV4, THE TIERRA BLANCA MEMBER. *Picture by C. P. Valentine.*



A



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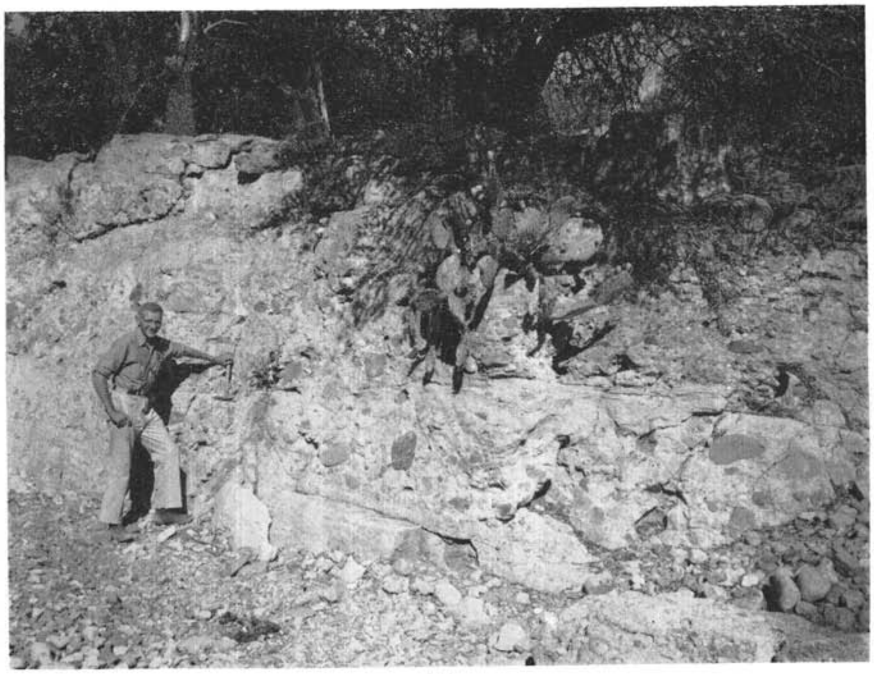


B

tances. For example, in the section measured by the author in the Lake Valley area there are several differences in the thickness of the members as compared with the section of Laudon and Bowsher (1949, p 60) measured scarcely a mile away. The Nunn member especially shows a change, gaining about 40 feet of beds in that distance. Considerable changes in thickness also can be found in the Andrecito and Alamogordo members in the sections measured in Cooks Range.

TABLE 2. COMPARATIVE THICKNESSES OF THE LAKE VALLEY FORMATION IN VARIOUS PARTS OF COOKS RANGE AND THE LAKE VALLEY AREA

	1	2	3	4	5
Tierra Blanca	35*	25*	50	50	60
Nunn	155	146	140	65	106
Alamogordo	50	9	13	33	23
Andrecito	133	270	130	71	56
Total thickness	373	450	333	219	245

1. North Cooks Range Section, SW¼NE¼ sec. 24, T. 20 S., R. 9 W. (Laudon and Bowsher, 1949, p 76).
2. Middle Cooks Range Section, S center sec 24, T. 20 S., R. 9 W. (ibid., p 78).
3. South Cooks Range Section, SW¼ sec. 1, T. 21 S., R. 9 W. (ibid., p 80).
4. Lake Valley Type Section, NE¼NW¼ sec. 21, T. 18 S., R. 7 W. (ibid., p 60).
5. Lake Valley Section (Jicha), SW¼NW¼ sec. 20, T. 18 S., R. 7 W.

*Does not include beds which are referred to the Kelly formation by Laudon and Bowsher. These beds are included in the Lake Valley formation by the author.

The fauna of the Lake Valley formation is large and varied. Many of the forms which have been found are undescribed. The most common forms found in the Lake Valley area (Laudon and Bowsher, 1949, p 61) are:

ANDRECITO MEMBER

Cyathaxonia arcuata
Zaphrentis cliffordana
Rhipidomella missouriensis
Dictyoclostis fernglenensis
Fenestella
Penniretepora
Rhombopora
Leioclema
Hernodia
Lichenotrypa
Thamniscus

ALAMOGORDO MEMBER

Zaphrentis

PLATE 3.

A. BASE OF RHYOLITE SILL IN BLISS SANDSTONE. DARK, SLABBY ROCK IS HEMATITIC BLISS SANDSTONE. NOTE FLOW STRUCTURE AND CRUMPLING IN LOWEST TWO FEET OF SILL.

B. SANTA FE (?) FANGLOMERATE IN BEAR SPRINGS CANYON. NOTE THE SUBANGULAR NATURE OF THE PEBBLES AND COBBLES AND THE RAPID CHANGE IN PARTICLE SIZE FROM MEDIUM AT TOP TO LARGE IN NEXT BED, TO SMALL IN LOWEST BED. *Picture by* C. *P. Valentine.*

NUNN MEMBER

Zaphrentis centralis
Caninea arcuata
Rhodocrinites wortheni
Cactocrinus cf. C. *multibrachiatus (?)*
Cactocrinus (?) cf. C. *extensus*
Amphoracranus divergens
Steganocrinus pentagonus
S. araveolus
Physetocrinus lobatus
Platycrinites peculiarie
P. nodostriatus
P. burlingtonensis
P. subspinosus
P. springeri
P. pocilliformis
Eucladocrinus tuberosus
Dictyoclostis fernglenensis
Rhipidomella oweni
Schazophoria poststriatula
Leptaena analogs
Rhynchopora persinuata
Spirit er rowleyi
S. louisianensts
Syringothyris texta
Tylothyris novamexicana
Athyris lamellosa
Cliothyridina glenparkensis
C. obmaxima
Phillipsia sampsoni
P. obesa

TIERRA BLANCA MEMBER

Spirifer rowleyi
Cliothyridina obmaxima
Crinoid fragments

In Cooks Range the most common forms (ibid, pp 74-80) are:

ANDRECITO MEMBER

Spirifer louisianensis
Dictyoclostis fernglenensis
Athyris lamellosa
Cyathaxonia arcuata
Spirifer vernonensis
Platycrinites sp.
Zaphrentis
Rhipidomella missouriensis

NUNN MEMBER

Steganocrinus pentagonus
Cactocrinus (?) cf. C. multibrachiatus
Amphoracrinus divergens
Platycrinites spp.
Physetocrinus
Rhodocrinites
Spirifer rowleyi
Dictyoclostis fernglenensis

TIERRA BLANCA MEMBER

Spirifer rowleyi
Cliothyridina obmaxima
Crinoid fragments

A typical section of the Lake Valley formation near Lake Valley is given below:

LAKE VALLEY FORMATION—NEAR LAKE VALLEY
(SW¼NW¼ sec. 20, T. 18 S., R. 7 W.)

UNIT NO.	DESCRIPTION	THICKNESS IN FEET
	Limestone-chert conglomerate (Pennsylvanian). Incomplete	**(3.0)**
	Unconformity	
	Tierra Blanca member	
9.	**Limestone (calcarenite), purplish- to brownish-red, medium-grained, possibly somewhat recrystallized. Contains white chert nodules, both rounded and elongate, 0.1-0.7 foot thick and 0.5-5.0 feet long. Beds massive, up to 3 feet thick. Some beds highly fossiliferous (criquina or crinoidal coquina). Weathers creamy gray**	**57.7**

8.	**Transition zone; crinoidal calcarenite (criquina), gray, composed mainly of crinoid and bryozoan remains in a fine-textured matrix, weathers gray to brownish gray, contains white chert; grades into unit 9**	**3.0**
	Nunn member	
7.	**Crinoidal calcarenite (criquina), gray, composed mainly of crinoid and bryozoan remains in a fine-textured matrix, weathers gray to brownish gray with some limonite staining. Interbedded with soft blue-gray marl. These beds are slightly more resistant and massive than those below**	**49.4**
6.	**Interbedded limestone and blue-gray crinoidal marl; limestone is gray, with pale-brownish tinge, fine-grained, forms ledges, with beds up to 0.3 foot thick, containing abundant crinoid and bryozoan remains and some brachiopods and corals**	**54.7**
	Alamogordo member	
5.	**Calcilutite, dark brownish-gray to black, massive, weathers blue gray, beds up to 3 feet thick, some limonite along bedding planes, contains *Zaphrentis***	**16.8**
4.	**Calcarenite, light amber-brown to orange-brown, weathers brownish gray, contains many corals *(Lithostrotion, Zaphrentis)*, in some areas highly crinoidal**	**6.2**
	Andrecito member	
3.	**Calcilutite, dark grayish-brown, in layers up to 0.7 foot thick with thin (up to 0.2 foot thick) layers of brown marl; contains large numbers of dark-gray to black chert nodules, lenticular, up to 4.0 feet long, 0.8 foot thick; limestone weathers pale gray with some yellow-buff limonite stain; scattered crinoidal beds weathering pinkish gray**	**31.2**
2.	**Calcilutite, dark brownish-gray to black, slightly silty, some pinkish crinoidal layers, beds up to 1 foot thick, with thin partings of brown marl, weathers pale bluish-gray and pinkish gray**	**15.7**
1.	**Calcarenite, silty, dark purplish- to grayish-brown, crinoidal, sandy at base, grayish marl layer 2.0-2.5 feet**	**10.5**
	Unconformity	
	Total Lake Valley formation	**245.2**

Kelly Limestone

Laudon and Bowsher (1949, pp 74-78) have reported 15-30 feet of cherty crinoidal limestone without distinctive fossils overlying the Tierra Blanca member of the Lake Valley formation in the southern part of Cooks Range. These beds were tentatively referred to the Kelly limestone. The absence of faunal evidence, and the lack of any definitive break between the formations, has led the author to consider them to be part of the Tierra Blanca member of the Lake Valley formation, and they were so mapped.

PENNSYLVANIAN SYSTEM

Magdalena Group

North of Cooks Peak is a section of 180 feet of Pennsylvanian sediments which are regarded as upper Des Moinesian and lower Missourian by Bowsher (personal communication, February 1952) . This section consists of chert, cherty limestone, and limestone containing Pennsylvanian fossils. These sediments are referred to the Magdalena group. The following is a typical section of these beds:

MAGDALENA GROUP—COOKS RANGE NORTHWEST SECTION (SW¼ sec. 25, T. 20 S., R. 9 W.)

Unit No.	Description	Thickness in feet
	Lobo formation (Permian ?)	
	Unconformity	
19.	Limestone (calcilutite), grayish-brown, fine-grained, weathers light gray; contains remains of brachiopods, corals, bryozoans, gastropods	7.5
18.	Covered	7.4
17.	Limestone (calcilutite), dark-gray to black, weathers buff to orange brown, contains fusulinids in some layers	1.4
16.	Covered	8.5
15.	Limestone-chert conglomerate; calcarenite, medium-gray, containing pebbles of angular to subangular chert up to 0.5 inches in diameter; chert is mostly red; beds 1-2 feet thick	6.3
14.	Covered	2.5
13.	Limestone (calcilutite), mottled green-gray and red-brown, weathers brown, unfossiliferous	1.4
12.	Limestone-chert conglomerate; calcarenite, medium-gray, containing numerous white and gray, subangular to subrounded chert grains up to 3 inches in diameter	5.5
11.	Covered	5.6
10.	Limestone (calcilutite), medium-gray, weathers light gray; contains numerous interstitial patches of crystalline calcite; *Myalina* (?)	20.4
9.	Covered	6.0
8.	Limy siltstone, purplish reddish-brown, with limonite streaks, weathers similar to original color, nonfossiliferous	5.8
7.	Limestone-chert conglomerate; calcarenite, medium-gray, massive, weathers brownish gray, with numerous pebbles of white chert, mostly subangular. Chert resembles that found in underlying beds	23.9
6.	Covered slope with float of white chert. Chert is dense, fine-grained, weathers yellow buff	35.8
5.	Limestone (calcilutite), black, with some large crystals, in massive beds up to 2 feet thick; most only 0.5 foot thick; upper layers become cherty; top is mainly yellowish-white chert with limestone nodules; limestone weathers medium gray	24.2
4.	Limestone (calcarenite), dark purplish-gray to black, some red mottling, weathers light gray with some brownish layers; thin-bedded, abundant fauna mainly of brachiopods	7.3
3.	Limestone (calcilutite), black with red mottling, weathers blue gray with occasional limonite streaks, massive, nonfossiliferous	1.8
2.	Covered	17.4
1.	Limestone (calcilutite), dark-gray, very cherty; chert is white; gives aspect of buff layer owing to weathering	11.6
	Unconformity	
	Lake Valley formation (Mississippian)	——
	Total Magdalena group	182.9

On the east and south sides of Cooks Range the Pennsylvanian has a thickness of 40-80 feet and consists of limestones and chert conglomerates with limestone matrices. These beds were originally correlated with the Gym by Darton (1916), but later examination of the fossil evidence makes it appear that they are Pennsylvanian. Bowsher (personal communication, February 1952) has examined fossils from the section north of Cooks Peak, and states in his report:

> I believe that only Pennsylvanian strata are represented above the Lake Valley formation and below the Lobo formation. Mr. Jicha submitted his collection as Permian, but I believe that it is Pennsylvanian in age because (1) there are no fossils in the collection characteristic of the Permian, (2) strata 9 feet below (Bed 17) contain fossils characteristic of Middle Pennsylvanian strata, and (3) there is no stratigraphic break between the beds containing the collections.

The following fossils have been identified in the collections by Dr. A. L. Bowsher and are presented here with his comments through the courtesy of the U. S. National Museum:

Collection 185 A—Bed 4 (of measured section)

indet. Coral
Phricodothyris ? sp. indet. *Spirifer*
occidentalis Girty *Cornposita* cf. C.
argentea (Shepard)
Derbya cf. *Derbya crassa* (Meek and Hayden) type
Chonetina cf. *flemingi* (Norwood and Pratten)
Dictyoclostus cf. *D. portlockianus* (Norwood and Pratten)
Dictyoclostus cf. *D. portlockianus* var. *crassicostatus* Dunbar and Condra
Linoproductus? gen. and sp. indet.
Buxtonia ? gen. and sp. indet.
Punctospirifer kentuckyensis (Shumard)
Dielasma ? a large specimen, gen. and sp. indet.

> *Spinner occidentalis* Girty is the only diagnostic fossil in this collection; this species is common in the Cherokee shale of Oklahoma and equivalent strata elsewhere. These strata in New Mexico were called the Armendaris group by Thompson (1942) . This form is confined to Atokan and Desmoinesian strata. The remainder of the fauna resembles forms common to upper Desmoinesian and lower Missourian strata; therefore, **I** favor considering the strata from which the above fossils were obtained as middle Desmoinesian in age.

Collection 185 I–Bed 17 (of measured section)

Triticites cf. *T. springervillensis* Thompson, Verville, and Bissell

> This form resembles *T. irregularis* Staff and *T. phymaeus* Dunbar and Condra. Fusulinids of similar stage of evolution having very thin walls, small proloculus, weak septal fluting along the axis only, short axis of coiling and small size, etc., characterize the lower Missourian strata of North America. Thompson (1942, p 61) notes that forms in the Coane formation of the Veredas group are questionably primitive forms of the genus *Triticites.* This statement adequately applies to the forms in this collection. Although **I** have been unable to get ample sections of this form, I believe that these fusulinids are from strata belonging to the Veredas group of New Mexico, and equivalent in age to those of the Kansas City group of Oklahoma, Kansas, and Missouri and to the upper part of the Oquirrh formation of Utah.

Collection from Bed 18 (of measured section)

Batostomella ? sp.
Indet. productid
Euomphalus? gen. and sp. indet.

> None of the fossils in this collection is diagnostic and no age determination is possible.

On the basis of the above evidence the beds formerly classed as Gym (Darton, 1916, 1926, 1928) in Cooks Range are referred to the Pennsylvanian. Further research into this problem is necessary. The Pennsylvanian and Permian stratigraphy in the southwestern part of New Mexico appears to need intensive study.

The Pennsylvanian crops out on the margin of the Cooks Peak intrusive south and west of Cooks, in the high ridge of sediments which rises above the intrusive on the south, and on the face of the large faulted block of Sarten sandstone and other rocks about 2 miles north and east of Cooks.

PERMIAN (?) SYSTEM

Lobo Formation

The Lobo formation, which occurs only in the Cooks Peak area of Lake Valley quadrangle, is known to thicken to the south, but apparently it pinches out to the north, as it has not been identified in any locality north of Cooks Range. It was classified as Triassic (?) by Darton (1916, pp 39-41) . Data from subsequent investigations, however, make it more probable that this formation is the equivalent of the Abo formation, of Permian age, which it resembles both lithologically and in stratigraphic position.

In Cooks Range the Lobo formation ranges in thickness from 80 to 150 feet and consists of reddish-brown sandstones and shales, and chert conglomerates with limestone matrix. At one point on the ridge south of Cooks Peak this conglomerate is almost 50 feet thick. A general section of the formation in Cooks Range is as follows:

UNIT No.	DESCRIPTION	THICKNESS IN FEET
4.	Sandstone, greenish-buff	0-20
3.	Chert conglomerate, limestone matrix	20-50
2.	Shale, red	40-50
1.	Chert conglomerate, limestone matrix	10-15

The formation appears to be thickest in the area just north of Cooks Peak. A measured section in this area is given below.

Correlation. As described by Darton (1916), the Permian system in the Deming area of southwestern New Mexico consists of the Gym limestone of Lower Permian age. Although the Gym is not known to be represented in Lake Valley quadrangle, some problems of its correlation merit discussion here.

Restudy by the author of the faunal lists of the Gym, Hueco, and Chupadera formations indicates that the Gym fauna (Darton, 1916) is probably more closely allied to that of the Hueco limestone (Darton, 1928) than to that of the Chupadera formation. Not one characteristic Leonard fossil has been found in the so-called Gym limestone. Distinctive Leonard forms are found in the Chupadera formation. It is probable that Girty's original idea (Darton, 1916) is correct, that the Gym fauna resembles that of the Hueco limestone. This conclusion was rejected by

Darton (1926), apparently on the ground that the Abo formation was the base of the Manzano group and, therefore, as the group was then defined, the base also of the Permian. It became necessary, therefore, to place the Gym limestone above the time of the "missing" Abo formation. King and Read (King, 1942, pp 16-17) have demonstrated that the base of the Abo is not the base of the Permian, but rather that part of the underlying upper Magdalena group is basal Permian in age. This, together with the known fact that in places tongues of the Hueco limestone underlie the Abo, suggests that the Gym limestone can be correlated with either or both of these sets of beds. Though conclusive evidence is lacking, the author is of the opinion that the Gym limestone is not younger than Wolfcamp in age.

The Lobo formation was classified by Darton (1916, 1926, 1928) as Triassic (?) on little evidence other than its position above the supposed "Chupadera equivalent" and below the Lower Cretaceous Sarten sandstone, and the widespread occurrence of red beds in the Triassic. The author believes that the Lobo formation is probably the equivalent of the Permian Abo formation. This conclusion is based not only on the resemblance of the Lobo formation to the Abo in other areas, but also on its position directly above the Pennsylvanian beds in Cooks Range. On the basis of the Abo flora and the fauna of the dolomites and limestones which are equivalent to the Abo in the southeastern part of New Mexico and west Texas, King and Read (1942, pp 16-17) have stated that the Abo is probably upper Wolfcamp and lower Leonard in age. Skinner (1946) agrees with this conclusion. A Wolfcamp and lower Leonard age for the Lobo would be consistent with the age of the Gym limestone as here postulated. It is also possible that the Gym may be representative of the facies change in the Abo which is represented farther east by the Hueco limestone (Thompson, 1942, p 20, pl II). It should be noted that, according to Kelley and Bogart (1952) , there is considerable doubt as to the existence of a discrete Gym formation. The beds referred to the Gym at the type locality have been found to include several formations: Fusselman, Percha, and some beds of Pennsylvanian-Permian age. It is the Pennsylvanian-Permian (probably Hueco) fauna from this locality which was the basis for the proposal to regard the Gym limestone as a formation. Thus, the Gym formation should be redefined. No definite proof has been found as to the actual age of the Lobo formation, based on its stratigraphic position and lithology, but it is here classed as Permian (?) for the reasons given above.

LOBO FORMATION—COOKS RANGE NORTHWEST SECTION
(SW¼ sec. 25, T. 20 S., R. 9 W.)

Unit No.	Description	Thickness in feet
	Sarten sandstone (Cretaceous)	
	Unconformity	
11.	Shale, arenaceous, red	6.0
10.	Sandstone, yellow-brown, fine-grained	4.0
9.	Shale, arenaceous, red	12.0
8.	Sandstone, brown, fine-grained, thick-bedded	9.0
7.	Shale, arenaceous, red	35.0

6.	**Covered**	**5.0**
5.	**Limestone and limestone-chert conglomerate; calcarenite, dark-gray, weathers brown gray, with pebbles of white, gray, and red chert up to ½ inch in diameter**	**14.5**
4.	**Sandstone, red-brown, fine-grained, massive**	**0.5**
3.	**Limestone-chert conglomerate; calcarenite, medium-gray, with white, gray, and red, mostly angular to subangular, chert pebbles up to 4 inches in diameter**	**18.2**
2.	**Covered; lower 12 feet has limestone float; limestone is calcilutite, mottled dark brownish-purple, nonfossiliferous, weathers blue gray**	**34.8**
1.	**Limestone-chert conglomerate; calcarenite, medium- to dark-gray, with numerous fragments of white, gray, black, and red subangular to subrounded chert from 0.1-1.0 inch in diameter**	**11.6**
Unconformity		
	Beds of Pennsylvanian age	**——**
	Total Lobo formation	**150.6**

With a few minor exceptions, the Lobo formation crops out wherever the Pennsylvanian is encountered in Cooks Range.

CRETACEOUS SYSTEM

Sarten Sandssone

The Sarten sandstone, of Lower Cretaceous (Comanchean) age, consists of 300 feet of light-gray, massive sandstone, mostly quartzitic or very hard. In many areas, especially where the beds are somewhat slabby, broken blocks show concentric color banding by reddish iron stain, and some iron mineralization (hematite) occurs along joints and bedding planes. This resistant formation forms the capping layer on a high hogback south of Cooks Peak, and on a large fault block which forms a high ridge and covers a broad area north and east of Cooks. Small outliers also occur in the region directly north of Cooks Peak and on the highest points in the sedimentary belt on the eastern margin of the intrusive.

This formation was correlated by Darton (1917b) with the Beartooth quartzite of the Silver City area. Its accepted age is Fredericksburg (Lower Cretaceous) (Cobban and Reeside, 1952) , although Lasky (1947, p 24) has attempted to correlate it with the Corbett sandstone of the Little Hatchet Mountains, which is upper Trinity in age. The fauna of the Sarten, as determined by T. W. Stanton from Darton's collection in sec. 17 (?) , T. 12 S., R. 8 W., in the southern part of Cooks Range, is as follows:

Cardita belviderensis Cragin
Cardium kansasense Meek
Protocardia texana Conrad
P. quadrates Cragin
Tapes belviderensis Cragin
Turritella aff. *T. seriatim-granulate* Roemer

Ostrea sp.
Nucula sp.
Trigonia sp.
Lunatia sp.
Cyjyrimerta sp.
Anchura sp.

This collection was made from limy beds not far below the middle of the formation (Darton, 1916, p 44) . Fossils are rare, and the author was unable to find any in the areas which he mapped.

Colorado Shale

The Colorado shale is a dark-gray to black, blocky shale with interbedded thin layers of buff sandstone, sandy shale, and dark blue-gray limestone which weathers brownish buff. About 30 feet of slabby sandstone appears about 75 feet above the base of the formation. This formation is of Upper Cretaceous (Benton) age and was deposited considerably later than the Sarten sandstone, upon which apparently it rests conformably.

Small outcrops of the Colorado shale appear in the synclinal valley south of Cooks, where streams have cut down through the alluvium to expose the underlying bedrock.

A large molluscan fauna was collected by A. L. Bowsher and the author from a shale exposure along the road to Cooks, at E½ SW¼ NE¼ sec. 30, T. 21 S., R. 8 W. The following faunal list is provided through the courtesy of Dr. J. B. Reeside, Jr., of the U. S. Geological Survey:

Gryphaea newberryi Stanton
Luctna juvenis Stanton
Aporrhais prolobiata White
Cinulia sp. (n. sp. ?)
Romaniceras n. sp. aff. **R.** *loboense* Adkins
Reocardisceras septimseriatim (Cragin)
Parapusosia ? n. sp.

The following additional forms were collected at the same locality by R. H. Flower and the author, and identified by Dr. Flower:

Acanthoceras ? kanadense Stanton
Baculites cf. gracilis Shumard
Buchicheras cf. *swallovi* Shumard

Another collection from 50 feet above and north of the road to Cooks, at the center of the north line of sec. 30, T. 21 S., R. 8 W., has yielded *Gryphaea newberryi* Stanton and *Inoceramus labiatus* Schlotheim. These fossils were identified also by Dr. Reeside. He indicates that the two collections are from beds equivalent in age to the Greenhorn limestone of the Plains region (i. e., lower Turonian of the European sequence) . These beds are probably the equivalent of the Colorado shale of Stanton (1893) .

TERTIARY SYSTEM

In the Old Hadley (Graphic) mining district, about 3 miles south of Cooks, there is a small outcrop of dark micaceous sandstones, greenish-gray shales, and coarse conglomerates, which are probably older than the volcanics. They are surrounded entirely by volcanic rocks, but the conglomerates contain pebbles representative only of the Paleozoic and Mesozoic sediments which crop out nearby. Further evidence of the age of the conglomerates is lacking. Since, however, the postvolcanic Santa Fe (?) formation contains little but detritus from the tuffs and lavas in the area, and since this conglomerate, which is of similar lithologic nature, contains none, it is assumed that these sediments are prevolcanic.

Santa Fe (?) formation

A thick series of fanglomerates and water-laid fragmental volcanic material is correlated tentatively with the Santa Fe formation, as it resembles the rocks of Santa Fe age in other areas. Though no fossils have been found, the beds are thought to be of Pliocene-Pleistocene age. They are mainly valley fill formed during and after a period of uplift which marked the end of the principal period of volcanic activity in the Lake Valley area. The Santa Fe (?) formation is exposed in a broad outcrop area, which runs for 12 miles from the south-central part of the quadrangle in a northwesterly direction parallel to the edge of the area where the earlier volcanics are exposed. At its widest point perpendicular to the general strike the Santa Fe (?) outcrop is over 4 miles wide. North of Cooks Range this formation is the only one along the western boundary of the quadrangle for a distance of almost 8 miles.

The Santa Fe (?) formation in Lake Valley quadrangle consists of three main facies:

1. Fanglomerates: These rocks are pale yellow-buff in color and vary from very coarse conglomerates to medium-grained sandy layers. The conglomerates, which were probably formed as alluvial fan deposits, contain, in a matrix of quartz sand, angular to subangular pebbles of almost every volcanic rock exposed in the northeastern portion of the quadrangle. The pebbles and cobbles of the earlier rocks generally are more highly rounded than those of later rocks. However, the distance from outcrop must also be considered.

Some of the beds show graded bedding, but the fragments are largely unsorted. Near Cooks Range a few fragments of sedimentary rocks, and even the intrusive granodiorite porphyry, have been found. Though consolidated, the fanglomerates are fairly soft and friable, and weather into a series of low hills. The dips are almost uniformly to the southwest at angles ranging from 10 to 25 degrees. However, one small dome and several minor faults which cause dip variations occur in the fanglomerates. Fanglomerates are exposed in the two- or three-mile wide belt closest to the northeastern volcanic area. A small outcrop of fanglomerate may be seen also on the road from Barenda Creek to Macho Creek, south of the Nellie Latham ranchhouse.

2. Water-laid fragmental volcanic material: This type of "fanglomerate" crops out for a distance of 5 miles west of the drainage divide and north of secs. 25 and 26, T. 19 S., R. 9 W. This rock is very similar to the fanglomerates described under (1) , except that it is slightly more consolidated and darker buff in color. However, the matrix is made up almost entirely of fragmental volcanic material rather than the quartz sand found in the normal fanglomerate. The higher degree of consolidation is easily attributable to this feature, as the decomposition of such material, especially feldspars, would yield a large amount of calcium carbonate and some silica and clay. The considerable quantity of arkosic material present seems to indicate a relation in time to the formation of tuffaceous deposits of Santa Fe age in other parts of New Mexico. It is possible that some penecontemporaneous volcanic activity is responsible for these tuffaceous deposits. It may also be a simple result of the weath-

ering of some of the large masses of tuff found in parts of Lake Valley and Dwyer quadrangles.

3. Highly indurated fanglomerate: These rocks are reddish brown to reddish pink, and are made up of boulders, cobbles, and pebbles of many types of volcanic rocks, in a highly indurated arkosic matrix. The enclosed fragments range in size from pebbles to large boulders more than 6 feet in diameter. When first seen, these rocks were thought to represent some type of agglomeratic rock; later evidence, including the bedded nature of the rocks, the sorting of the material, and the high degree of conformity to the rest of the Santa Fe (?) rocks, made this improbable. It is more likely that the rocks have undergone some action by hot springs or other waters, which caused them to become indurated after deposition. In one area, at the extreme north end of the outcrop belt, this rock looks as though it has been intruded by a red-brown rhyolite. Bedding is absent, and the whole rock appears to be one mass, with angular inclusions of numerous other types of volcanic rock, which are much more widely separated than one would expect to find in a fanglomeratic rock. The rock has not been examined microscopically. This area may have been a center of hot springs activity during the time of induration of the rock.

These highly indurated rocks form massive cliffs in the area just northeast of Cooks Range, west of Mule Springs Peak. They are exposed about 1 mile southwest of the Lee McKinney ranchhouse, and extend from this point to about 2 ½ miles north of the granite outcrop at the northern end of Cooks Range, and as far east as Mule Springs Peak.

W. E. Elston (personal communication) has indicated that the Santa Fe (?) conglomerates are fanglomerates deposited from uplifted masses, and has been able to delineate, to some extent, the outlines of the fans and the directions from which they were deposited in Dwyer quadrangle. This follows closely the picture presented by Heindl (1952) of the deposition of the Gila conglomerate in Arizona. Though the prevailing westward dip in Lake Valley quadrangle and the width of outcrop would indicate a total thickness of 10,000 feet for the Santa Fe (?) rocks, such a thickness is thought to be much too great. There is no evidence to show that such a large amount of subsidence occurred during the deposition of the Santa Fe (?) . It is also found that outliers of pre-Santa Fe (?) volcanic rocks occur in places where the maximum subsidence should have taken place if the formation is very thick. If the deposits were laid down as fans, which is probable, a wide belt of uniformly dipping sediments of not very great thickness could be formed. The details of the deposition of the Santa Fe (?) formation are unknown, but it is probable that the thickness of the Santa Fe (?) does not exceed 1,500 feet in Lake Valley quadrangle.

Correlation. This series of fanglomeratic rocks is correlated tentatively with the Santa Fe formation. Derry (1940) , in his study of the latter formation near Santa Fe, has assigned it to the Miocene and Pliocene, using the age determination of Frick (1937, p 6) . Smith (1938, pp 957-958) refers the Santa Fe to the Pliocene, and possibly Upper Miocene, in Abiquiu quadrangle, where it is underlain by the Abiquiu tuff of possible Upper Miocene age. Derry (1940, p 680) states:

> The name Santa Fe formation is now used for those deformed and predominantly fluviatile deposits of the Santa Fe region that contain the vertebrate fauna. Similar deposits which contain a few vertebrate remains are found throughout the Rio Grande depression in New Mexico and correlated with the type region (Bryan, 1938, p 205). These deposits are probably the equivalent of the Gila conglomerate of southern Arizona (Gilbert, 1875; Knechtel, 1936).

Similar gravels in the Silver City region have been correlated with the Gila (Paige, 1916, p 6) , which is considered to be Pliocene-Pleistocene (Knechtel, 1936, p 87) . That the conglomerates in Lake Valley quadrangle are at least partly equivalent to the Gila or the Santa Fe is suggested strongly by their relation to the postrhyolitic period of diastrophism, which they postdate. The fact that they have been disturbed also by later (Pleistocene ?) deformation places them in a stratigraphic position similar to that occupied in time by the Santa Fe and Gila conglomerates. Indeed, such gravels are found in this part of the column almost throughout the Basin and Range province. It is, therefore, considered that the fanglomerates in Lake Valley quadrangle are Santa Fe equivalents.

Other Sediments

Scattered small lenses of fine and coarse sandstones and conglomerates are found in the tuffaceous members of the volcanic series. These probably represent the sites of old stream channels which developed as a result of erosion between periods of volcanic activity. One such lens, in the Razorback formation (nontuffaceous), has been mapped (pl 1) .

QUATERNARY SYSTEM

Pleistocene (?) Gravels

These gravels are defined as those deposits which underlie an old land surface thought to have formed late in Pleistocene time. In places parts of the surface still remain undissected and form the tops of low hills. At other places the gravels are true pediment gravels, lying not far above the bedrock surface. These deposits have been distinguished from the bolson deposits which form the present plains by the fact that they stand out above the latter deposits. They lap up on the Santa Fe (?) formation and on several areas of volcanic rocks at a level which is from 50 to 150 feet above the present base level, and are now in a state of rather marked dissection. The deposits are thought to have been laid down late in Pleistocene time when the base level was considerably higher, and a mature stage of erosion had developed in this part of southwestern New Mexico. Uplift at the end of Pleistocene time is thought to be responsible for the rejuvenation of the region and erosion of the gravels. This unit is designated Qtg_1 on the geologic map (pl 1).

Terrace Gravels

Along some of the major streams in the area there is a terrace level from 10 to 100 feet above the beds of the streams, the variation depending upon where along the length of the streams the terrace is located. Farther up the streams the terrace level is higher. These terrace deposits are made up mostly of unconsolidated sands and gravels. Some of them have a thin soil cover. In many areas the, terraces are rock-defended and delineate the extent of some of the meander channels of the streams. Some of the terraces are cut in the Pleistocene (?) gravels mentioned above, and must therefore be younger than the gravels. They are thought to be early Recent in age and to represent parts of old channels of the now more deeply incised streams. These gravels are designated Qtg_2 on the geologic map (pl 1) .

There are also some very recent terraces which represent the latest downcutting of the streams in their present channels. These terraces are mostly sand-covered, average only 5-10 feet high, and are probably of ephemeral nature. They have been included, therefore, under the general term Quaternary alluvium.

Talus

In many areas where there are steep scarps, masses of large broken blocks occur at the base of the scarps. These blocks have broken from the face of the scarp by Recent erosion. They have been mapped separately from other alluvium under the designation Talus (Qt) .

Bolson Deposits and Alluvium

On the flat bolson plains in the southeastern part of Lake Valley quadrangle there are many deposits of sand, gravel, and clay now being incised by the present streams. Along the lower flats and in the stream beds are some deposits of Recent alluvium, but these cannot be separated from the earlier deposits. However, slope wash, talus, and accumulations of detrital material in stream beds which cut through areas of high relief have been classified as Recent alluvium. Bolson deposits and alluvium have been mapped together under the symbol Qal, as they cannot be separated conveniently from each other.

The maximum thickness of the bolson deposits in the intermontane areas is unknown. Alluvium ranges in thickness from a few feet to several tens of feet. The age of the bolson deposits is probably Pleistocene and early Recent.

SUMMARY

A total of about 3,000 feet of Paleozoic and Mesozoic sediments has been measured in the Cooks Range area of Lake Valley quadrangle, where the most complete section is exposed. This is not an exceptionally thick sedimentary pile, especially when it is considered that the formations include representatives of parts of nine geologic periods. Of these, the Ordovician is represented by slightly more than 1,100 feet, more than one-third of the total. The remaining eight periods, with the exception of the Cretaceous, are each represented by 300 feet or less of section.

Throughout the Paleozoic era, the part of southwestern New Mexico in which Lake Valley quadrangle is located was a fairly stable area. It was an area where apparently less than 1,000 feet of subsidence occurred during any given period of the Paleozoic era, with the exception of the Ordovician (Eardley, 1949; McKee, 1951) . It may be looked

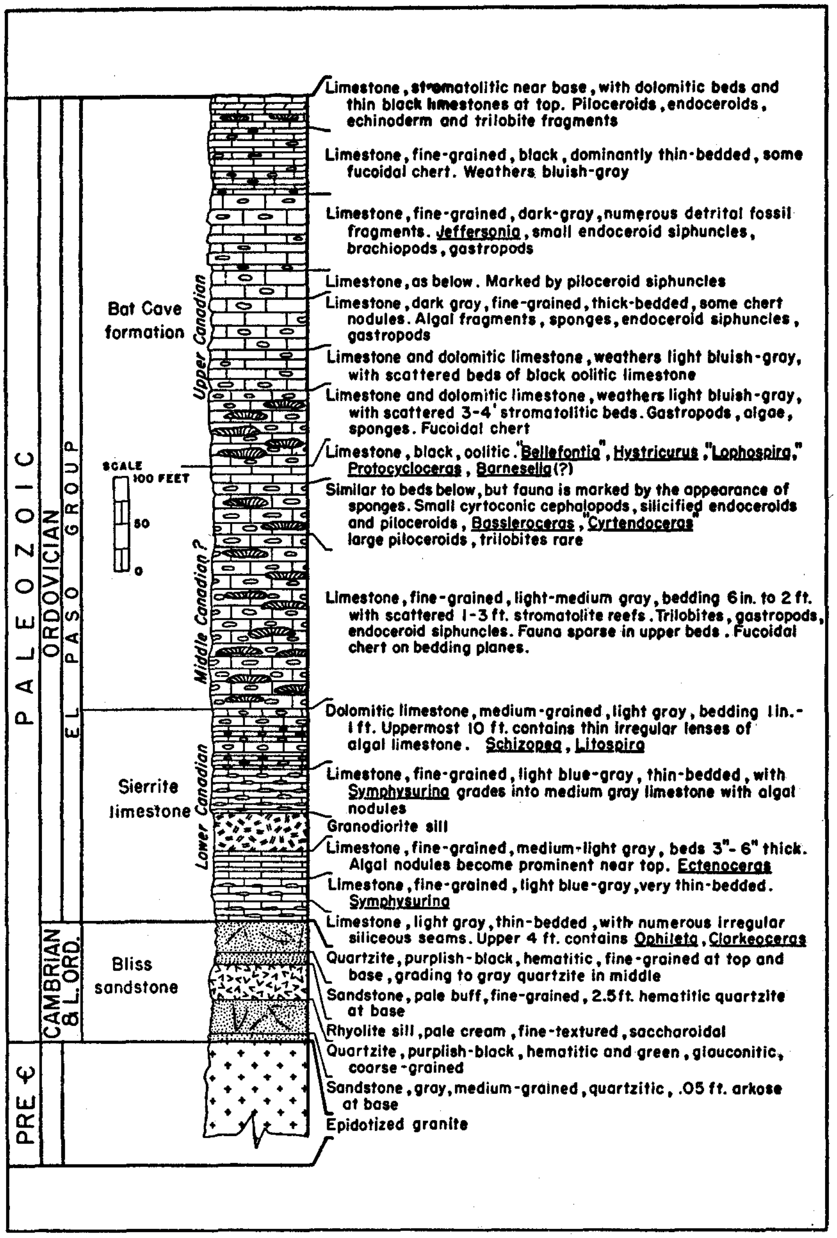


Figure 1

COMPOSITE STRATIGRAPHIC SECTION IN COOKS RANGE (PART 1).

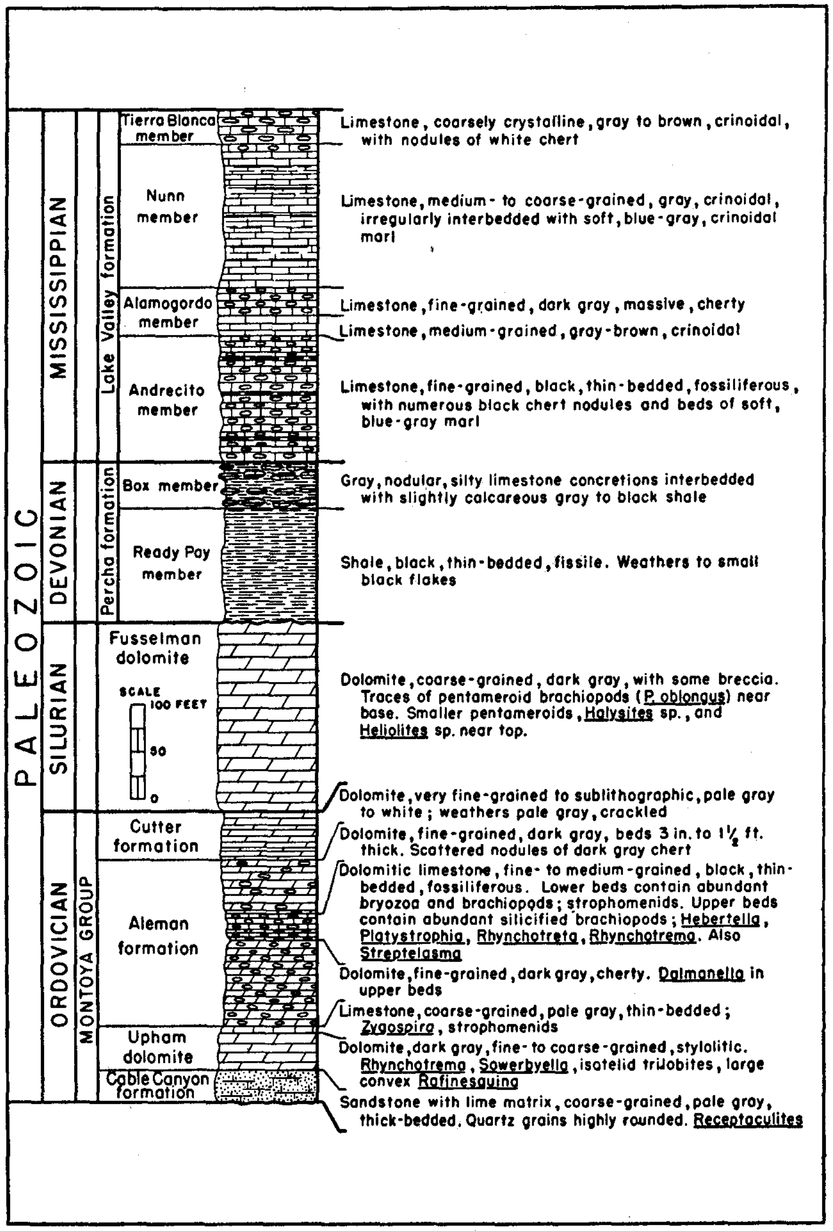


FIGURE 2

COMPOSITE STRATIGRAPHIC SECTION IN COOKS RANGE (PART 2).

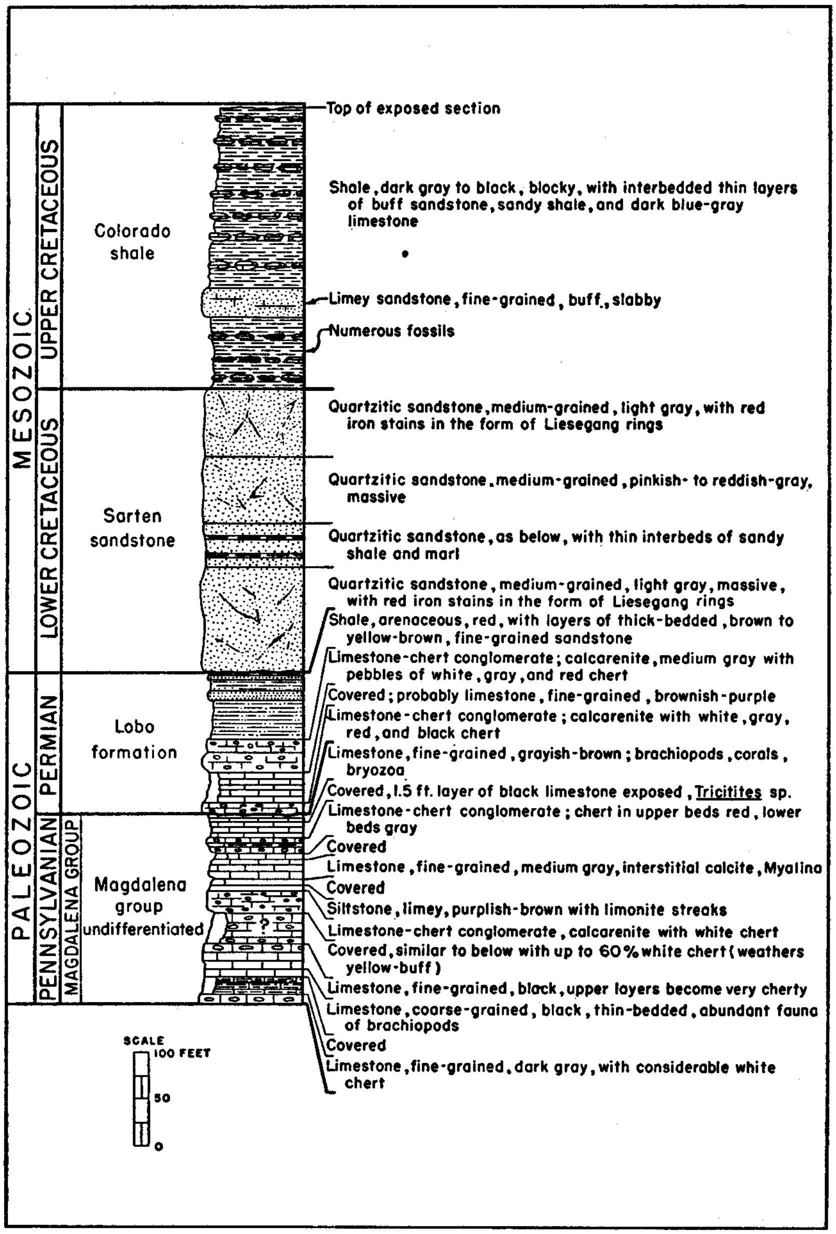


Figure 3

COMPOSITE STRATIGRAPHIC SECTION IN COOKS RANGE (PART 3) .

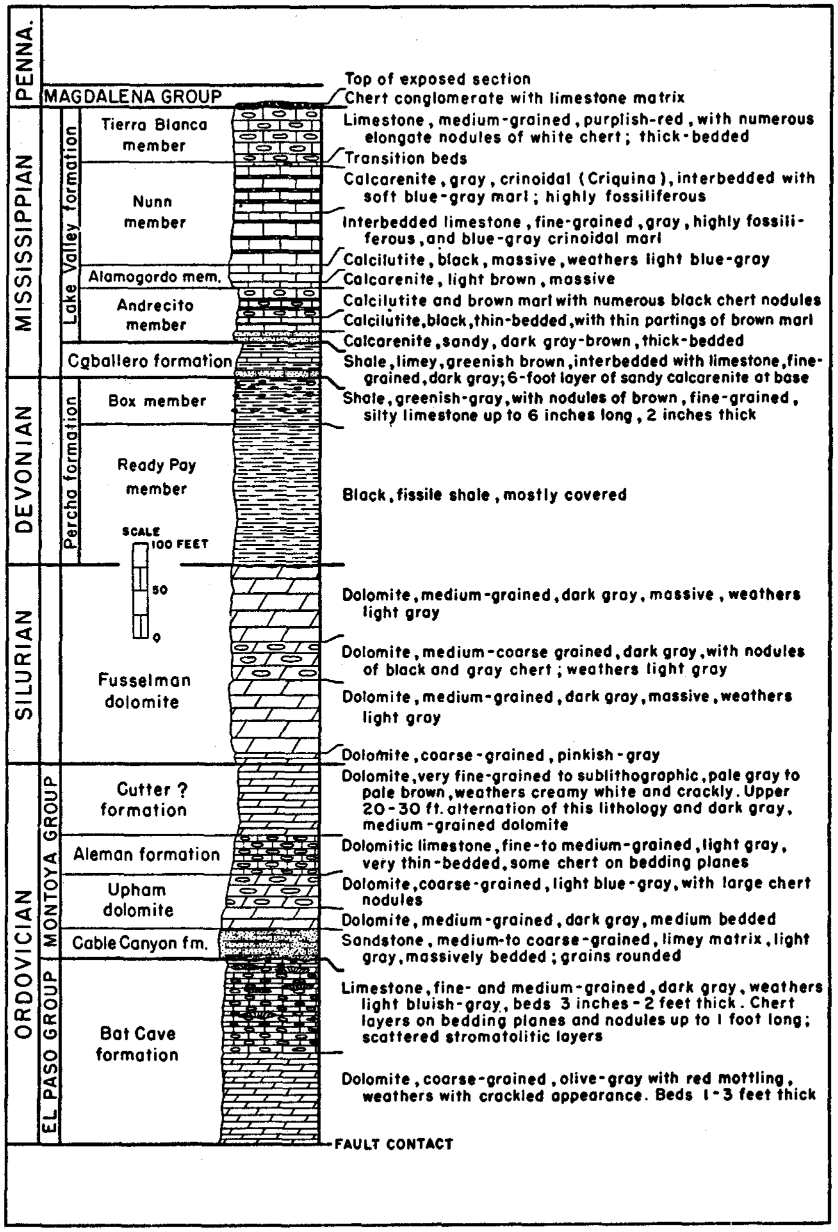


Figure 4

COMPOSITE STRATIGRAPHIC SECTION IN THE LAKE VALLEY FAULT BLOCK.

upon as a region mainly of minor regional warping during Paleozoic time. Although every period of the Paleozoic is represented by some sediments, most periods are characterized by sediments which represent only a small part of the time interval. Uplift and erosion, or at least nondeposition, are in evidence for parts of every geologic period in this era. The character of the sediments indicates shallow marine sedimentation on a fairly stable continental shelf area, and was varied according to the distance from the source and the amount of orogenic activity in the source area. The lack of sharp unconformities, which necessitates recognizing them on a regional, rather than a local scale, substantiates the hypothesis of warping rather than orogenic movement. This regional warping does not appear to have raised the land very far above the level of the sea at any time, with the possible exception of the end of the Mississippian period. At that time widespread erosion occurred, and conglomerates were developed in the basal Pennsylvanian, accompanied in places by faulting. Similarly, the nature of the sediments (mostly limestones and dolomites of shallow marine origin) and their generally small thickness show that subsidence was never very great. That differential subsidence took place is indicated best in the variations in extent and thickness of the various members of the Mississippian series (Laudon and Bowsher, 1949) .

The Mesozoic era is characterized by erosion in the first two periods. The comparatively thin Cretaceous sedimentary units present in Cooks Range indicate that Lake Valley quadrangle was on the margin of a large geosynclinal area (Mexican geosyncline) during the Cretaceous period. The only Lower Cretaceous unit in Cooks Range is the Sarten sandstone, about 300 feet thick, whereas Lasky (1947) has reported 21,000 feet of Lower Cretaceous sediments, including 9 units, in the Little Hatchet Mountains, 50 miles to the southwest. Similarly, only 300 feet of Upper Cretaceous shales are found in Cooks Range, whereas considerable thicknesses of Upper Cretaceous sediments occur to the southwest (Lasky, 1947) and to the northwest (Paige, 1916) . A greater thickness of Cretaceous shale may have been present in Cooks Range and later eroded, but good evidence for this hypothesis is lacking. In any event, the amount of subsidence in that area could not have been very great. Cretaceous volcanics occur in southwestern New Mexico, but none occur in Lake Valley quadrangle.

The period of relative stability was terminated in this part of southwestern New Mexico with the development of large-scale folding, faulting, uplift, and intrusion in late Cretaceous and early Tertiary time. In southwestern New Mexico large Basin-and-Range type fault blocks were developed, though some thrusting is in evidence. The exact extent in time of this orogeny in southwestern New Mexico is in doubt, but, broadly speaking, the revolution took place in late Cretaceous and early Tertiary time. After the development of these orogenic features, southwestern New Mexico became a fairly unstable, rather high, land mass. Orogenic activity continued sporadically throughout Tertiary time, accompanied by volcanism. The major period of volcanic activity appears to have been the Miocene and early Pliocene times. Its conclusion was marked by a period of orogenic activity, presumably Pliocene, which caused renewed movement on older faults and development of some new faults. That this orogenic movement was widespread in New Mexico and Arizona is shown by the wide areal distribution of conglomerate deposits of the Gila and Santa Fe types, which probably were derived from the faulted mountains thus formed by subaerial erosion. Renewed regional uplift in late Pleistocene time is demonstrated in the present downcutting and lowering of the base level which was in force during the Pleistocene period, when peneplanation apparently took place after the period of aggradation during which conglomerates were deposited. That the lowering of the base level has been a stepwise process is seen in the development of terrace levels above the present base level. Present-day sedimentation is mainly in intermontane valleys in the form of valley fill or bolson-type sediments.

INTRUSIVE ROCKS

The intrusive rocks of Lake Valley quadrangle are largely dikes, though some plugs and a large stock occur. The dike rocks of the quadrangle will be referred to in a separate section.

The Cooks Peak granodiorite stock is by far the largest and economically the most important intrusive in Lake Valley quadrangle. The granodiorite is of uncertain age. Mr. Robert Hernon (personal communication, 1951) has stated that most of the intrusive activity in the Santa Rita area took place after the first (Cretaceous ?) period of volcanism, with the exception of a small number of diorite dikes. It seems a logical inference that the Cooks Peak stock was emplaced in that major intrusive epoch, though there is little direct evidence to support such a statement. The Tertiary volcanics near the stock have not been intruded, but the contact between the stock and the volcanics is faulted. Sandstones in the lower part of the Macho series contain pebbles of granodiorite. The assignment of an age to the Cooks Peak stock is difficult, but it has been tentatively designated as late Cretaceous or early Tertiary, the periods when intrusive activity was prevalent in the Silver City region (Paige, 1916) .

The only other intrusive in Lake Valley quadrangle that is not a dike is in the northwest corner of the quadrangle. It is a basalt plug, perhaps 50 yards in diameter, which intrudes the volcanics and is probably of Pleistocene or early Recent age.

Granodiorite Porphyry

Large masses of intrusive porphyry occur in Cooks Range, and Cooks Peak consists of that rock. Several dikes and sills occur in the Lake Valley limestone northwest of Cooks Peak. The porphyry cuts the sediments from Silurian to Upper Cretaceous in age and is thus assumed to be late Cretaceous or early Tertiary. It is evident that the intrusive was in a semifluid state when it was emplaced, because stoped blocks of Lake Valley limestone have been found in the granodiorite near the contact between the intrusive and the Lake Valley limestone. These blocks are metamorphosed into a hornblende rock. However, the intruded sedimentary rocks show little evidence of any widespread metamorphism. The sediments are altered only for about one-sixteenth of an inch directly along the contact with the granodiorite. At places the granodiorite is cut by diorite dikes, some of which are as much as one mile in length. The intrusion of the granodiorite appears to have caused some disruption of the sediments just north of Cooks Peak, where faulting appears to be controlled in part by the granodiorite intrusions.

The intrusive rock is a massive porphyry of gray color with prominent phenocrysts of andesine and lesser amounts of hornblende and biotite. The phenocrysts show well-developed flow structure. The groundmass is microcrystalline granular and consists of the same minerals with the addition of quartz, orthoclase, and lesser amounts of apatite and chlorite (pl 4-B). The analysis and norm of this rock appear in Tables 4 and 5.

The rock is designated a granodiorite porphyry, as it contains too much plagioclase to be termed a quartz monzonite.

TERTIARY VOLCANIC ROCKS

About one-third of Lake Valley quadrangle is covered by Tertiary volcanic rocks. The rocks represented are rhyolites, quartz latites, amphibole latites, pyroxene andesites, basalts, and their fragmental equivalents.

The exact ages of these rocks are still in doubt. No fossils have been found in the stream gravels associated with some of them. The lower pyroxene andesites resemble those which, in the Silver City area, have been termed late Cretaceous or early Tertiary (Paige, 1916) . They are regarded tentatively by the writer as early Tertiary and may be as young as early Miocene. The amphibole latites and other rocks are thought by the writer to be late Tertiary; there is some possibility that a few of them may be as young as earliest Pliocene. So recent an age, however, is doubtful, as the rocks are overlain by Santa Fe (?) beds, which may include latest Miocene (very doubtful) and Pliocene, depending upon the part of Santa Fe time represented by the upper unit. As the region is not far from the area in southeastern Arizona where the Gila conglomerate of Pliocene-Pleistocene age occurs, it is thought that the age of the Santa Fe (?) in this area, like that of the Gila, is Pliocene-Pleistocene.

The volcanic rocks of this region follow the general eruptive pattern found in many other areas in southwestern New Mexico. The earliest of these rocks in Lake Valley quadrangle are fairly basic (pyroxene andesites) . They became gradually more silicic (latite-rhyolite) , and then there is a return to basic rocks (pyroxene andesites and basalt) . The latest volcanic rocks in Lake Valley quadrangle are olivine basalts. This alternation between silicic and basic rocks is also typical in the latest part of the volcanic sequence, though basalts are the youngest volcanic rocks found in New Mexico.

Table 3 is a generalized stratigraphic section of the Tertiary rocks of the area.

Petrographic Methods

Rock names used in this paper are in accord with those used by Johannsen (1939). Determinations of mineral compositions of the rocks were made using a Leitz micrometer stage. Data are given in volume percentages. In certain of the rocks, plagioclase feldspars were determined by the Rittman method on the universal stage. Average compositions are given. Norms have been calculated by the CIPW system (Washington, 1917) as modified by Barth (1931) .

TABLE 3. GENERALIZED TERTIARY SECTION, LAKE VALLEY QUADRANGLE, NEW MEXICO

AGE	FORMATION	LITHOLOGY	THICKNESS IN FEET
Pliocene-Pleistocene (?)	Santa Fe (?) formation	Consolidated sands and gravels, fanglomerate, water-laid fragmental volcanic material	0-1500
	Unconformity; major faulting		
Late Tertiary	Bear Springs basalt	Flows of purple, porphyritic, iddingsite-bearing rock, at times scoriaceous	150 ±
	Unconformity		
	Razorback formation	Fine-grained pyroxene andesites and possibly some rhyolite flows, with minor interbedded sandstone layers	250-500
	Disconformity		
	Pollack quartz latite	Pinkish-brown quartz latite flow with large phenocrysts of feldspar and fewer of quartz	300 ±
	Disconformity		
	Mimbres Peak formation	Banded pink-gray rhyolite flows and intrusive rhyolites, spherulitic and stony rhyolites, perlite, and associated red intrusive rhyolites. Possibly also pumiceous tuffs with rhyolite fragments	200 ±
	Disconformity		
	Kneeling Nun rhyolite	Pale lavender-gray and dark-brown welded tuffs with prominent quartz phenocrysts, columnar jointing	10-200
	Disconformity		
	Sugarlump tuffs	Pink and white explosion tuffs of quartz latitic composition	1000 ±
	Unconformity; faulting (?)		
	Rubio Peak formation	Varied porphyritic flows and breccias of intermediate composition, ranging from sodic to calcic (amphibole latites and pyroxene andesites)	2500 ±
	Unconformity		
Early (?) Tertiary	Macho pyroxene andesites	Purple porphyritic pyroxene andesite flows, breccia, and varicolored tuffs, with interbedded sandstones	1000 ±
	Major unconformity; late Cretaceous and early Tertiary orogeny		

Macho Pyroxene Andesites

The Macho pyroxene andesites and andesite tuffs are named from the Macho mining district at W ½ sec. 20, T. 19 S., R. 7 W., where they form a fairly thick series of flows, flow breccias, and tuffs. The tuffs are not exposed in the Macho district, but only in the Old Hadley (Graphic) district, southeast of Cooks Peak. The pyroxene andesite flows are mostly dark-purple to purplish-gray porphyritic rocks with phenocrysts of white feldspar (labradorite) and augite, hypersthene, and other dark minerals. The breccias are purple to brownish red and contain fragments of pyroxene andesite flow rock in a groundmass similar to the flow rock except for color.

The tuffs appear to form the earliest part of the series. They range in color from bright purple through chocolate brown to bright red and pale bluish-gray. These rocks are mostly porphyritic, with prominent crystals of plagioclase feldspars and hornblende and other dark minerals. The tuffs are often interbedded with white or green-gray magnetite-bearing sandstones and lenses of red conglomerate. Graded bedding in the tuffs suggests that they were water-laid. The tuffs are exposed only in the Old Hadley district.

Megascopically, the typical pyroxene andesite of the Old Hadley district is purple, fine-grained, and porphyritic, with phenocrysts of plagioclase up to 2 mm long and microphenocrysts of augite. Microscopically, the rock consists of (1) a fine-grained, partly crystalline groundmass which makes up about seven-eighths of the rock, and (2) phenocrysts of labradorite ($Ab_{42}An_{58}$), augite, greenish-brown biotite, brown hornblende (lamprobolite), and minor apatite. The groundmass consists of these minerals together with hematite, magnetite, and minor potash feldspar (probably sanidine). See Plate 4-C.

The pyroxene andesite of the Macho district resembles that of the Old Hadley district almost exactly in megascopic and microscopic character, with the possible exception that the andesite of the Macho type contains slightly more augite and less lamprobolite.

In many areas the Macho series has been mineralized. Veins of copper, lead, and zinc minerals are accompanied by marked alteration of the pyroxene andesite.

Pyroxene andesites crop out in the Old Hadley (Graphic) district, in and near the Macho district, and at Lake Valley. In general, these rocks crop out only in areas which are topographically low. Thus, it is probable that the Macho pyroxene andesites were eroded to form a low, rolling surface upon which the later volcanics were deposited, and that the andesites are exposed only in areas where the later volcanics either were not deposited or have subsequently been eroded away. Where the later Rubio Peak flows dominate, there are few outcrops of Macho andesite, and these are confined to stream beds or other topographically low areas.

An analysis and norm for the Macho pyroxene andesite are given in Tables 4 and 5.

Rubio Peak Formation

The Rubio Peak formation was named by W. E. Elston (1953) from a prominent butte at secs. 9, 10, 15, and 16, T. 19 S., R. 10 W., in Dwyer quadrangle. In Lake Valley quadrangle these rocks are the most voluminous group of volcanics. They range in composition from fairly silicic amphibole latites containing up to 63 percent SiO_2, to pyroxene andesites containing as little as 59 percent SiO_2. Their color range extends from pinkish gray through various shades of red, lavender, purple, brown, and black. Phenocrysts may be large or small, and the rock may be glassy or almost entirely crystalline. Microscopically, the rocks are much more uniform, however. Although the proportion of phenocrysts to groundmass varies to some degree, the mineral composition appears to remain fairly constant.

Pyroxene andesites appear sparsely throughout the Rubio Peak series. They were formed for the most part early in the period in which amphibole latites predominated. It would appear, however, that the pyroxene andesites were being extruded from various vents or volcanoes at almost every stage of the period of latite development, although normal latites preponderate in all but the early stages.

In the north central part of the quadrangle the Rubio Peak formation is exposed in a broad outcrop which covers an area of about 45 square miles. Other outcrops are east of Lake Valley, north pf the Lee McKinney ranch near Mule Springs Peak, and south of the Old Hadley (Graphic) district, which is southeast of Cooks Peak. Similar rocks may be traced for some distance to the south and north of the borders of the quadrangle. However, on the south and west they are separated by bolson plains or by outcrops of other rocks from the main body of volcanics here described.

No attempt has been made to secure a detailed section of the Rubio Peak series, because not all the flows are exposed. The flows, moreover, are so numerous and of such short extent that such a section would be practically useless for the purposes of an areal study. The thickness of the Rubio Peak formation in Lake Valley quadrangle is estimated to be about 2,500 feet. The top of the formation is marked by a prominent unconformity, above which are quartz latite tuffs and some other rocks.

Megascopically, a typical amphibole latite is pale lavender gray, fine-grained, porphyritic, with phenocrysts of potash feldspar up to 2 mm long, lamprobolite up to 3 mm long, and minor biotite. The matrix appears holocrystalline; the rock weathers grayish buff.

Under the microscope, about two-thirds of the rock is finely crystalline groundmass and one-third large phenocrysts of andesine ($Ab_{63}An_{37}$), potash feldspar (probably sanidine) , basaltic hornblende (lamprobolite) , and lesser brown biotite with some magnetite. The phenocrysts are mostly subhedral to euhedral. The plagioclase crystals are zoned. Twinning according to the albite and Carlsbad laws is common. Peridine twinning is rare. Lamprobolite is often resorbed and converted wholly or in part to magnetite. The groundmass is made up mostly of laths of feldspar, both orthoclase and andesine, with minor amounts of ferromagnesian minerals and magnetite (pl 4-E) . A typical volumetric Rosiwal analysis is as follows:

	PERCENT
groundmass	68.0
andesine	19.6
sanidine	7.0
lamprobolite (including magnetite)	4.3
biotite	1.1
	100.0

Magnetite pseudomorphs after lamprobolite have been included under that designation.

A typical pyroxene andesite within the Rubio Peak formation is dark purple to almost black, very fine-grained, porphyritic, with sparse tiny phenocrysts of plagioclase and augite up to 1 mm long. It weathers slabby, orange brown.

About nine-tenths of the rock is made up of a groundmass of tiny feldspar crystals with a crude flow structure; some augite, magnetite, and hematite are also present. The groundmass feldspars are mostly potash feldspar and andesine. The remaining one-tenth is phenocrysts of albite-twinned andesine, sanidine, augite, and some hypersthene (el 4-D). A volumetric Rosiwal analysis gives the following composition:

	PERCENT
groundmass	92.5
sanidine	0.9
andesine	1.0
augite	4.3
hypersthene	1.3
	100.0

Chemical analyses and norms of these rocks are given in Tables 4 and 5.

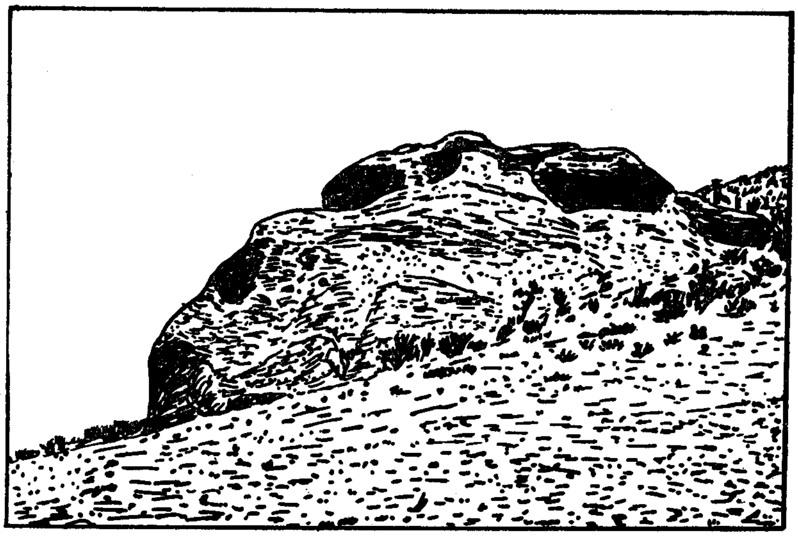
Pyroxene andesites of the Rubio Peak formation have been included with amphibole latites in mapping, because the complex intermingling of the flows made separate mapping impossible in the time available.

Sugarlump Tuffs

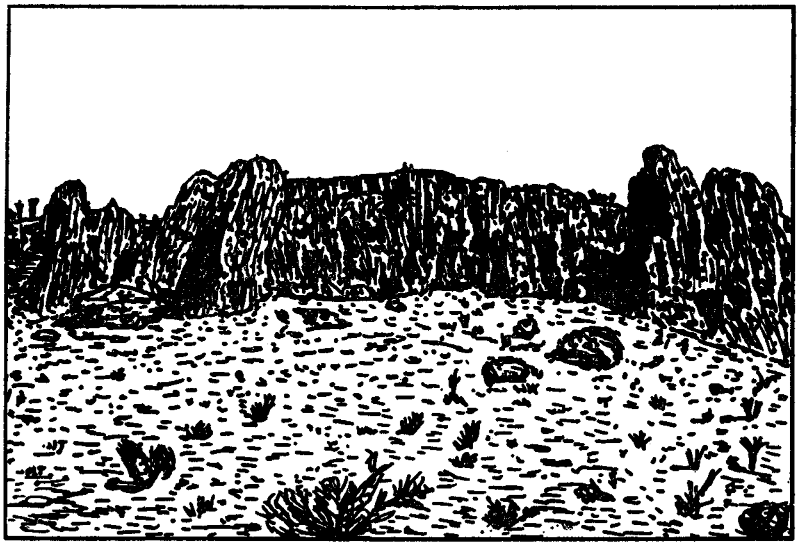
The Sugarlump tuffs were named by W. E. Elston after a prominent, steep, loaf-shaped mountain at NE¼ sec. 15, T. 19 S., R. 10 W., in Dwyer quadrangle, where they are very thick and prominently exposed. There the tuffs include some andesitic and latitic members which are not present in Lake Valley quadrangle (Elston, W. E. 1953) .

In Lake Valley quadrangle the Sugarlump tuffs consist of pink and white quartz latite tuffs which lie unconformably on the Rubio Peak formation. Apparently, erosion had not progressed very far beyond the youthful stage before the deposition of the tuffs, as they are found to fill moderately wide valleys in the buried topography developed on the Rubio Peak formation. This is especially well marked near the headwaters of White Rock Creek, where the contact between the two formations is very sharp and at such a steep angle that it was at first thought to be a fault. The relief on the Rubio Peak formation does not appear to have been the result of faulting, although it is possible that the streams which formed these valleys followed fault lines (see pl 1, cross-sections B-B' and C-C').

Most outcrops form prominent stratified masses. The beds, which are pink, white, and orange, may weather as separate ledges, but more commonly weather together into a single rounded mass (see fig 5) . In areas where there are latites nearby, the rocks contain scattered large fragments of latite. The Sugarlump tuffs are generally overlain by rhyolites. A typical tuff is a pale grayish-white rock containing numerous subangular fragments. The fragments are white, pale bluish-gray, and pale reddish-brown. The rock weathers pale cream to white. Some tuffs



A



B

Figure 5

A. SUGARLUMP TUFFS, SHOWING TYPICAL ROUNDED WEATHERING. B. SUGARLUMP TUFFS, SHOWING MORE MASSIVE COLUMNAR WEATHERING. THIS TYPE OF WEATHERING OCCURS ONLY IN MORE HIGHLY INDURATED TUFFS.

contain large fragments, including many pumiceous ones up to 2 cm long. Most tuffs contain particles 2-10 mm in diameter or smaller. The finer-grained tuffs greatly resemble coarse, chalky sandstone.

Typical tuff is made up of about 60 percent groundmass of glass shards and 40 percent larger particles, the latter for the most part being fragments of glassy nature (pl 4-F) . Phenocrysts, less than 5 percent of the volume of the rock, include andesine, sanidine, quartz, tridymite, biotite, and hematite. A few of the glassy inclusions appear to be made up of microcrystalline intergrowths of sanidine and cristobalite, but no definite determination was possible. More generally, fine-grained tuffs contain up to 15 percent phenocrysts and considerably fewer glassy fragments. The coarse-grained tuffs are more pumiceous than the finer ones and contain about the same proportions of phenocrysts, inclusions, and groundmass as the medium-grained varieties. The mineral composition shows slight variations, but none of the rocks is markedly different. The shardy nature of the groundmass, the included latite fragments, and the paucity of true phenocrysts indicate that the Sugarlump tuffs are products of volcanic explosions. Some of them may be in part welded tuffs. The thickness of the Sugarlump tuffs is estimated to be about 1,000 feet.

Kneeling Nun Rhyolite Tuff

The Kneeling Nun rhyolite is named after the prominent rock monument which overlooks the town of Santa Rita and the Chino copper pit. The Kneeling Nun is an isolated column of welded rhyolite tuff which stands a short distance in front of a high escarpment of the same rock. It is a famous landmark in the Santa Rita area.

The Kneeling Nun tuff is characterized by many features which have been described as characteristic of welded tuffs. The latter have been described by numerous authors. The first mention of such rocks was made by Iddings (1899) in his famous monograph on the geology of Yellowstone National Park. Other welded tuffs have been described in Alaska (Fenner, 1923) , Idaho (Mansfield and Ross, 1935) , California (Gilbert, 1938) , Oregon (Moore, 1934) , the Lesser Antilles (Anderson and Flett, 1903; La Croix, 1904; Ferret, 1934) , Peru (Fenner, 1948) , and New Zealand (Marshall, 1935) .

Paige (1916) originally described the Kneeling Nun as a flow rhyolite. The Kneeling Nun, with its prominently developed columnar structure, is called a welded tuff by the author, because it varies considerably in character from flows of the same rock type. The gently dipping, widespread (tens of square miles) rocks are fragmental, with a glassy groundmass, including some attenuated shards. They lack vesicular or scoriaceous zones, suggesting strongly that they were not flow rocks rendered fluid by high gas content. All of these characteristics point to the probability that the Kneeling Nun is a welded tuff. The rocks may have been formed by a nu& ardente (cloud of hot, particle-laden gases) , or possibly by eruption of fragmental material from a vent, without rising high in the air—simply a gaseous particulate flow eruption.

Megascopically, the rock is 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. The large number of quartz and feldspar crystals give the rock the appearance of a granite porphyry. Quartz and feldspar phenocrysts appear to be somewhat fragmental, some even having the aspect of shards. The rock has marked columnar jointing and, at places, faint horizontal sheeting.

Microscopically, the rock consists of about one-third phenocrysts and two-thirds cryptocrystalline groundmass. The phenocrysts are large subhedral to anhedral crystals of quartz, oligoclase, sanidine, and some brown biotite. The groundmass surrounding the crystals is translucent and pale brown in color. It contains small spherulites which show radial structure under crossed nicols (pl 5-A). Very tiny particles of magnetite are embedded in the glass, whose refractive index is less than that of balsam. A volumetric Rosiwal analysis gives the following composition:

	PERCENT
glassy groundmass	67.5
quartz	21.5
sanidine	7.9
oligoclase	1.6
biotite	1.0
magnetite	0.5
	100.0

The chemical analysis and norm of this rock indicate that it is a rhyolite (tables 4 and 5) .

The Kneeling Nun welded rhyolite tuff generally lies conformably upon quartz latite tuffs of the Sugarlump formation. In Barenda Valley, directly west of the Lake Valley fault block, and in a separated outcrop about one mile west, the Kneeling Nun formation has a thickness of about 200 feet. To the southwest, near the headwaters of White Rock Creek, the thickness is only 6-10 feet.

Mimbres Peak Formation

The Mimbres Peak formation was named by Elston from a hill located in sec. 8, T. 19 S., R. 10 W., in Dwyer quadrangle, where it crops out prominently. It is made up of several types of rhyolitic rocks, all of which are genetically related. These rocks include rhyolite flows, perlite, minor pumiceous rhyolites, and their intrusive equivalents. Some of the pumiceous rhyolites are tuffaceous. Much of the rhyolite in Lake Valley quadrangle forms dome eruptions. These eruptions push up earlier volcanics at many places. The rhyolites of the Mimbres Peak formation vary in physical characteristics. The more prominent types are stony, flow-banded or laminated, microspherulitic flow-banded, and spherulitic. The spherulitic type contains large numbers of nearly spherical, brown, stony balls, 1-5 cm in diameter, with radial internal structure. They are apparently the result of devitrification of glassy phases, probably pitchstone, in the rhyolitic mass. The stony type is generally gray, with some pinkish areas, and aphanitic; it shows minor flow structure. Fresh, flow-banded rhyolite is pink, gray, to creamy white in alternate layers. It weathers cream. The rock is, for the most part, microcrystalline, and may be silicified. At most places it displays prominent flow structure, which is crinkled and contorted like a crumpled piece of paper. The configuration of this flow structure makes it highly probable that much of this rhyolite was extruded as domes, since it dips more nearly horizontally at the edges and approaches verticality near the centers of the rhyolite masses.

In general, where rhyolite is encountered in a sequence, it directly overlies tuff of the Sugarlump series or the Kneeling Nun welded rhyolite tuff. However, large masses occur in eruptive centers with little or no tuff. One of these centers is just southwest of the junction between Macho and Pollack Canyons, near the headwaters of Road Creek, and the other just southwest of Lake Valley. A chemical analysis of the rhyolite from the eruptive center near Lake Valley is given in Table 4.

Several outcrops of perlite are associated with these centers and other rhyolite flows. The perlite occurs in small domes, dikes, and sills. The largest area in which perlite is known to occur is located in the rhyolite mass just southwest of Lake Valley. It has been given the field name "McKinney perlite" after the name of the holder of the mineral rights, C. A. McKinney. Here the perlite is in the form of a large sill. The perlite of Lake Valley quadrangle varies in color from black to light gray and red. Most of it is partly devitrified and contains stony bands or bands of the little brown balls previously described. Some of the smaller masses do not show these features. The perlite in this area is thought to have the composition of a rhyolite, as analyses of various volcanic glasses which exhibit perlitic structure in New Mexico all show a rhyolitic composition, varying largely only in water content.

Perlite is often associated with a red intrusive rhyolite, which occurs just beneath the sills and adjacent to the dikes and domes. Some of the red rhyolite contains small inclusions of rhyolite with flow structure. One specimen has been found in which the red rhyolite actually forms a small dike in the laminated rhyolite. In many areas, masses of yellowish, fine-grained rocks, which break with a conchoidal fracture, occur in association with rhyolite and perlite. These yellowish rocks are probably a devitrified phase of perlite.

The microspherulitic phase of the flow-banded rhyolite is found associated always with the laminated rhyolite. It appears, however, to be confined to the interior of rhyolitic intrusive masses. It is cream-colored with a slight greenish tinge. The entire rock appears to be made up of tiny spherulites less than 1 mm in diameter. Other forms of rhyolite also occur, but these are very local. The most striking of the local forms is a rhyolitic breccia, consisting of fragments of laminated rhyolite in a rhyolitic matrix. Flow rhyolites are generally less than 300 feet thick.

In addition, rhyolite tuffs which resemble the Sugarlump tuffs, except that they contain rhyolite fragments, occur in Dwyer quadrangle. The presence of tuffs belonging to the Mimbres Peak formation in Lake Valley quadrangle is suggested by the fact that many of the tuffs in the northwestern part of the quadrangle contain rhyolite fragments. However, the Kneeling Nun rhyolite, which serves as a marker in Dwyer quadrangle, is not present in that part of Lake Valley quadrangle, nor do the tuffs contain flow rhyolites, as they do in places in Dwyer quadrangle. Thus, these tuffs cannot be correlated with any great certainty and may belong to the Mimbres Peak or to the Sugarlump formation. For that reason they have been mapped as Sugarlump and Mimbres Peak, undifferentiated.

Pollack Quartz Latite

The Pollack quartz latite is named from its exposure on Pollack Creek, although the type area is along Taylor Creek, which branches off to the north. It is exposed over an area of about 4 square miles in the north central part of Lake Valley quadrangle on Macho, Taylor, and Pollack Creeks, and in the northwest corner of the quadrangle. Two other small outcrops occur on the west side of White Rock Creek near its junction with Fuller Creek. The Pollack quartz latite lies unconformably on both rhyolite tuffs and rhyolites, and thus appears to be later in age than the Kneeling Nun formation, which has been found to lie only on tuffs of the Sugarlump formation and is in turn overlain by rhyolites. Flows of the Razorback formation lie on the Pollack formation along Taylor Creek.

The Pollack quartz latite ranges in color from a dominant pinkish brown to light red and purple. It contains phenocrysts of andesine and sanidine up to 2 cm long, with smaller phenocrysts of quartz, brown hornblende (lamprobolite), and greenish-brown biotite (p1 5-B). Though the rock superficially resembles the Kneeling Nun tuff, it more nearly resembles a flow rock than a welded tuff; it lacks columnar jointing. The Kneeling Nun and Pollack rocks are very different chemically (see table 4). The largest differences occur in the percentages of silica, alumina, and lime contained.

The rock contains 25 percent phenocrysts, including large euhedral quartz crystals, sometimes twinned, and large crystals of sanidine, andesine ($Ab_{58}An_{42}$), lamprobolite, and brown biotite. Smaller grains of these minerals and some magnetite are associated with the finely crystalline groundmass.

The Pollack formation attains a maximum thickness of about 300 feet.

Razorback Formation

The Razorback formation was named by Elston (1953) from Razorback Mountain, sec. 36, T. 18 S., R. 11 W., in Dwyer quadrangle. There the formation consists of rhyolites and pyroxene andesites, whereas in Lake Valley quadrangle the rocks are mainly pyroxene andesites. In one area, on the west side of White Rock Canyon, a 40-foot layer of fairly coarse-grained, well-sorted sandstone is interbedded with two of the flows of this formation.

The Razorback formation is overlain by the Bear Springs basalt and, in Lake Valley quadrangle, overlies the Mimbres Peak formation with pronounced unconformity. In the neighboring Dwyer quadrangle there may be one or more units between the Mimbres Peak formation and the Razorback. These intervening units are Box Canyon rhyolite, the Rustler basalt, and the Caballo Blanco tuff. The Caballo Blanco tuff is the most important of these formations. It can be traced from several miles west of Lake Valley quadrangle to the Santa Rita region, where it has been called the "bun tuff" (Paige, 1916) . The other formations occur only locally in Dwyer quadrangle (Elston, 1953) .

Megascopically, andesites of the Razorback type are uniformly purplish black, with red hematite bands or red rims around the augite phenocrysts. The rocks have a characteristic slabby fracture and blue-gray color on weathering. Once seen, they are rather easily distinguishable from other similar rocks. Flows of the Razorback formation crop out in small areas along Taylor, Pollack, and South Taylor Creeks (in the north central part of the quadrangle) , on Gavilan Arroyo and at Black Mountain in the northwest near the headwaters of Bear Springs and White Rock Creeks, and in small outcrops north of the junction of Bear Springs and Mule Springs Creeks.

Under the microscope the Razorback andesites are very similar to the rocks of the Macho formation. Phenocrysts of augite, hypersthene, oligoclase, potash feldspar (probably sanidine) , and minor brown hornblende make up only about one-eighth of the rock. The very fine-grained groundmass contains a small amount of the same minerals, but is mostly feldspar. The Razorback andesite contains scattered crystals of quartz which have been partly resorbed and surrounded by a reaction rim of augite crystals (pl 5-C) . Oligoclase is partly resorbed also. According to Elston (1953) these quartz and oligoclase crystals are xenocrysts, and the rock is probably a contaminated basalt. Further evidence of an original basaltic composition is offered by small amounts of iddingsite which he reports in the rock.

Bear Springs Basalt

The Bear Springs basalt has been named from an outcrop at the intersection of secs. 17, 18, 19, and 20, T. 20 S., R. 8 W., about half a mile distant from Bear Springs Canyon. The porphyritic, slightly scoriaceous rock is reddish purple, fine-grained, with some large, egg-shaped masses of calcite (up to 1 cm in diameter) , small phenocrysts of feldspar, and amygdale fillings of zeolites up to 2 mm in diameter. Bright-red iddingsite and some augite, up to 1 mm in diameter, are visible megascopically. Weathering causes pitting of the rock because of preferential solution of feldspar and calcite. In overall aspect the rock is entirely different from any other rock found in Lake Valley quadrangle.

Basalt has been found to crop out not only in the area described, but also on Black Mountain, and north of Black Mountain along Gavilan Arroyo. In the Gavilan Arroyo locality the rock is mottled red, very fine-grained, and presumably an ash bed. The basalt lies on the pyroxene andesites of the Razorback formation at Black Mountain and in Gavilan Arroyo, and is therefore later in age than the Razorback formation. The Bear Springs basalt is separated from the Santa Fe (?) rocks by a period of faulting and a major erosional unconformity.

Microscopic features: The somewhat amygdaloidal rock consists of large phenocrysts in a holocrystalline groundmass, which makes up three-fourths of the rock. The groundmass consists of numerous tiny laths of plagioclase (mostly oligoclase [$Ab_{74}An_{26}$] and andesine) , magnetite, small subhedral crystals of iddingsite, and minor augite and hypersthene. The cavities are filled with zeolites which have been identified as stilbite and analcite (pl 5-D). A volumetric Rosiwal analysis gives the following composition:

	PERCENT
plagioclase	75.0
zeolites	11.5
magnetite	3.1
iddingsite	5.4
hypersthene and augite	5.0
	100.0

This same analysis has been recalculated to exclude zeolites. The percentages thus obtained are as follows:

	PERCENT
plagioclase	84.9
magnetite	3.4
iddingsite	6.2
hypersthene and augite	5.5
	100.0

Although no olivine has been found in this rock, the crystal form of the iddingsite suggests that it has replaced olivine. Olivine occurs in similar rocks in Dwyer quadrangle, where it is only partly replaced by iddingsite. The large feldspar crystals appear to be somewhat corroded. Minor calcite was found also in the thinsection examined.

A chemical analysis and norm of rock of this type are given in Tables 4 and 5.

PETROLOGICAL NOTES

Microscopic study of the various volcanic rocks in Lake Valley quadrangle shows that certain minerals are fairly characteristic in each rock group. For example, latites and quartz lathes are characterized by basaltic hornblende (lamprobolite) and minor brown biotite, and andesites by augite and hypersthene. However, there are a few transitional rocks in the latite (broad sense) group in which minor amounts of lamprobolite or biotite, or both, occur with predominant augite. Some hypersthene may also be found in lamprobolite-biotite rocks. Nevertheless, where basaltic hornblende and biotite make up more than 50 percent of the ferromagnesian minerals, hypersthene, if present, is minor. Conversely, where the ferromagnesian minerals are dominantly augite and hypersthene, biotite and lamprobolite, if present, are minor.

It is notable that basaltic hornblende, biotite, and augite may occur together in fairly similar amounts in Macho pyroxene andesites. In andesite of the Macho type hypersthene is rare or absent. This association of ferromagnesian minerals has been used as a criterion in the identification of Macho andesites. Basalts are characterized by iddingsite (Lake Valley quadrangle) and olivine (Dwyer quadrangle) , although some andesites may contain very minor amounts of these minerals.

DIKE ROCKS

In Cooks Range there are several varieties of dike rocks, all of which, with one exception, cut the Cooks Peak intrusive. In the area between White Rock and Macho Creeks, in the latitic rocks, there are also several large lathe dikes.

TABLE 4. CHEMICAL ANALYSES OF SOME ERUPTIVE ROCKS OF LAKE VALLEY QUADRANGLE, NEW MEXICO[1]

	1	2	3	4	5[2]	6	7	8	9
SiO_2	62.95	61.28	62.43	59.37	74.49	71.23	76.50	66.07	51.17
Al_2O_3	15.91	16.58	16.50	16.17	13.81	12.72	11.46	16.11	14.43
Fe_2O_3	3.30	2.49	4.32	4.49	1.19	2.72	1.12	2.96	4.49
FeO	1.37	1.58	0.43	1.20	0.22	0.72	0.43	0.29	5.90
MgO	2.18	1.76	1.78	3.00	1.04	0.55	0.25	0.92	6.43
CaO	4.46	5.42	4.55	5.12	2.63	1.49	0.68	3.50	8.33
Na_2O	4.05	4.10	4.10	3.46	2.03	3.50	3.43	3.21	3.05
K_2O	2.95	3.47	2.87	2.81	4.10	4.81	4.46	4.24	1.62
H_2O-	1.91	1.09	0.86	0.86	12.27	0.49	0.33	1.11	0.19
H_2O+		1.36	1.52	1.80		0.83	0.63	1.38	1.68
TiO_2	0.67	0.51	0.70	1.01	0.32	0.44	0.12	0.48	2.00
P_2O_5	0.18	0.25	0.29	0.36	0.07	0.12	0.02	0.20	0.55
MnO	0.08	0.06	0.08	0.07	0.03	0.06	0.09	0.07	0.17
BaO	0.03	—	—	—	—	—	—	—	—
SrO	0.03	—	—	—	—	—	—	—	—
Sum	100.07	99.95	100.43	99.72	100.00	99.68	99.52	100.54	100.01
alkali/lime	1.6	1.4	1.5	1.2	2.3	5.6	11.6	2.1	0.6
K_2O/Na_2O	0.7	0.8	0.7	0.8	2.0	1.4	1.3	1.3	0.5
Analyst	George Steiger	H. B. Wiik	H. B. Wiik	H. B. Wiik	H. B. Wiik	H. B. Wiik	H. B. Wiik	H. B. Wiik	H. B. Wiik

1. See Table 5 for identification of rocks.
2. Analysis recalculated excluding water because of high water content.

TABLE 5. NORMS OF SOME ERUPTIVE ROCKS OF LAKE VALLEY QUADRANGLE, NEW MEXICO

	1	2	3	4	5	6	7	8	9
quartz	16.56	12.58	16.50	14.70	39.96	30.12	38.15	22.56	3.30
orthoclase	17.79	20.57	17.24	16.68	24.46	28.36	26.13	25.02	9.45
albite	34.06	24.58	34.58	29.34	16.77	29.34	28.82	27.25	25.68
anorthite	16.40	16.68	18.07	20.29	13.07	3.06	2.78	16.68	20.85
corundum	—	—	—	—	—	—	—	0.10	—
wollastonite	2.09	3.36	0.81	0.93	—	1.81	0.23	—	6.96
enstatite	5.50	4.40	4.50	7.50	2.60	1.40	0.60	2.30	16.10
ferrosilite	—	—	—	—	—	—	—	—	4.09
magnetite	2.55	3.71	—	1.16	1.28	1.39	1.39	—	6.50
ilmenite	1.37	0.91	1.06	1.98	—	0.76	0.15	0.76	3.80
apatite	0.34	0.67	0.67	1.01	—	0.46	—	0.34	1.34
hematite	1.60	—	4.32	3.68	0.61	1.76	0.16	3.04	—
rutile	—	—	—	—	0.03	—	—	0.08	—
titanite	—	—	0.39	—	—	—	—	—	—
Normative plagioclase	$Ab_{67}An_{33}$ andesine	$Ab_{64}An_{36}$ andesine	$Ab_{66}An_{34}$ andesine	$Ab_{59}An_{41}$ andesine	$Ab_{56}An_{44}$ andesine	$Ab_{91}An_{9}$ albite	$Ab_{91}An_{9}$ albite	$Ab_{62}An_{38}$ andesine	$Ab_{55}An_{45}$ andesine
CIPW class	II 424	II 424	I 424	II 424	I 422	I 412	I 412	I 422	III 544

1. Cooks Peak granodiorite (Lindgren, 1910, p 39)
2. Macho pyroxene andesite (SE¼SW¼, sec. 20, T. 19 S., R. 7 W.)
3. Rubio Peak amphibole latite (SE¼NE¼, sec. 36, T. 18 S., R. 8 W.)
4. Rubio Peak pyroxene andesite (NW¼NW¼, sec. 18, T. 18 S., R. 7 W.)
5. Sugarlump quartz latite tuff (NW¼NE¼, sec. 16, T. 19 S., R. 8 W.)
6. Kneeling Nun rhyolite welded tuff (center, northern boundary, sec. 17, T. 19 S., R. 10 W.)
7. Mimbres Peak rhyolite (SW¼, sec. 20, T. 18 S., R. 7 W.)
8. Pollack quartz latite (sec. 28, T. 18 S., R. 8 W.)
9. Bear Springs basalt (SE¼SE¼, sec. 22, T. 18 S., R. 10 W.)

The dikes which are not considered postintrusive have not yet been definitely dated. They are buff, fine-grained rhyolitic rocks with quartz phenocrysts, intrude only the lower Paleozoic limestones, and are perhaps preintrusive. The postintrusive dikes are of several varieties. Besides the granodiorite porphyry dikes and sills which are associated with the intrusive, there are diorite and basalt dikes, and a latite dike. Some of the dikes are green-gray glass with refractive index of 1.495. The composition of these dikes has not been determined. The diorite dikes are black, fine-grained rocks, which at many places cut the intrusive. Under the microscope the diorite varies from fine-grained and holocrystalline to coarser-grained and porphyritic. The feldspars are oligoclase, andesine, and labradorite. Augite is present, and magnetite is a prominent accessory mineral. Only one 'ante dike was found in the Cooks Peak region. It cuts the pyroxene andesite tuffs of the Old Hadley district. The latite, very hard, buff-colored, and porphyritic, with numerous large phenocrysts of plagioclase, is highly altered and silicified. If unaltered, this rock would probably be similar to the blue-gray latite dikes found in the Rubio Peak formation farther to the northeast. The latite dike here

PLATE 4. Photomicrographs. (In each case the line is 1 mm in length.)

A. PRECAMBRIAN GRANITE CONSISTING OF MICROCLINE (TWINNED), QUARTZ (LIGHT-GRAY "VEINLET" IN CENTER OF PICTURE), CHLORITE (DARK GRAINS, CENTER OF PICTURE AND LOWER LEFT), WITH EPIDOTE (DARK-GRAY GRAINS WITH HIGH RELIEF), AND SERICITE (UPPER PART OF PICTURE). CROSSED NICOLS.

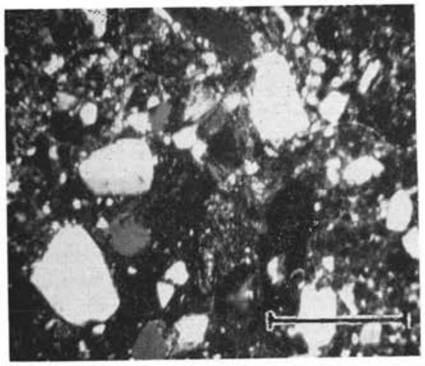
B. COOKS PEAK GRANODIORITE PORPHYRY. CHLORITE (UPPER LEFT), ORTHOCLASE (RIGHT CENTER), AND AUGITE (CENTER BOTTOM) IN A GROUNDMASS OF PLAGIOCLASE, ORTHOCLASE, MAGNETITE, AND OTHER MINERALS. CROSSED NICOLS.

C. MACHO PYROXENE ANDESITE. HYPERSTHENE AND AUGITE (LARGE WHITE CRYSTALS) AND PLAGIOCLASE (TWINNED) IN FINE-GRAINED GROUNDMASS. SMALL WHITE CRYSTALS ARE QUARTZ. THE ROCK IS PARTLY SILICIFIED. CROSSED NICOLS.

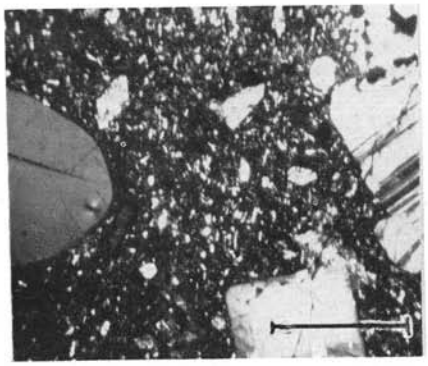
D. RUBIO PEAK PYROXENE ANDESITE. HYPERSTHENE (RELIEF), MAGNETITE (BLACK), AND PLAGIOCLASE (UPPER AND LOWER RIGHT) IN A FINE-GRAINED GROUNDMASS CONSISTING LARGELY OF SMALL LATHS OF PLAGIOCLASE AND ORTHOCLASE. CROSSED NICOLS.

E. RUBIO PEAK AMPHIBOLE LATITE. PLAGIOCLASE (TWINNED) AND LAMPROBOLITE (DARK DIAMOND SHAPES) IN FINE-GRAINED GROUNDMASS CONSISTING LARGELY OF TINY LATHS OF ORTHOCLASE. LAMPROBOLITE IS PARTLY REPLACED BY MAGNETITE. CROSSED NICOLS.

F. SUGARLUMP TUFF. FRAGMENTS OF GLASS AND MICROCRYSTALLINE CRISTOBALITE AND SANIDINE IN A GROUNDMASS WHICH CONTAINS QUARTZ FRAGMENTS (WHITE). CROSSED NICOLS.



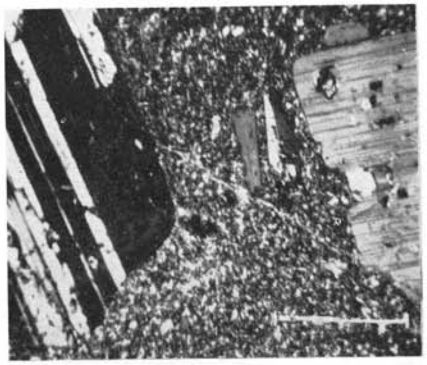
A



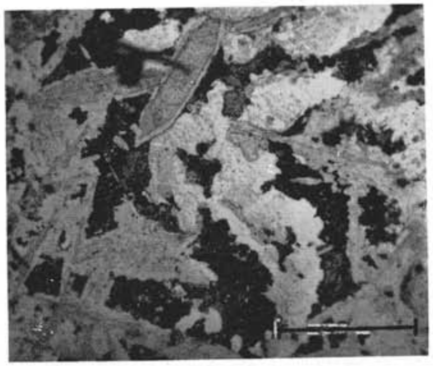
B

C

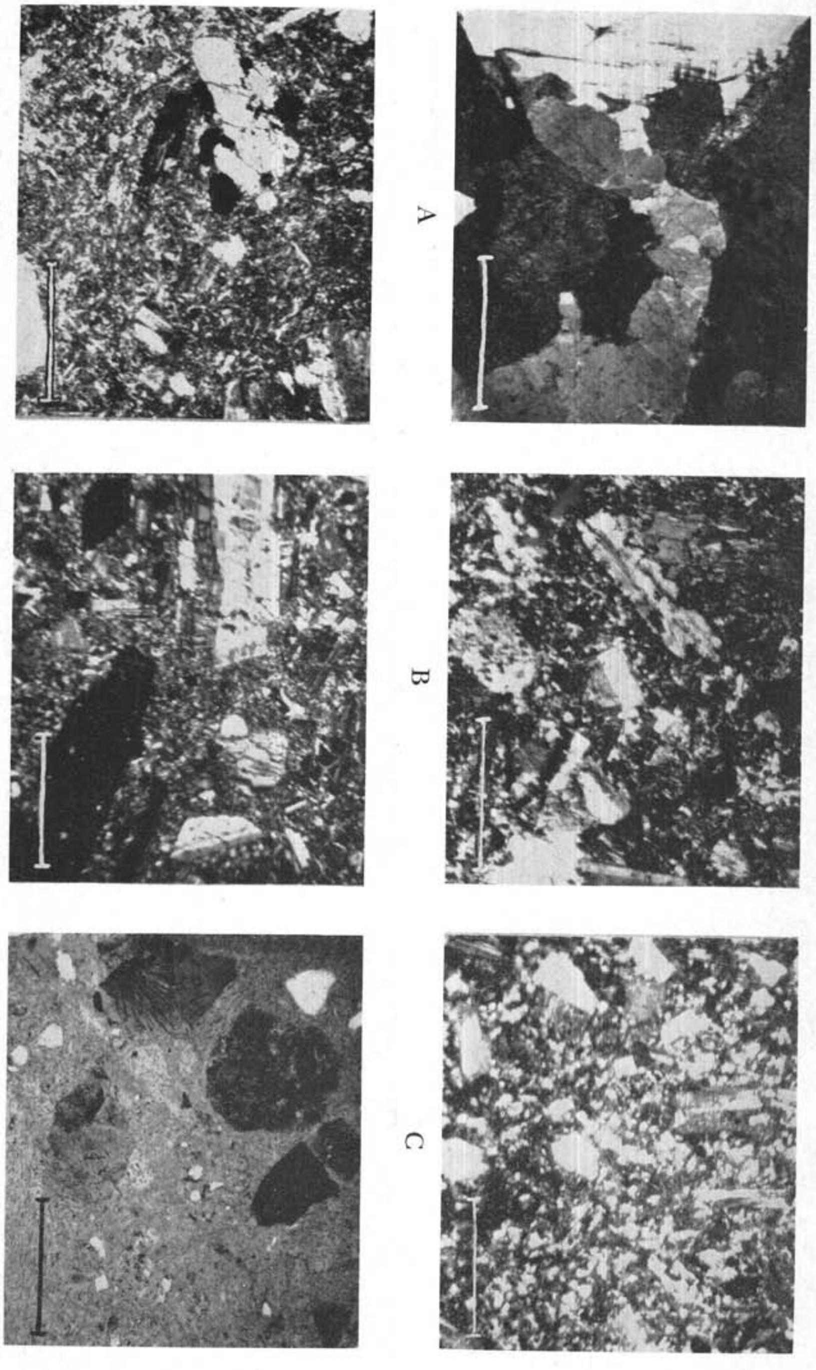
D



E



F


A
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C
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E
F

described has the same general N. 35° E. strike as the other latite dikes; the feldspars, too, are similar to those in the blue-gray dikes.

The blue-gray porphyritic latite dikes in the Rubio Peak formation are 10-50 feet wide. They have a general N. 25°-35° E. strike and, though usually discontinuously exposed, may extend for as much as 1 1/2 miles. Phenocrysts of sanidine up to 1 cm long and smaller phenocrysts of biotite are visible megascopically. Microscopically, the groundmass is finely crystalline feldspar, some pale-brown biotite, and minor green hornblende and magnetite. The phenocrysts, which make up one-quarter of the rock, are large crystals of sanidine, andesine, and biotite, and smaller crystals of hornblende (pl 5-E) . Volumetrically, it has the composition:

	PERCENT
groundmass	74.3
andesine	15.0
sanidine	3.1
biotite	5.6
hornblende	2.0
	100.0

This rock is a typical latite.

PLATE 5. Photomicrographs. (In each case the line is 1 mm in length.)

A. KNEELING NUN RHYOLITE WELDED TUFF. QUARTZ (WHITE), SANIDINE (CARLSBAD TWINS), AND LAMPROBOLITE (GRAY) IN A FINE-GRAINED MATRIX. GLASSY FRAGMENT (CENTER, RADIATING STRUCTURE). GROUNDMASS CONTAINS HEMATITE (DARK AREA ON LOWER LEFT) AND MAGNETITE (BLACK). Nom FRAGMENTAL TEXTURE. CROSSED NICOLS.

B. POLLACK QUARTZ LATITE. QUARTZ (GRAY, LEFT CENTER), ANDESINE (TWINNED, RIGHT), AND HORNBLENDE (RHOMBIC CRYSTALS WITH RELIEF) IN FINE-GRAINED GROUNDMASS. CROSSED NICOLS.

C. RAZORBACK ANDESITE. QUARTZ WITH AUGITE REACTION RIM, AUGITE CRYSTALS (RELIEF), AND PLAGIOCLASE (WHITE LATHS) IN A GROUNDMASS OF TINY FELDSPAR LATHS WHICH SHOW FLOW STRUCTURE. MAGNETITE (BLACK) ALSO PRESENT. PLAIN LIGHT.

D. BEAR SPRINGS BASALT. PLAGIOCLASE (TWINNED), AUGITE (WHITE), AND IDDINGSITE (GRAY, RELIEF) AROUND A SMALL HOLE (FLAT GRAY IS BALSAM). ZEOLITES IN AMYDALE AT LOWER RIGHT. GROUNDMASS IS MOSTLY FELDSPAR LATHS WHICH SHOW FLOW STRUCTURE. CROSSED NICOLS.

E. LATITE DIKE. LARGE ANDESINE (LEFT) AND BIOTITE (RIGHT), WITH SMALLER LAMPROBOLITE (TWINNED, CENTER) IN A VERY FINE-GRAINED GROUNDMASS. CROSSED NICOLS.

F. VEIN MATERIAL. BARITE (BLADES), QUARTZ (WHITE), AND SULFIDES BLACK, MOSTLY GALENA). SEQUENCE OF DEPOSITION IS IN ORDER NAMED. SPECIMEN FROM MACHO MINING DISTRICT. PLAIN LIGHT.

STRUCTURAL GEOLOGY

The major structural features of Lake Valley quadrangle are normal faults; one large anticline is also known. Only the larger features of the quadrangle are easily seen in the volcanic areas. The smaller folds and faults are very poorly defined or impossible to recognize, because well-marked key horizons are lacking.

FOLDS

Though folding in the region is not widespread, a large anticline occurs in the northeastern part of the quadrangle. The axis trends northwestward and may be traced from sec. 15, T. 19 S., R. 8 W. to a point one mile beyond where it leaves the quadrangle border at the west line of R. 7 ½ W. Only the north-plunging half of the anticline is exposed, the southern half being covered by alluvium. The anticline folds Macho and Rubio Peak rocks and is probably post-Mimbres Peak in age. To the west, a large synclinal basin of similar axial trend is thought to exist. There progressively younger rocks are exposed, and the Rubio Peak formation has its thickest development in the quadrangle.

FAULTS

Major faulting in Lake Valley quadrangle follows two general trends. The dominant trend is N. 30°-40° W. A subsidiary trend is N. 45° E. It should be noted that these trends intersect at an angle of about 75 degrees. Normal faults of large throw divide the quadrangle into three structural units: (1) Cooks Range, an intruded horst of Precambrian, Paleozoic, and Mesozoic rocks, in the southwestern part of the area; (2) the central area, consisting largely of volcanic rocks, but with some Tertiary sediments and Quaternary gravels and alluvium; and (3) the Lake Valley fault block, a horst of Paleozoic sediments in the northeast corner of the quadrangle.

Cooks Range is a north-northwest- (south-southeast-) trending short structural high which forms the southern extension of the Mimbres Mountains. Its dominant feature is a large granodiorite porphyry stock, of which Cooks Peak is made. The granodiorite was intruded mainly into the Lake Valley limestone, but locally it penetrates the strata up to the base of the Sarten sandstone. On the west slope of the range the Lake Valley limestone is cut by irregular apophyses of granodiorite at several localities. The northern part of the range extends as an attenuated ridge of southwesterly-dipping sediments. At the northern end of the ridge Precambrian granite is exposed in a long slender tongue. To the south the granite is covered by the overlying Paleozoic rocks, which form a thick series adjacent to the intrusive. The sedimentary units exposed are the Lake Valley limestone, Percha shale, Fusselman limestone, Montoya group, El Paso group, and the Bliss sandstone, which rests unconformably on the granite. The ridge is bounded on the east by the eastward-dipping Sarten fault, which extends in a north-northwest (south-southeast) direction parallel to the east side of the range. The East Cooks fault, about 1 ½ miles to the east, is of slightly lesser throw, but strikes in

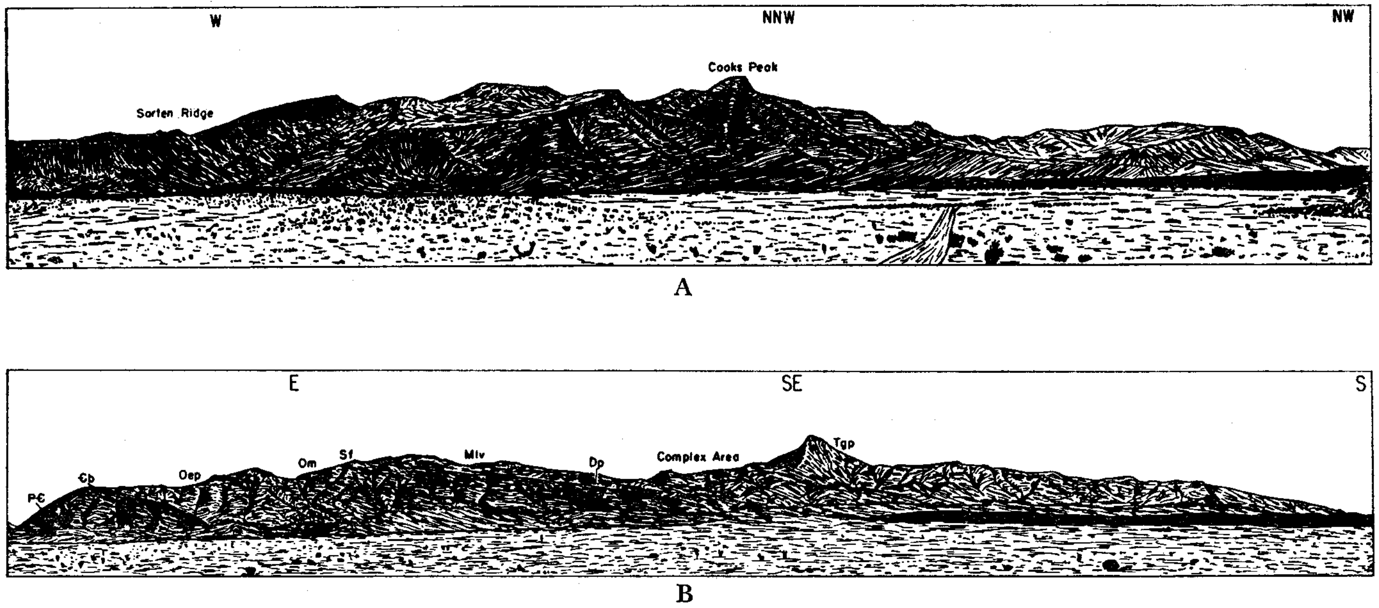

Figure 6

A. Cooks Range from the southeast. Sarten Ridge is a hogback of sediments capped by Sarten sandstone. Central portion of range is Cooks Peak granodiorite. B. The west side of the Cooks Range showing most of the Paleozoic section exposed in the northern part of the range. The Bliss sandstone (€b) lies on Precambrian granite (P€) and is in turn overlain by the El Paso group (Oep), Montoya group (Om), Fusselman limestone (Sf), Percha shale (Dp), and Lake Valley formation (Mlv). The complex area is one of considerable faulting, part of which was probably caused by the intrusion of the Cooks Peak granodiorite (Tgp).

the same general direction as the Sarten fault. It swings sharply westward and joins the Sarten fault about 2 miles north of Cooks. These faults have displacements of 2,600 feet or more, based upon the stratigraphic thicknesses of the formations cut. The Sarten fault brings the Precambrian on the west into contact with volcanics of Tertiary age on the east. The East Cooks fault brings the Lake Valley formation on the west into contact with the Santa Fe (?) formation on the east.

North of the junction of the Sarten and East Cooks faults, a shattered zone several hundred feet wide is formed which contains horses or "splinters" of Paleozoic rocks at various localities along the Sarten fault. The fault zone thus formed by the Sarten fault extends northwestward along Mimbres Valley and forms a great structural feature, which may be continuous with the most easterly of the large northwest-southeast-trending faults of the Santa Rita region, about 25 miles to the north and west (Elston, 1953) . Movement has apparently taken place along this fault several times during the Tertiary era. Early Miocene (?) faulting along this line is shown by the absence of some tuff beds (in Dwyer quadrangle) on the east side of the fault, which are present on the west. This suggests movement along the fault after the deposition of the latites and before the formation of the tuff beds. Within the Cooks Peak mining district the Sarten fault forms the eastern boundary of the main area of ore deposition. The fault appears to predate mineralization, although some postmineral movement probably took place along the same zone.

It is likely that Cooks Range is cut off from the plains on the west by another large normal fault with a dip to the west. The presence of this fault is evidenced by a few small downthrown blocks of Sarten sandstone on the west flank of the range. The displacement on the west, or "Range Front" fault, based on thickness of the formations displaced, is about 2,000 feet.

The town of Cooks (sec. 24, T. 20 S., R. 9 W.) lies in a broad valley which extends south-southeastward for two or three miles. The east border of the valley is formed by the East Cooks fault. To the south this fault diminishes in throw and is overlapped by the pyroxene andesite flows and tuffs of the Old Hadley (Graphic) district. The throw of the East Cooks fault is greatest at the point where it joins the Sarten fault. At that point uplift of the formations along the East Cooks fault has diminished the apparent displacement along the Sarten fault to about 700 feet.

On the west side of the Cooks synclinal valley, the Lake Valley formation, Pennsylvanian -beds, and the Lobo and Sarten formations crop out in a long narrow band which strikes parallel with, and clips into, the north-south-trending west edge of the Cooks Peak stock; and these formations are bounded by the Sarten fault on the east. At a point about a mile south of the town of Cooks, an outlier of Sarten sandstone and Lobo shales, dipping away from the intrusive at a steep angle, lies against the Lake Valley limestone.

A cross fault (Othello fault) extends across Cooks Range from the Range Front fault on the west to the Sarten fault on the east. This fault trends east-west, intersecting the Sarten fault just west of the town of

Cooks. It is a normal fault downdropped on the north, with a maximum throw of about 400 feet, based on the thickness of the strata disrupted. No evidence of faulting on this same line is found east of the Sarten fault.

The central area of the quadrangle does not appear to have been highly disturbed structurally. A few normal faults as much as a mile long occur in the volcanic area in the northwest. These faults have a N. 30°-40° W. trend and may have throws of as much as 300 feet. Minor faults in this area occur in the Santa Fe (?) conglomerates. They are of varying strikes and dips and seldom cause displacements of more than a few tens of feet. The presence of veins, narrow altered zones, and dikes in the volcanics, all of which features have a general N. 35° E. strike, suggests that tensional fractures have been developed along that trend.

The main structural feature of the Lake Valley area is the Lake Valley fault block, a tilted block of Ordovician to Mississippian sediments projecting through, and entirely surrounded by, Tertiary volcanics. The block is elongate parallel to the strike of the formations, which is generally N. 35°-45° E. The dip of the beds is 15-20 degrees to the southeast. Along the scarp of the fault on the northwest side of the block, the Ordovician El Paso limestone is in contact with the Tertiary Rubio Peak formation. The throw of the fault has been calculated by Harley (1934, p 175) to be not less than 625 feet, based on the thickness of the sediments; probably it is much more. On the southeast the beds dip under the Macho pyroxene andesites at an angle of about 20 degrees, with some minor crumpling at the contact, caused by the tilting of the block. The southwest end of the block is cut off abruptly by a fault trending N. 40° W., the throw of which is unknown, but sufficient to bring Tertiary rhyolite into contact with Paleozoic rocks, an estimated displacement of the order of 1,000 feet. The limestones on the upthrown side of the fault have been shattered and tilted into a .broad drag zone which formed the locus of mineralization in the Lake Valley district.

Minor faulting is widespread in Cooks Range and in the Lake Valley fault block. In both areas the minor faults appear to have been large factors in the localization of the ore deposits.

Minor faults in the Cooks Peak area are either of the normal or the tear type. There are three systems of minor faults. Of the two more prominent systems, one strikes N. 55°-65° E., and dips steeply to the northwest; the other strikes N. 0°-15° W., and dips steeply to the northeast. Both appear to be premineral and of less than 100-foot displacement. These faults break the Fusselman limestone in the Cooks Peak district into a series of "steps" parallel to the Sarten fault. Locally displacement is apparently very small, since dikes follow the fractures and there is no discontinuity of the beds on either side of the dike. A third system of faults shows a general east-west trend and small displacement (probably not over 20 feet). These faults appear to be postmineral, as they displace the ore.

The order of faulting in the Cooks Peak district is based upon good evidence. The N. 0°-15° W. faults and fractures were the earliest system, as evidenced by the fact that dikes following these fractures were cut off by the later en echelon N. 55°-65° E. system. That both of these fracture systems are premineral is demonstrated by the fact that mineralization occurs both around and in the north-south-trending dikes and in the fractures or fault zones of the N. 55°-65° E. system. The more recent age of the east-west fractures is shown by the fact that they cut the ore zones.

Later faults, of random strikes, appear in the Lake Valley limestone and Percha shale in Cooks Range. Large masses of strata have been faulted down from the faces of cliffs by these faults and are thus dependent upon the trend of the cliff face for their direction. The traces of these faults are arcuate, suggesting landslides. In one place it was found that the beds had broken away from the cliff on only one side, giving a scissorlike appearance to the related fault. Faults of this group are assumed to have formed as the result of failure of the relatively incompetent Percha shale in the steep places along which they appear. There is no relation between this group of faults and the mineral deposits. It appears, rather, that they are an example of large-scale slumping in a topography like that of today.

In the Lake Valley area, the face of the Lake Valley limestone escarpment is broken in several places by faults of northwest-southeast trend with displacements of 5-40 feet. The faults are apparently tension fractures, which developed as the result of conditions which caused the central part of the main fault block to be raised slightly higher than the sides. Faults of minor displacement (a few inches to 5 feet) are also present on the southeast slope of the limestone hill. These strike northeast, parallel with the strike of the beds.

Northwesterly striking fractures are probably present in the mining areas, because siliceous and manganiferous stringers trend in that direction. Some of these fractures may be extensions of minor faults on the face of the escarpment. Slight undulations (several square yards in area) were noted on the surface of the limestone beds on the dip slope of the cuesta. They are probably the result of bedding plane slippage.

All of the above-mentioned minor structures have important effects in controlling the emplacement of the ore bodies of the Lake Valley mining district.

A large outcrop of limestone near Lake Valley, in sec. 21, T. 18 S., R. 7 W., is so intensely shattered as to have the appearance of a large-scale breccia. In no area larger than 50 feet square have the beds been found to be of the same horizon or to have the same attitude. This structure is thought to be a talus deposit resulting from the weathering back of the Lake Valley limestone scarp.

Small blocks of Lake Valley limestone broken up in a similar manner, and found among the andesites and latites on the dip slope of the Lake Valley fault block, are thought to be floated blocks which have been broken off by, and floated up on, the lava flows. A second explanation is also possible: It may be that minor faulting and brecciation at the "bending point" of the large fault block developed such structures, and that these limestone blocks may be remnants of a fractured zone which provided the locus of development of fissures, from which the effusives issued.

TECTONIC HISTORY

The geologic history of the Lake Valley region is complex. Very little can be determined about its pre-late Cretaceous structure. In general, the area was one of minor regional warping in Paleozoic time. Unconformities between almost all formations indicate alternating sedimentation and erosion, or at least nondeposition. In Triassic and Jurassic time the area was probably a lowland source of detritus for the Mexican geosyncline to the south. Only thin Cretaceous beds were laid down. It does not seem probable that much tectonic activity took place in the region between Precambrian and late Cretaceous time, as no pre-late Cretaceous faulting occurs in the exposed older sediments.

It is believed that the intrusion of the Cooks Peak granodiorite mass, and the major faulting in the area, began in late Cretaceous or early Tertiary (probably Laramian) time. Movement along some of the major faults probably continued through a large part of Tertiary time, and uplift of Santa Fe (?) rocks indicates that the orogeny did not end until late Pliocene, or possibly even early Recent times. That some movement has taken place in late Pliocene or Pleistocene time is demonstrated by the fact that the Santa Fe (?) formation of Pliocene-Pleistocene (?) age is cut by many minor faults and has even developed minor folds in some areas. It cannot be demonstrated, however, that these minor structures are related to larger movements. The lesser faults of N. 30°-40° W. trend were developed in middle or late Miocene (?) time, after the extrusion of the Bear Springs basalt. The broad major folds, which are represented by the anticline in the northeastern part of Lake Valley quadrangle, also were developed, it is likely, at that time. The post-Bear Springs orogenic activity probably accounts for the formation of the great thicknesses of fanglomerate which mark the Santa Fe formation not only here, but throughout the state.

It is interesting to note that in Lake Valley quadrangle the Cooks Peak stock probably was emplaced in prevolcanic time. This possibility is based on the fact that the volcanics near the intrusive have not themselves been cut by intrusions. In contrast, in the Santa Rita area the intrusives are mainly intravolcanic in age.

Mineral Deposits

COOKS PEAK AND JOSE MINING DISTRICTS

The Cooks Peak and Jose mining districts are on the north side of Cooks Peak, about 18 miles southwest of Lake Valley, and the same distance north and east of Deming, in sections 13, 14, 23, 24, and 25, T. 20 S., R. 9 W. The districts are separated by a northward trending ridge of Lake Valley limestone. The Jose district is located near the mining town of Jose, now deserted, in the northwest corner of the mineralized area. The Cooks Peak district includes the southern and eastern parts of the area, around the town of Cooks.

GEOLOGIC RELATIONS

The ore bodies occur chiefly in the upper part of the Fusselman limestone (Silurian), just below the Percha shale. They generally lie below the siliceous zone that follows the contact between the limestone and the shale (modified manto- [blanket-] type deposits). According to Lindgren and Gordon (1910, pp 287-290), "The ore deposits occur under broad arches in the limestone beds." Some small pockets of ore also have been found in the Cretaceous Sarten sandstone east of Cooks, and some in the granodiorite itself. A three-foot vein of quartz with scattered sulfides occurs in the granodiorite about 1 mile southwest of Cooks. This vein strikes roughly northwest with a steep dip. The ore that occurred in pockets in the granodiorite was generally of higher grade than the ores in the limestone, especially with respect to silver content; it amounted, however, for the most part, to only a few tons or less in each pocket. The main ore bodies occur in the Fusselman limestone in the Cooks Peak and Jose districts.

The emplacement of the primary ores appears to have been governed by a complex of features. The ore follows the minor N. 0°45° W. faults at many places, in a fissure replacement type of mineralization; such fissure replacements are often modified into small mantos at junctions with favorable beds and at the base of the overlying, fairly impermeable Percha shale. In addition, some pipelike bodies are formed at the junctions of faults striking N. 0°-15° W. with faults striking N. 55°-65° E. At such localities replacement has been more extensive than along single fractures.

Several types of dikes occur in the mining areas, but only two varieties seem to affect ore deposition. Both of the latter are granodiorite dikes which follow the same trends as the minor premineral faults. No sills were noted in the mines visited, but a former miner indicated to the writer that porphyry (granodiorite) sills are also present and are pre-ore in age. He described the ore bodies, moreover, as flattening out and becoming larger where a sill is encountered. The upper contact of such sills with the limestone generally is barren.

CHARACTER OF THE ORES

The primary ores consist chiefly of galena and sphalerite, with a gangue of pyrite, minor fluorite, and ankeritic carbonates. Primary ores

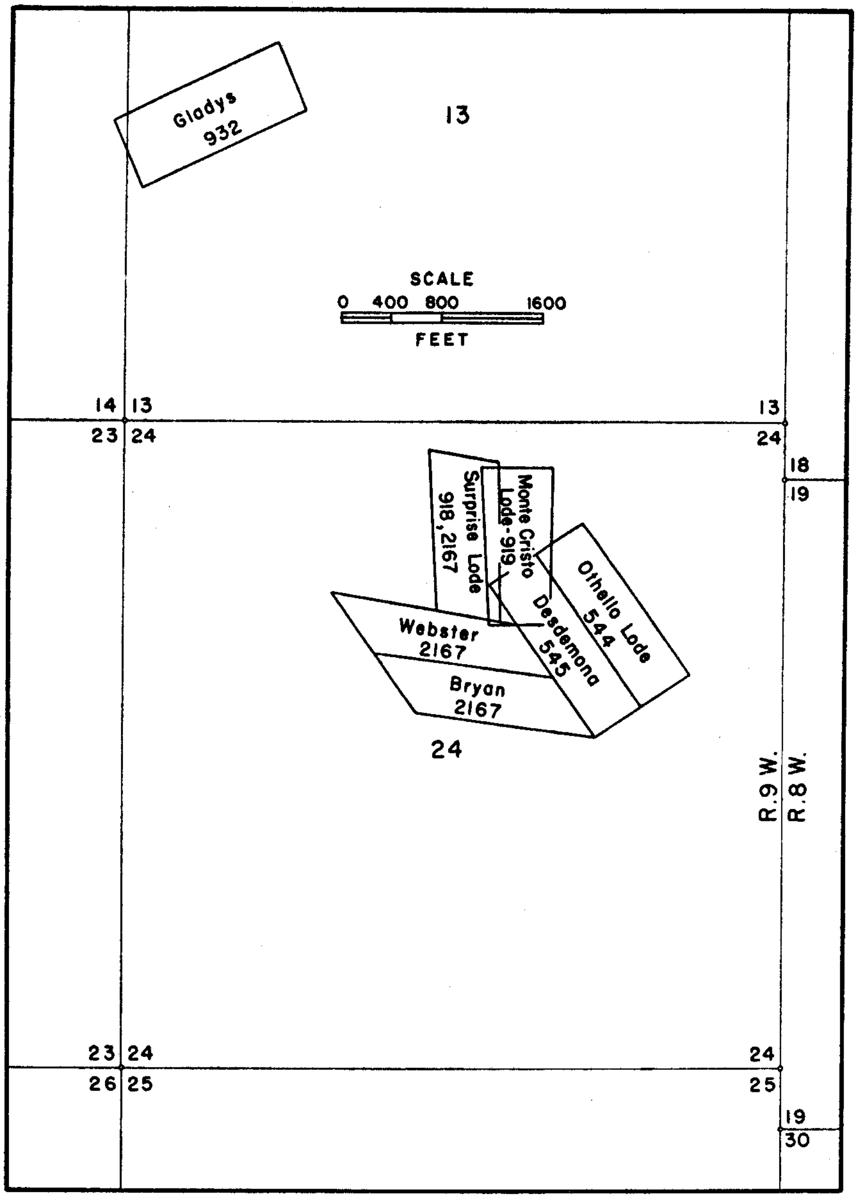

Figure 7

PATENTED CLAIMS IN THE COOKS PEAK MINING DISTRICT, T. 20 S., R. 9 W., LUNA COUNTY, NEW MEXICO.

were not exploited at first, because of their depth and the easy access to the oxidized ores near the surface. The oxidized ores, from which most of the recorded production of the district was derived, are mostly lead carbonate, with some zinc carbonate and zinc silicate, and a gangue of limonite, gypsum, and calcite.

It has been assumed that much of the oxidized ore, especially if it consists mostly of lead carbonates, was formed in place from the sulfides, and that the examined stopes give a fair indication of the original character of the ore deposits. This assumption is substantiated by the discovery of places where the primary ores have not been oxidized completely and still remain in place within the oxidized masses. In the Jackson Tunnel the ore deposits are in the form of small irregular bodies, mostly flat-lying, and pipes, which follow vertically along the dikes and fault planes. The appearance is like that of a line of flat beads with irregular offshoots, a modified form of blanket deposit. One room was found in which the central part of the ore shoot was a large crystal cave (Kieft cave) about 100 feet long and 35-50 feet wide. Several smaller caves have also been cut through by the mine workings. These caves in the limestone appear to be of secondary origin and were probably formed by solution during and after the oxidation of the secondary ores.

In the Jose district primary ores are still in place in many of the old workings. Many show slight oxidation. The oxidation is slight owing to the tightness of the limestone.

SILICIFICATION

Silicification in and around the mineralized area is marked. In the Cooks Peak district there are scattered masses of silica overlying the Fusselman limestone outcrop. These appear to be remnants of a siliceous layer which formed at one time along the contact between the limestone and the overlying Percha shale. At some localities the base of the shale has been found to be silicified over small areas. The silica is generally in massive form and has the appearance of chert, chalcedony, or jasperoid, the shade of color depending upon the amount of associated iron. Vugs containing quartz crystals are common. The relations of several colors and types of siliceous material within the mass indicate that it has been brecciated and recemented. Thus, silicification is thought to have gone on over a considerable period of time in more or less discontinuous phases. Similar silicification has been found at other levels in the section, especially at the base of the Montoya group. At several localities a complete transition from limestone or sandy limestone to massive silica may be traced along the beds. Such siliceous masses are found also along nearby faults.

Silicification appears to be related to ore deposition. The ore bodies are surrounded by silicified limestone, which is silicified most intensely where closest to the ore bodies. It is entirely possible, however, that the silicification on a grand scale is not so closely related to the ore deposition as the minor silicification, because volcanic rocks believed to be later than the mineralization are silicified also in other areas. Probably silicification took place at various times during the history of the region, both before and after the time of actual ore deposition, and the silicify-

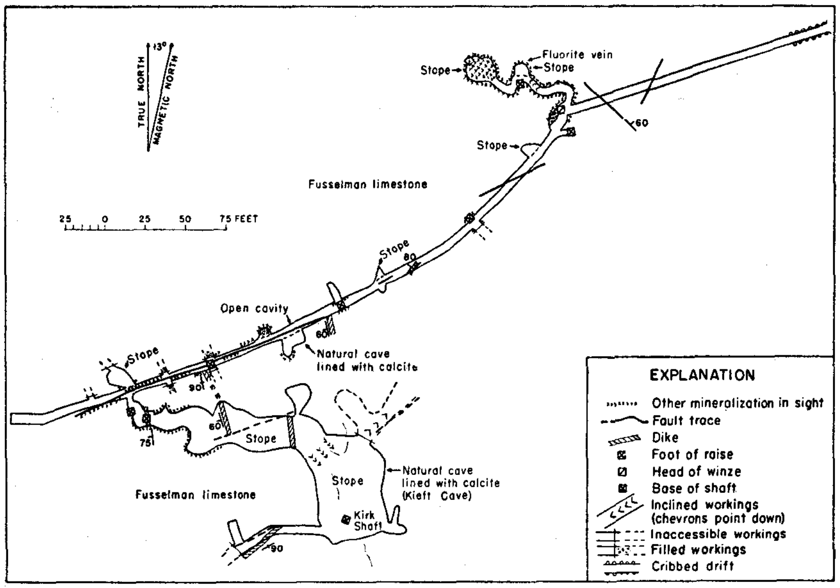

Figure 8

RECONNAISSANCE MAP OF THE JACKSON TUNNEL SHOWING STOPED AREAS
AND NATURAL CAVES. COOKS PEAK MINING DISTRICT, SW¼ NE¼ SEC. 24, T. 20 S., R. 9 W., LUNA COUNTY, NEW MEXICO.

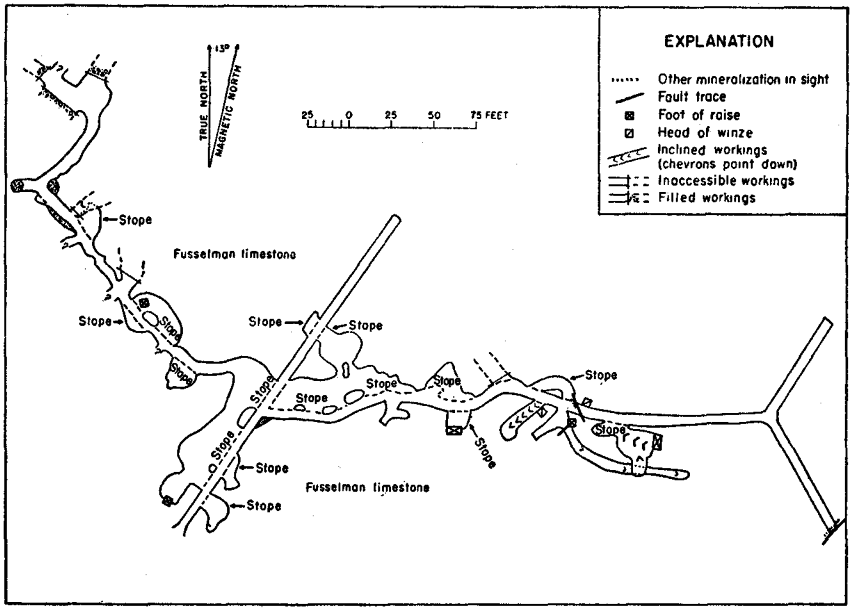

Figure 9

RECONNAISSANCE MAP OF A TYPICAL MINE IN THE JOSE MINING DISTRICT
SHOWING STOPED AREAS. SE¼ NE¼ SEC. 14, T. 20 S., R. 9 W., LUNA COUNTY, NEW MEXICO.

ing solutions were, in different areas, related to different epochs of hot springs activity.

Despite the above observations, the writer believes that at least some silicification of the wall rock accompanied mineralization in the Cooks Peak area.

SOURCES OF THE MINERALIZING SOLUTIONS

The ores of the Cooks Peak and Jose districts are of the mesothermal type. The mineralizing solutions may have been related in some way to the Cooks Peak granodiorite stock, though the ores might have been formed at a later time by solutions unrelated to any visible intrusive. As the solutions have formed pockets of ore in the granodiorite, mineralization must have taken place after the granodiorite stock was intruded.

HISTORY AND PRODUCTION

According to Lindgren and Gordon (1910), ores were first discovered in the Cooks Peak region in 1876, but no important claim locations were made until 1880, when the principal producing areas were located by Taylor and Wheeler. There was much activity in the years between 1880 and 1905, during which time the yearly production ranged up to 1,500,000 lbs of lead and 6,000 oz of silver. The oxidized lead ores of the area were rich and eagerly sought by smelting companies, with the result that often they were shipped long distances for smelting and refining. By 1905 most of the richest ore had been removed and large-scale production ceased. Production dropped to less than 100,000 lbs of lead per annum by 1911, after which time only sporadic attempts were made at further exploration, most of which met with little success. Production up to 1910 was estimated at $3 million.

In 1951 Mr. H. E. McCray, of Deming, obtained leases on some of the properties in the Cooks Peak district and brought the district back to an active status. Production was small (about 250 tons per month), but some of the ores were rich and brought high prices. After the commencement of operations Mr. McCray stated that work was being carried on in the Surprise, Mahonney, and A. S. & R. groups of claims. It was hoped that possible large bodies of ore might be developed to the west of the present workings.

From the time of opening the mines in mid-February to the end of December 1951, production was about 2,500 tons. The sulfide ore in the southern area was said to average 25 percent combined lead and zinc, made up of 13 percent lead and 11-12 percent zinc, with 11/2-2 oz of silver per ton. The ore in the northeastern area was richer, containing about 45 percent combined lead and zinc, and averaging 24 percent lead and 15-16 percent zinc. The ores also contain considerable amounts of pyrite. Most of the richer ores are higher in lead than the lower-grade ores.

The sulfide ores were being shipped in 1952 to the Peru Mining Company mill at Deming, 24 miles away by road. The average value of the ores sold there was about $40 per ton. Gross value of the ore removed during 1951 was estimated by Mr. McCray to be between $100,000 and $125,000. About 150 tons of oxidized ores were also produced, but these

TABLE 6. ANNUAL PRODUCTION—COOKS PEAK DISTRICT (1902-1947)[1]

YEAR	ORE (TONS)	GOLD (VALUE IN DOLLARS)	SILVER (OZ)	COPPER (LBS)	LEAD (LBS)	ZINC (LBS)	VALUE (IN DOLLARS)
1902	1,778		9,275		663,300		$ 31,176
1903	2,050		5,748		1,343,361		59,997
1904	1,078		4,401		576,795		27,347
1905	846		5,199		463,956		24,946
1906	1,133		7,519		627,344		40,808
1907	811		5,354		592,151		34,918
1908	253		1,009		127,535		5,891
1909	695		4,317	46	597,488		27,943
1910	457		1,917	47	242,137		11,695
1911	45		200		32,638		1,575
1912	927		960		142,680	433,129	36,897
1913	1,271		1,248	1,395	255,901	695,697	51,189
1914	1,995	68	2,423	2,181	381,324	793,588	57,043
1915	1,352	7	422		64,382	647,210	83,506
1916	2,562		433		56,275	1,390,119	190,444
1917	2,330	20	3,602	99	272,140	1,067,853	135,340
1918	1,252	33	1,947	3,150	156,549	463,445	56,046
1919	122		745	941	26,473	31,575	4,717
1920[2]	136	10	1,322	2,223	52,738	21,098	7,788
1922	81		72	1,130	9,087	24,288	2,106
1923	8		15	13	1,988		153
1924	454	70	1,658	573	152,199		13,432
1925	1,740	109	2,657	1,200	416,230	119,300	47,402
1926	319		492	242	106,500	42,000	12,011
1927[2]	1,006	257	1,335	367	162,238		11,283
1938	50		393		46,700		2,402
1939	106		595	800	54,000	9,000	3,563
1940	152		152		27,000	49,000	4,545
1941	45		218	200	26,400		1,684
1942[2]	17	14	97		11,000		1,296
1947	77		95		15,900		2,376
Totals	25,148	$578	65,820	14,607	7,704,409	5,787,302	$991,519

1. Reports prior to 1902 not available. Source: U. S. Bureau of Mines files.
2. Production suspended during the year(s) immediately following.

were of low grade, averaging only 10 percent lead. Oxidized ores were sent to the smelter in El Paso, Texas.

Operations in the Cooks Peak district ceased in 1953 as a result of a decrease in the price of lead and zinc, which closed down most of the lead and zinc mines in New Mexico.

FUTURE POSSIBILITIES

In 1952, exploration was being carried on mostly by drifting, and development of the ore bodies was by following ore in sight. Thus, known reserves were at a minimum. However, much of the Fusselman limestone west of the known ore-bearing area is probably mineralized, and it was considered safe to estimate that enough ore would be found

TABLE 7. COOKS PEAK MINING DISTRICT PRODUCTION BY PROPERTIES (1904-1943) [1]

PERIOD	MINE OR CLAIM	ORE (TONS)	GOLD (OZ)	SILVER (OZ)	COPPER (LBS)	LEAD (LBS)	ZINC (LBS)
1941	Busted Banker	12	—	43	111	7,109	—
1924-42	Graphic	22¼	150.00?	476	94	7,233	—
1941	Gladys	6	—	8	—	1,543	—
1904-27	Desdemona	8,704	9.50	13,033	2,225	1,958,159	437,844
1938-42	Lookout[2]	71	0.85	541	—	61,970	10,888
1904-18	Contention group	1,488	0.20	1,412	3,292	108,944	880,531
1920	Webster	42	—	378	—	33,611	—
1904-27	Inez	1,756	11.62	3,292	2,647	637,812	105,327
1904-18	Summit group	3,305	0.34	5,533	124	1,050,636	1,530,888
1914	Poe group	922	3.18	1,274	481	307,973	481,553
1942	Surprise and Mahonney No. 1 shaft	5	—	33	—	4,656	—
1920	Jumbo	1	—	11	—	361	—
1941-42	Mickey	10	—	59	—	6,100	—
1912-16	Silver Cave	471	—	253		13,250	343,690
1904-17	Lead King	447	—	—		—	—
1910-12	Old Commodore	27	—	171	—	29,195	—
1909-19	Hope, Faith & Constant	63	—	675	—	50,399	—
1906-08	White Oaks	301	—	3,102	—	386,878	—
1912	West Side	55	—	49	—	7,382	—
1912-14	Hadley	12	—	57	2,832	447	—
1911-12	Clara K	29	—	126	—	21,634	—
1939	Big Lead-Silver[2]	27	—	100	—	21,317	—
1923-24	Sycamore, Burrell & Florida 1 & 2	19	—	37	16	4,640	—
1918	Little Mary	13	—	51	—	8,931	—
1920	Raithel	65	—	122	—	16,907	26,371
1936-42	85 group[2]	110	14.95	520	181	79,416	17,159
1904-37	Faywood[2]	2,358	0.39	13,777	12	1,268,495	213,071
1939	Greenleaf 2, 3, 4, 5	19	0.20	129	822	149	—
1909-40	Miscellaneous	932	1.38	3,476	4,487	167,200	384,844
Totals		21,292¼	192.61	48,738	17,324	6,262,347	4,432,166

[1] Source: U. S. Bureau of Mines files.
[2] In Jose district.

to continue operations at the same rate as in 1951 for a period of several years. It is also possible that further exploration might develop larger ore bodies which are now hidden, but without drilling the nature and possible extent of such hidden reserves is a subject only for speculation.

OLD HADLEY (GRAPHIC) MINING DISTRICT

The Old Hadley (Graphic) mining district is located about 4 miles to the south and east of the town of Cooks, in an area of Tertiary pyroxene andesites and andesite tuffs. Lead-zinc ores were mined there in the period from about 1880 to 1929.

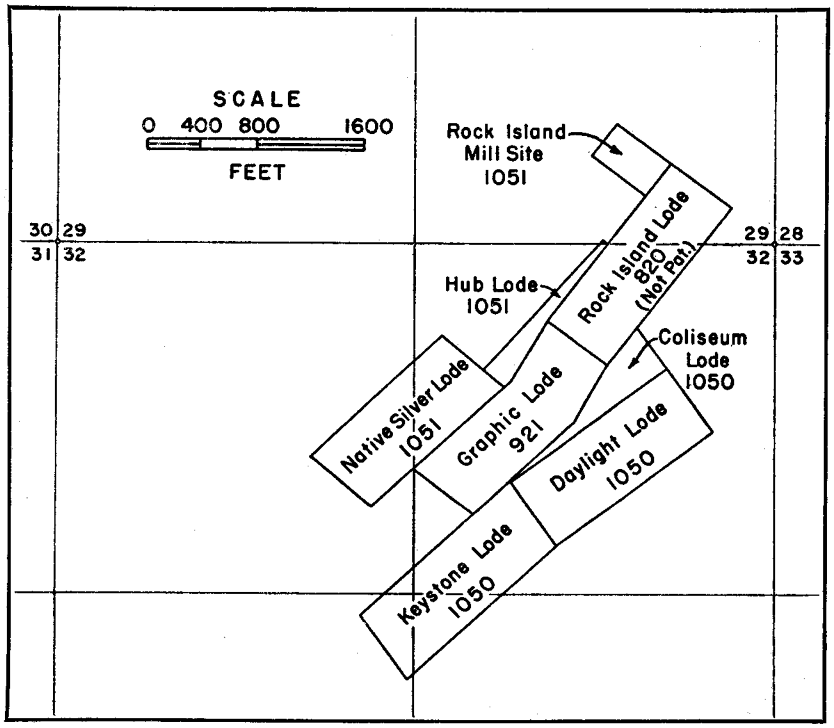

Figure 10

PATENTED CLAIMS IN THE OLD HADLEY MINING DISTRICT, T. 20 S., R. 8 W., LUNA COUNTY, NEW MEXICO.

OCCURRENCE

The dominant country rock in the Old Hadley (Graphic) district is pyroxene andesite of the Macho series. The ores occur as shoots in steeply dipping veins, some of which strike parallel to the fault systems, which trend N. 0°-15° W. and N. 55°-65° E., as in the Cooks Peak district. Others follow a more prominent N. 35° E. trend. Along faults and fractures, the andesite is altered to a yellowish clayey, slickensided, and gypsum-bearing mass. The silica and clay are commonly stained reddish by iron and manganese minerals, probably introduced at the time of silicification. Both silicification and the alteration mentioned are prominent near the mines, but the ores themselves appear to be richest in the less silicified areas. Such relation seems anomalous, as the altered material on the dumps indicates by its intimate association with the ore minerals that the mineralizing solutions are at least partly responsible for such alteration. Perhaps the rocks were silicified before the ore was deposited, thus blocking the silicified fractures to ore-bearing solutions. Silica may have been introduced also during the mineralization as a secondary phase. This effect, by which the rock is sealed off from ore replacement by silica, occurs widely in mining districts, having been reported from Leadville (Colorado), Tintic (Utah), and elsewhere. The ore deposits were silicified during two periods, one accompanying or postdating ore-deposition, the other earlier. The pre-ore silicification, however, seems to have been much more widespread.

A small copper deposit was located at the northeastern extremity of the district. In that area there are several veins of chrysocolla in andesite. The veins trend N. 35° E. and dip 65°-70° to the northwest, The mineralization is sporadic and apparently occurs in shoots. The chrysocolla is associated with barite in the upper parts of the veins to a depth of 65-70 feet. Below this depth the ore becomes more siliceous and has a matrix of jasper. Mining apparently was last carried on in this area in 1938. Several small shafts and prospect pits have been sunk on the "Copper Mine" claim. The main shaft is about 70 feet deep and follows the dip of the vein. Whether there were any drifts along the vein at the base of the shaft was not determined, as these workings are no longer safely accessible. Fred Grover, an old miner familiar with the district, stated that the ore may have a lateral extent of 250-300 feet on a vein 3-6 feet wide. This vein crops out only sporadically on the surface, but an outcrop in a stream bed 300 feet to the northeast is mineralized. Other outcrops show only alteration without ore.

CHARACTER OF THE ORES

As observed and as described to the author by former miners, the lead-zinc ores of the Old Hadley (Graphic) district are similar to those of the Cooks Peak district, with the exception that barite is a prominent gangue mineral in this area. Oxidized copper ores, consisting of the minerals cuprite, melaconite, native copper, and chrysocolla, are also present. Assays and production figures for this district are included in the figures for the Cooks Peak district under "Graphic group." The two districts were separated because they are not immediately adjacent to each other, and the ores occur in different ways.

LAKE VALLEY MINING DISTRICT

GENERAL GEOLOGIC FEATURES OF THE DISTRICT

The manganiferous silver-lead deposits of the Lake Valley mining district are confined to a triangular area about half a mile wide and 1 ½ miles long, approximately half a mile north of the town of Lake Valley, on the southeastern slope of the Lake Valley fault block. In this region the Lake Valley limestone, the host formation of the ore deposits, is divided by Clark (1894) into three members: the Nodular limestone (Caballero formation and Andrecito member) at the base, the Blue limestone (Alamogordo member) next, and the Crinoidal limestone (Nunn and Tierra Blanca members) at the top. The Blue and Crinoidal limestones have been referred to as the "Footwall" lime and "Hanging

Wall" lime respectively, because the ore deposits are for the most part confined to a level at or near the contact between the two.

The most important ore deposits of the Lake Valley district occur in a drag zone in limestone formed by the N. 40° W. fault which brings the Mimbres Peak rhyolite on the west into contact with the Lake Valley formation. Faults of minor displacement (a few inches to 5 feet) parallel with the N. 45° E. strike of the beds, minor fractures trending northwest, and slight undulations in the beds, apparently caused by bedding-plane slippage, are also important factors in the control of ore deposition.

The ore deposits of the Lake Valley district were examined only in their surface expression, as most of the old workings are accessible only with difficulty. Even from surface examination it is apparent that the workings are confined to a layer between the lowest beds of the Blue limestone and the base of the overlying Crinoidal limestone.

The underground workings and primary mineralization have been described by Harley (1934, pp 176-184) and Gordon (1910, pp 276-282). Creasey and Granger (1953) have mapped some of the underground workings. The mineralization is of the bedded type, formed by replacement of the basal layers of the Crinoidal limestone and the upper layers of the Blue limestone. Exceptions are some parts of the area on the southwest, where disruption and brecciation of the footwall chert layer have allowed mineralizing solutions to enter. This has resulted in recementation and transformation of the chert breccia into a siliceous ore. Where the overlying Crinoidal limestone is replaced, the folded and dragged zones have provided the most favorable sites for ore deposition. The highest stopes in the district (Thirty stope, Twenty-five cut, Bridal Chamber) are located in this zone.

An interesting feature of the area is a large outcrop of material identified and mapped by Clark (1894) as a latite porphyry intrusive. Keyes (1908) referred to this material as "wash." Creasey and Granger (1953) describe the rock as "interbedded conglomerate and unconsolidated sand beds derived from the underlying crinoidal and blue limestone members of the Lake Valley limestone intermixed with volcanic detritus." The author agrees with Creasey and Granger in their evaluation of the rock. There is a possibility that some intrusive porphyry may be present, but the rock fragments found in the area are so altered as to make any detailed petrographic analysis practically impossible. As this rock is largely covered by a thin layer of soil and alluvium, it has been mapped as alluvium (Qal).

NATURE AND COMPOSITION OF THE ORES

At the surface and in open cuts and stopes the remaining visible ore shows a progressive change from southwest to northeast. The ores of the southwestern part of the district are highly siliceous. Stringers and pockets of fairly pure manganese oxides occur in massive red, green, yellow, and milky chert, which is permeated by a virtual web of thin veinlets of manganese minerals. This chert should be distinguished from the chert indigenous to the sedimentary formations, as it has formed by a different process. To the northeast the silica content gradually diminishes, and the ores show a more homogeneous mixture of fine-grained manganese and iron oxides and hydroxides, which appear as a massive, porous black ore. The silver content of the remaining manganiferous ores is too small to permit mining for silver. Their high lime content makes them desirable as a basic flux for other ores; during World War II they were mined as a source of manganese. Manganese contents of up to 50 percent have been reported, but later exploration by the U. S. Bureau of Mines has shown that, for the most part, the overall manganese content in the remaining material is fairly low. Beneficiation tests indicate that even if the ore were milled, it would be almost impossible to obtain a sinter containing over 45 percent manganese economically. The concentrate is higher in iron and silica than specifications allow for usable manganese ore (Dean, 1948). Ore from this area has been found usable for the production of electrolytic manganese with standard processing (Jacobs and Fuller, 1946).

NATURE, SEQUENCE, AND SOURCE OF MINERALIZING SOLUTIONS

The variations in silica content of the ores and differences in the manner of replacement have led some (Keyes, 1908) to postulate dual and interacting solutions to explain the manner of ore deposition. A more tenable hypothesis seems to be that the earliest ore-bearing solutions had a high silica content, which diminished as deposition went on, the silica being gradually replaced by calcium carbonate. Harley (1934, p 177) states:

> At first the solutions were high in silica and contained small amounts of manganese, iron, and silver. The cherty replacement deposits that they formed contained about 75 percent silica, 3 percent iron, 6 percent manganese, and 2 to 5 ounces of silver to the ton. Later the solutions were higher in calcium carbonate and silver, and during this period they deposited their load of silver and iron- and manganese-bearing calcite in the cracks and fractures formed within the cherty replacement bodies by the gradual elevation and tipping of the fault block within which the ore is found. The primary silver minerals were stephanite, proustite, pyrargyrite, and argentiferous galena locally, while the primary source of the manganese and iron was principally the iron- and manganese-bearing calcite or ankerite, and the iron and manganese content of the chert beds. Some pyrite was also deposited.

Ankerite has been found in some of the ores on the dumps. Alternatively, the manganese oxides may have been introduced in a separate epoch of mineralization.

The ore-bearing solutions are thought by the author to have been derived from some unknown deep-seated source, which possibly may be related to the volcanic activity in the area. The upward migration of these solutions was accomplished through fractures in the limestone.

OXIDATION OF THE ORES

The ore deposits were of commercial importance only because the original low-grade ore had been enriched by oxidation, transportation, and secondary precipitation, which had taken place since the elevation and denudation of the fault block. Oxidation has transformed the primary silver sulfantimonides to cerargyrite, embolite, and native silver; the galena to cerussite, vanadinite, and wulfenite; and the ankerite to manganese oxides, limonite, and manganiferous calcite. Secondary calcite occurs as veinlets and coatings on manganese minerals and cerargyrite. The interaction of calcite and the acid sulfate-bearing solutions has yielded large amounts of gypsum. The migration of the oxidizing solutions downslope to a level just below or within the cherty Crinoidal limestone has resulted in the formation of rich secondary ore bodies in the north-south fractures. Ore occurs in some of the fractures above and below this stratigraphic level, but is not of commercial value (Harley, 1934). In speaking of the oxidation and enrichment of the ores, Harley (1934) says:

> Where the chert has been fractured, the ore is siliceous as a rule, but where the chert was undisturbed the solutions filtered through the overlying bed of limestone, and replaced it to form the basic ores of the district, in which the lime content is 35 percent and silica about 20 percent. The solutions permeating the fractured limestones first filled the fractures and spaces with a mixture of manganese oxides, silver minerals, and calcite, and later dissolved out the fragments of limestone, leaving a coarse boxwork of the original cementing material; still later these openings were filled by ore and gangue minerals. Where the secondary ore-depositing solutions precipitated their mineral content in fractures in the chert the silica content is as much as 60 percent, the remainder consisting of limonite, manganese oxides, calcite, and silver minerals. In the intermediate ores, as in the Emporia and Thirty stope workings, the lime content averaged about 30 percent.

HISTORY AND PRODUCTION[1]

Ore deposits in the Lake Valley area were discovered first in August 1878 by George W. Lufkin. Mining started shortly thereafter, and the mines were worked continuously for the 15-year period ending in 1893. Within a short time after the discovery the best properties were all brought under the control of three companies, the Sierra Grande, Sierra Bella, and Sierra Apache; these names were derived from the names of the groups of claims under the control of each company. After 1893 the Sierra Grande company, having managed all the mines for several years, acquired control of almost all the properties in the mineralized areas. In the early eighties the district was made famous by the discovery of the Bridal Chamber, one of the richest single bodies of silver ore ever found.

The "Bridal Chamber" was discovered in the sinking of an exploratory shaft which was to test the extension of a known ore body. MacDonald (1908), in a discussion of a paper by Keyes (1908) on the area states:

> The vertical section of this shaft showed:

	Feet
Detritus	4
Fossiliferous lime stained with the oxides of iron and manganese	20
Ore averaging 40 oz.	5
Ore averaging 60 oz.	3
Ore averaging 150 oz.	4

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[1] Most of the following information was derived from Clark (1894) and Harley (1934, pp 178-179).

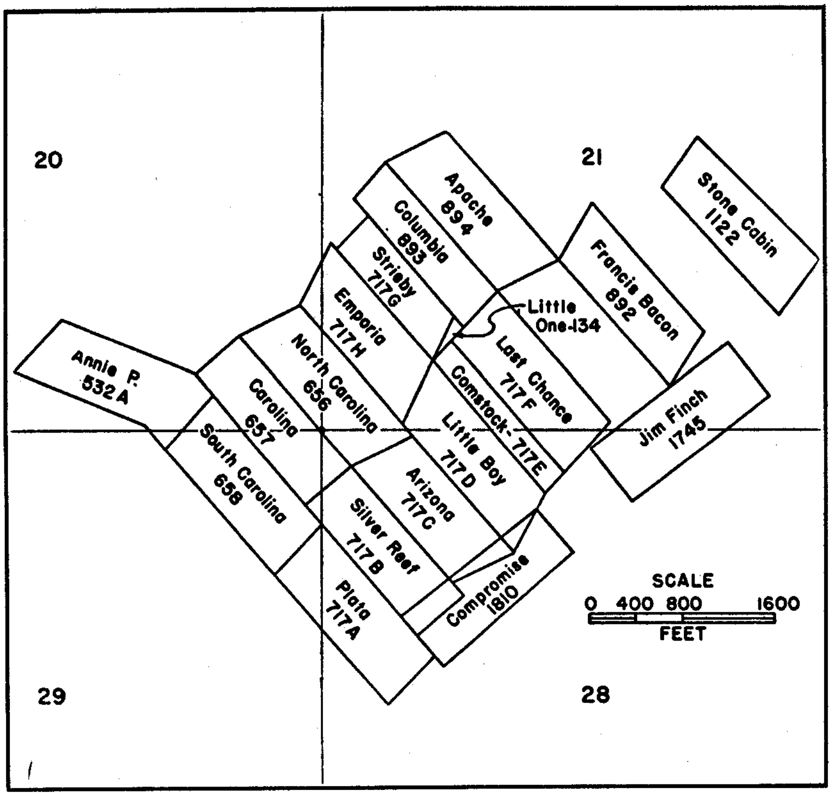

Figure 11

Patented claims in the Lake Valley mining district, T. 18 S., R. 7 W., Sierra County, New Mexico.

Open space	1 1/6
Horn silver, averaging 15,900 oz.,	4
Lead (sand) carbonates averaging 500 oz. silver and 40 per cent of lead	5
Decomposed lime heavily stained with iron and manganese	3
Total thickness of deposit	25
"Blue" lime	below (undetermined)

The extraordinary commercial value of the deposit developed at this place was due to the occurrence of the streak, 4 feet thick, of nearly pure cerargyrite. . . .

The downward continuation of this ore as a continuous sheet or bed was of limited extent, except for narrow pipes, which extended for considerable distances in the "blue" lime, but these finally feathered out and ceased entirely without leaving even a seam, . . .

I named the ore-deposit cut in the "joint" shaft the "Bridal Chamber" because of the sparkling light reflected by the myriads of crystals of cerargyrite and calcite studding the roof of the open space over the chloride streak. The

> purest specimens of the chloride streak assayed 20,000 oz. of silver to the ton, and the average across the 4-ft. faces was 15,000 oz. If the flame of the candle was held against any portion of this streak the ore would decrepitate in the flame and fuse to a slag. The streak of sand carbonates that underlaid the chloride deposit was practically coterminous with it, and as soon as the chloride streak broke up and disappeared the lead carbonates disappeared also. At a radius of 15 or 20 feet from the point cut by the "joint" shaft, the chloride streak broke up into small streaks and segregations, but the ore continued to average from 200 to 500 oz. for a considerable distance beyond this point, gradually lowering still further as the edge of the deposit was approached.

No ore was being mined in the district in December 1952. During World War II, however, considerable quantities of manganese ore were mined in the district. At that time the U. S. Bureau of Mines conducted an extensive churn drill campaign to locate and block out the more valuable of the manganiferous sections of the deposits (Apel1, et al., 1947), though most of these are below standard for current metallurgical use, even with hand picking. Most of this substandard ore is still in a government stockpile at Deming.

In the period from 1910 to 1931 small shipments of silver ore and fluxing material were made periodically, mostly in times of high metal prices. Since 1910 the materials shipped (exclusive of manganese ores produced during the war years) totaled 46,261 tons, most of which was basic flux and siliceous furnace material low in silver.

No records of production from this district are available for the years from 1894 to 1910, but Harley (1934, p 179) compiled estimates obtained from persons familiar with operations. These indicate that a total of about 500,000 oz of silver was produced during that period. Another 250,000 oz of silver were derived from the 46,261 tons of ore shipped from the district between 1910 and 1931. Production of silver in the district from 1878 to 1893 was as follows (Clark, 1894, p. 150) :

TABLE 8. PRODUCTION OF SILVER IN THE LAKE VALLEY MINING DISTRICT (1878-1893)

PROPERTY	SILVER (OZ)
Bridal Chamber	**2,500,000**
Thirty stope	**1,000,000**
Emporia incline	**200,000**
Bunkhouse	**300,000**
Bella chute	**500,000**
Twenty-five cut	**200,000**
Apache and others	**300,000**
Total	**5,000,000**

Thus, the total production of silver from the Lake Valley district for the period 1878-1931 amounted to about 5,750,000 oz.

A core-drilling program undertaken in the years 1928-1929 with 2 ½ - inch shot drills showed a few minor stringers of ore below the main ore bodies, but these were poor and diminished rapidly with depth. The top of the Percha shale was found to be barren of ore. One hole, which penetrated 400 feet to the top of the Fusselman limestone, showed that brecciation and silicification had occurred in the uppermost layers of that formation, but no ore minerals were found.

FUTURE POSSIBILITIES

Intensive prospecting in the Lake Valley district near the contact of the Blue and Crinoidal limestones may yield a few small pockets and stringers of high-grade silver ores. Possibilities are also fair that some high-grade manganese ores may still be won from the district, but hand picking would probably be required to produce ores of metallurgical grade, even with the higher-grade ores. The lower-grade ores cannot be brought up to metallurgical grade economically, but some sintered concentrates containing 45 percent manganese may be produced by jigging and tabling the ores and sintering the concentrates thus produced.

Haile Mines, Inc., of Truth or Consequences (Hot Springs) , has shown interest in the development of these deposits. In December 1953 a mill with a capacity of 200 tons per day was under construction at Lake Valley to process the ores into a product of sufficient grade to bring a profit under a government contract for the purchase of low-grade manganese ore from the district. The mill was in operation, and mining was being carried on by open cut methods, early in 1954.

MACHO DISTRICT

LOCATION AND GEOLOGIC SETTING

The Macho mining district, a small lead-zinc mining area, is located about 8 miles southwest of Lake Valley and 13 miles northwest of Nutt, and about half a mile west of the Wallace ranch on Macho Creek. The main activity is confined to an area about 2,000 feet long and 600-800 feet wide, whose long dimension parallels the general N. 30°-40° E. trend of the veins. Most of the production in this district has been derived from the Bulldog and Anniversary claims, the only ones in the district which have been developed to any great extent. In fact, the only shipments of any importance, including practically all of the lead-zinc ores and most of the low-grade material which lies on the dumps, have been derived from the Old Dude and Anniversary shafts, on the Old Dude vein, within the boundaries of these claims. The Bulldog and Anniversary claims are owned by Mr. D. M. Miller, of Lake Valley.

The district is located on the northeast side of a low, nearly flat basin which drains to the southeast. In this basin and in other nearby low-lying areas, the Macho pyroxene andesite series of the Tertiary sequence crops out. These purple andesites, with a few minor exceptions, are the only rocks in which veins and mineralization are to be found within the district. Where the later flows, which form a series of low hills around the basin, have covered the andesites, no mineralized outcrops of any importance have been found. At places the lowest flows of the Rubio Peak series have been altered along the same trend as the strike of the veins, but no veins extend into the Rubio Peak andesites and latites. For the most part, the veins crop out as yellow altered areas in the Macho pyroxene andesites. At a few places, where silicification is more pronounced, the outcrops stand out a few inches above the level of the country rock.

No sedimentary rocks crop out within the district. The closest area of Paleozoic rocks is in the Lake Valley district.

PATTERN OF MINERALIZATION

In his description of the structure and mineralization of the Macho district, Harley (1934, p 185) has indicated that the veins are related to a series of latite dikes and occur between well-defined walls of andesite. Thinsection studies of the country rock and of material from various zones within the veins, indicate that Harley probably mistook the yellowish altered andesite near fractures for latite. Harley stated also that the supposed dikes radiate from a center believed to be a short distance southwest of the Anniversary shaft. In preparing a reconnaissance map of the area (fig 12), the author found no evidence for such a radial pattern on the surface. Rather, a series of veins and altered linear streaks follow the general N. 30°-40° E. strike characteristic of fractures throughout the entire length of the outcrop. An exception to this pattern is the Old Dude vein, which cuts obliquely across the rest with a N. 13° E. strike. Such a crosscutting fracture pattern also occurs in a mineralized area 1½ miles southwest. It appears that such crosscutting fractures localize mineralization, probably by providing access to the rising ore-bearing solutions at fracture intersections.

As previously stated, the latite dikes inferred by Harley appear to be alteration zones along fissures. Parallel fractures, perhaps slightly faulted, dissect the andesite, and along these fractures the mineralizing solutions seem to have risen. The solutions had a different effect along the length of the vein, probably depending upon such factors as tightness of the fracture, rate and duration of flow, and composition of the solutions. For the most part the andesite was altered and partly silicified, but in some areas the silicification went on to a much greater degree, and manganese, lead, zinc, vanadium, and barium minerals were introduced. The purple andesite of the country rock can be seen everywhere to grade into the yellowish "latite dikes," and there is a complete transition from andesite to silicified yellow altered rock. In the more heavily affected areas, the transition may be traced into the barite- and galena-bearing siliceous central zone of a given vein. Minute vuggy structures in the silica indicate that brecciated areas probably occurred near the centerlines of the veins, but for the most part the veins are the direct result of alteration and replacement of the pyroxene andesite country rock by hydrothermal solutions. This effect is similar in many respects to the alteration found at Butte (Sales and Meyer, 1949) , although the minerals are not the same. There is marked gradational zoning in the veins. It is assumed that each stage of alteration was carried on at the same time as the others, the zones developing and becoming more widespread as the solutions had more time to permeate the rock and cause further changes, enlarging the affected area and pushing the zone boundaries outward from the source of the solutions. In the outermost (first) zone, the pyroxene andesite has been chloritized for about 50 feet from the

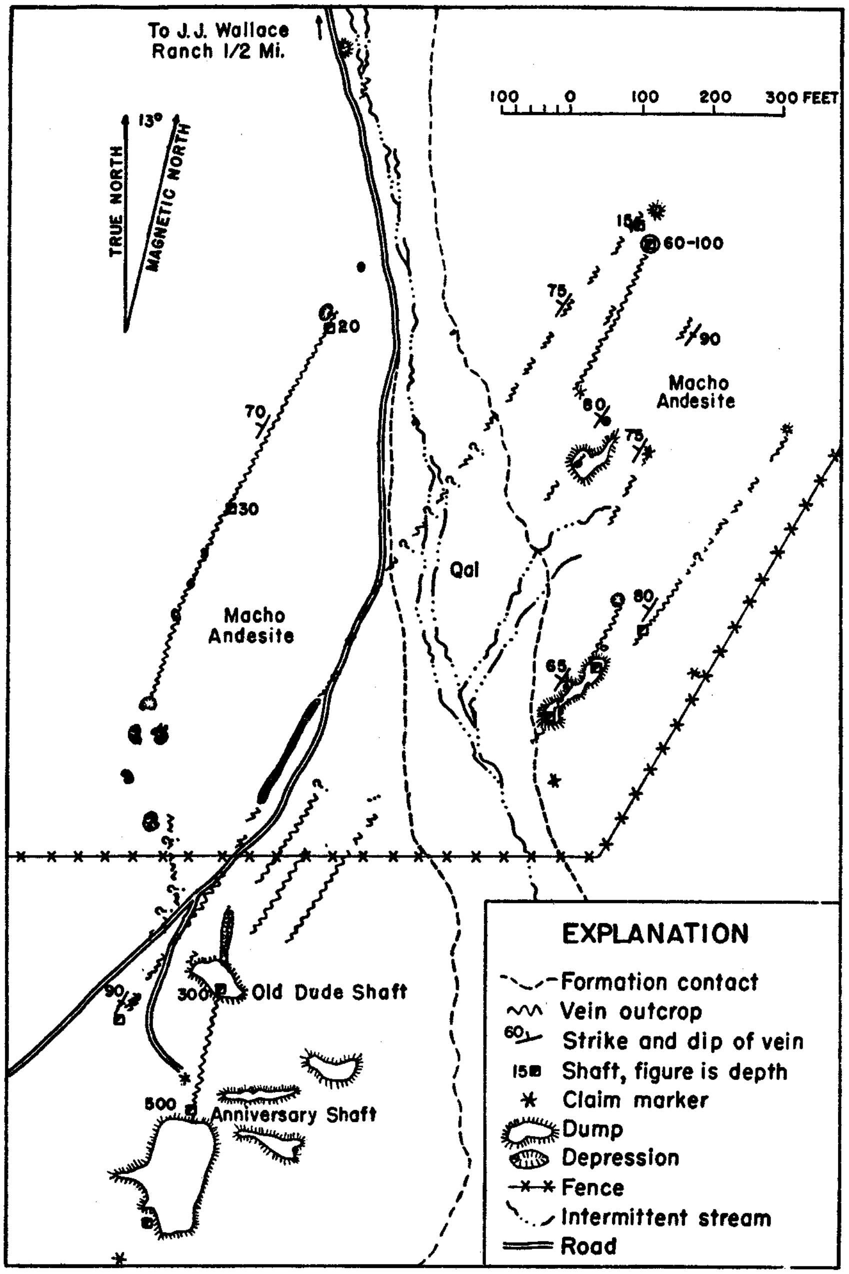

Figure 12

RECONNAISSANCE MAP OF THE MACHO MINING DISTRICT, SECTION 24, T. 19 S., R. 7 W., SIERRA COUNTY, NEW MEXICO.

centerlines of the veins. About 3-4 feet from the centerlines the feldspars begin to show the effects of the alteration. The second zone is the area where the feldspars are sericitized and some silicification takes place. The third zone is from 1 to 3 feet from the centerlines of the veins. There silicification is marked, the ferromagnesian minerals being replaced completely by silica, leaving halos of hematite and some magnetite; the feldspars are almost completely replaced by quartz and some sericite; and some barite was introduced. The veins proper are 6 inches to 1½ feet wide and consist almost entirely of quartz, barite, and sulfides (pl 5-F) . The Old Dude vein, which was not examined because the workings were all under water, is said to be 4-6 feet wide in the richest parts and to have a hard core of quartz, barite, and sulfides from 2 to 4 feet wide. Sulfides are said to make up between 15 and 40 percent of this core, which is surrounded by softer altered rock containing 3-5 percent sulfides. This indicates that the rock was probably silicified and altered before the sulfides *were* introduced, and that the metallizing solutions were low in silica. The third zone of alteration was metallized. The metallization was accompanied by the extensive silicification so characteristic of the narrower, lower-grade vein deposits on the surface.

In areas where the alteration has not gone beyond the second stage, or has advanced possibly as far as slightly into the third stage, there is no vein in the proper sense of the word, but only an altered zone about 3 feet wide. These altered zones have been traced by more or less discontinuous outcrops at least 2 miles to the southwest of the Macho district on the same remarkably constant N. 30°-40° E. strike, and 3 miles to the northeast. At various places along the strike, veins with manganese and lead-zinc minerals are seen. One is about 1½ miles southwest of the Macho district. There the veins are silicified to a width of 2 or 3 feet and contain stringers of manganese minerals (pyrolusite and psilomelane) for about 2,000 feet along the strike. Another is just south of the Wallace ranch, on Macho Creek, about half a mile northeast of the mines, where an old prospect pit reveals a narrow vein containing as much as 10 percent sulfides (estimated from megascopic examination).

The belt containing altered zones and some veins is about a third of a mile wide, but the whole width of this belt is exposed only at the Macho district, where the altered zones may be found in small outcrops for perhaps 1,200 feet southeast of the mineralized area.

NATURE OF THE ORES

The ore minerals of the district are galena, cerussite, anglesite, sphalerite, calamine (hemimorphite) , vanadinite, wulfenite, and pyrite. The gangue is mostly quartz, which is cherty and shows microvuggy structure.

The following is derived mostly from Harley (1934, pp 186-190). Hypogene ore mined in the brecciated portion of the Anniversary vein was reported to contain up to 15 percent lead. The low-grade ore in the altered pyroxene andesite averages 3-4 percent lead. The silver content of the ore averages 0.6 ounce per ton for each percent of lead in the ore. Gold in the ore averaged 60 cents to $1.06 per ton, depending upon the grade of lead. Sorted ore from the upper portions of the vein yielded 1 percent

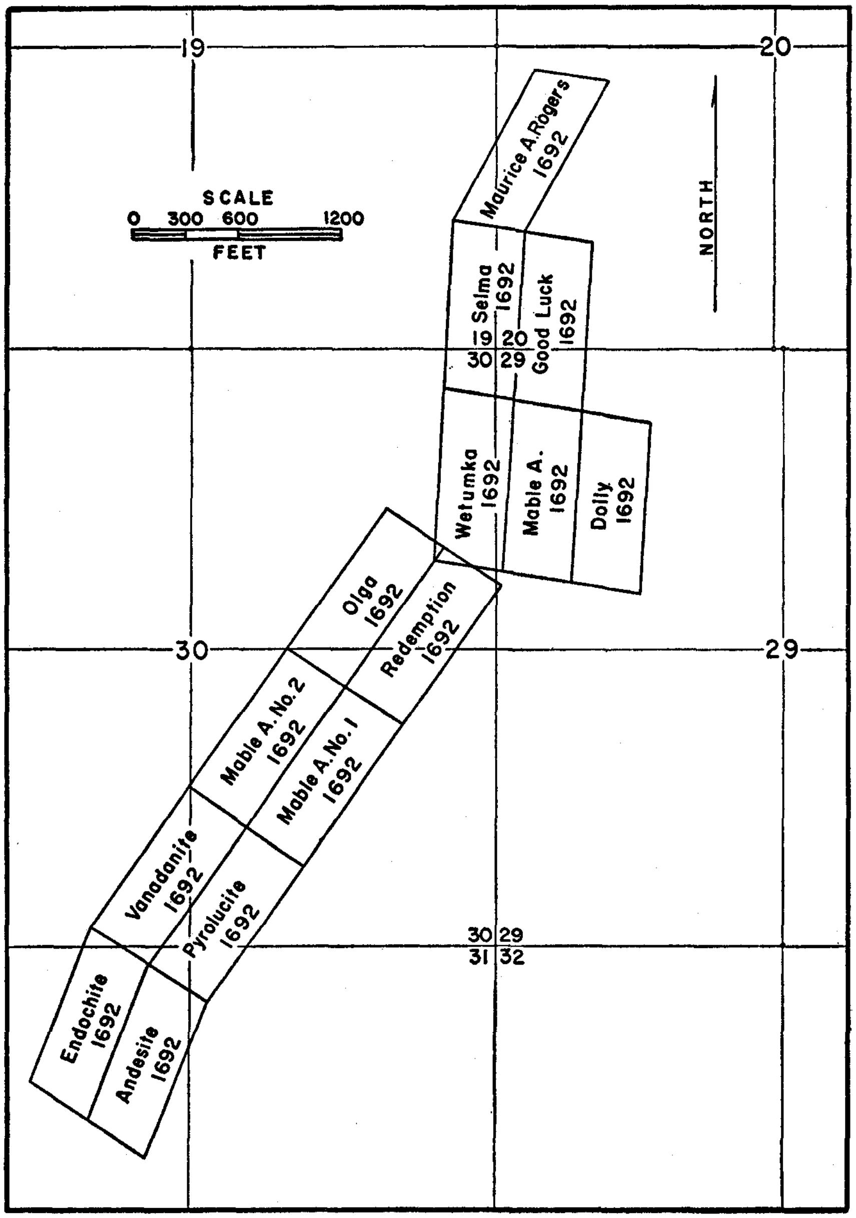

Figure 13

PATENTED CLAIMS IN THE MACHO MINING DISTRICT, T. 19 S., R. 7 W., SIERRA COUNTY, NEW MEXICO.

vanadium for each 5 percent lead. Ore from shafts on other veins contains considerable vanadinite, but little lead and zinc.

MINE WORKINGS

The main development work was done from the 500-foot Anniversary shaft, 300 feet south from the 300-foot Old Dude shaft. Levels were driven between the shafts at 100 and 300 feet. South of the Anniversary shaft, levels were driven at 100, 200, 400, and 500 feet below the surface. About 200 feet south of the shaft, a barren dike (?) is said to cut off the vein. A diamond-drill hole which extended from 300 to 400 feet below the 400-foot level at its end, 150 feet from the shaft, is reported to have struck Fusselman limestone at its bottom.

At the time of the writer's visit, water was standing at a level of from 40 to 60 feet below the collars of both shafts, and the underground workings could not be reached. Mr. Miller has stated that 40-60 gallons per minute had to be pumped when the mine was unwatered and working, and that this amount did not diminish during the entire period of operation. Other shafts are located 800 and 1,000 feet northeast of the Anniversary shaft (see map) . Neither of these was accessible. The dump of the former contains fragments of manganese oxides, probably psilomelane. The oxides appear to have developed in open spaces in brecciated andesite. The spaces were filled later with calcite. On fracture faces the rock gives the appearance of small black globules of manganese minerals embedded completely in calcite. The latter shaft, estimated to have been originally 300-400 feet deep, has now caved to about 100 feet below the surface. The workings are in slightly altered pyroxene andesite.

Harley (1934) mentions secondary enrichment and leaching, especially with relation to zinc, indicating that manganese oxides, limonite, anglesite, cerussite, smithsonite, and hemimorphite were formed. Probably enrichment did occur in the upper part of the Old Dude vein, but the author has found no evidence of secondary enrichment in the veins in other areas.

HISTORY AND PRODUCTION (Harley, 1934)

The Macho district was discovered in 1879 or 1880 by prospectors attracted to the region by the discovery of the rich Lake Valley ores nearby. Pay ore was found at the surface in the Anniversary vein, and some mining was done in 1880. It is estimated that 1,000 tons of ore were removed prior to 1904. Except for assessment work, the mines were idle from that time until 1926, when intensive development work was begun on the Anniversary and Bulldog claims. About 1,640 tons of ore were shipped during this period, which extended until 1928. Some 10,000 tons of material remain on the dumps from this period of activity. Ore not suited for direct shipping was screened through a ½-inch screen, the oversize being hand-sorted and the undersize jigged in a Joplin-type jig. The dump has been estimated to contain 4,000-5,000 tons of jig rejects averaging 3 percent lead, 1,000 tons of screened undersize averaging 4.5 percent lead, 4,000-5,000 tons of combined waste averaging 2-3 percent lead, and partly sorted broken material averaging 4-5 percent lead. The ore shows a remarkably consistent relationship between the metals in the various grades. The ore from the lower levels was richer than that from the upper levels of the mine. Lead content (including concentrates) varied from 7.7 to 26.1 percent, silver from 4.6 to 15 ounces per ton, and gold from 55 cents to $1.14 per ton (at $20.00 per ounce) .

FUTURE POSSIBILITIES

Harley (1934) indicated that there are large amounts of ore in place in the mines above the 300-foot level and probably considerable ore in place below the 300-foot level. He stated that "it appears that there may be enough ore on the dumps and in place in the veins to run a 50-ton mill for a period of three years," on the basis that low-grade ores would also be mined and the dumps reworked.

VICTORY CLAIMS

Early in 1941 Mr. 0. H. Franks located the Victory claims in sec. 6, T. 19 S., R. 7 W., on a vein which trends in a general northeasterly direction (about N. 65° E.) . This vein contains calcite, much of which is of suboptical grade. The vein averages 3 feet wide. It is traceable for only about 200 feet, but may continue for a considerable distance along the strike. It is located in latite porphyry which has been invaded by dikes nearby. The depth to which calcite may be traced was given as 300 feet by Mr. Franks, based upon the estimates of government geologists. The suboptical-grade calcite occurs in small pockets scattered thickly throughout the massive calcite of the vein. Up to the present time only one 14-foot prospect shaft has been sunk on the property. As the calcite crystals are of small size and difficult to remove without fracturing or straining, it remains to be seen whether the claims can be worked at a profit.

PERLITE DEPOSITS

Perlite is a glassy rhyolitic volcanic material with perlitic structure used as a light aggregate because of its peculiar property of expanding, on heating to about 1000°C, with little loss in strength relative to its bulk density. It has been found in several localities in Lake Valley quadrangle. The largest deposit crops out in association with rhyolitic flows in parts of sections 19, 20, 29, 30, 31, and 32, T. 18 S., R. 7 W., about 2 miles west and south of Lake Valley. From present indications, this deposit, a sill about 40 feet thick, covers an area of 3-4 square miles. Mr. C. A. McKinney, who owns or leases the land for grazing, holds the mineral rights to the property by right of claim. The perlite samples provided by him are of good quality, with exceptionally good properties of expansion and strength. However, most of the perlite is overlain by 100-200 feet of overburden. The nearest railhead is 16 miles away at Nutt.

Another deposit of perhaps several hundred tons was located on the Booth property in NE ¼ sec. 1, T. 19 S., R. 8 W. Other deposits have been found in NW ¼ sec. 2, T. 19S., R. 8 W., SW ¼ NW ¼ sec. 15, SE ¼ SW ¼ sec. 16, and center sec. 17, T. 18 S., R. 8 W. These deposits are small and inaccessible by road.

REGIONAL FEATURES OF MINERALIZATION

STRUCTURAL RELATIONS

The Macho district (lead-zinc) lies along a zone of mineralization that has been traced by means of scattered outcrops for a distance of five miles along a N. 30°-40° E. trend. The same trend is followed by latite dikes in the Rubio Peak series. The Old Hadley (Graphic) district on the southwest and the Lake Valley district on the northeast appear to be located on extensions of this same trend. Mineralization appears to occur on this trend in areas where cross faults have provided fracture intersections which allowed mineralizing solutions access to favorable host rocks. Though there is no conclusive evidence that this trend is continuous between the districts, it may provide a useful guide to exploration. It is possible that other mineral deposits may occur in the region on or near the same trend.

ORIGIN OF THE MINERALIZING SOLUTIONS

Mineralization in Lake Valley quadrangle probably took place in two or more epochs. The ores of the Cooks Peak mining district are sufficiently different from those of the Old Hadley (Graphic) district and the Macho district to make it probable that they had different origins in space and time. The ores of the Lake Valley district may have been deposited during one of those epochs or at a different time. Manganese mineralization in the northeast-trending veins also is thought to be a product of a different epoch.

It is probable that mineralization in the Cooks Peak mining district is related to solutions associated with the source of the granodiorite stock. As in most mineral districts near intrusives, the mineralization appears to have taken place after the emplacement of the stock and its related dikes. The Cooks Peak stock is the only intrusive nearby, and small sulfide pockets have been found in the stock itself. The ores that occur within the granodiorite contain the same minerals as occur in the limestone replacements of the Cooks Peak district, but are generally higher in silver content. There is also a small possibility that the ores may have been deposited by solutions which were the product of deep-seated activity in another epoch.

The ores of the Macho and Old Hadley districts were probably formed by solutions generated at deep levels during one of the later volcanic epochs. They do not appear to be closely related to the ores of the Cooks Peak district. The Cooks Peak stock appears to be earlier than the Macho andesites. The only contact between the intrusive and the volcanics is a faulted one. It is inferred nevertheless that the volcanics would have been intruded by granodiorite, if the intrusion occurred after their emplacement. Further evidence of a younger age for the volcanics is the fact that the conglomerates in the lower part of the Macho formation contain pebbles of granodiorite. The lead-zinc mineralization in the Macho and Old Hadley districts is confined to Macho rocks. Some alteration extends into the lower flows of the Rubio Peak series, but the only metallization in Rubio Peak rocks is manganese oxides, which apparently are a product of a later epoch. Thus, the lead-zinc metallization in the Macho rocks may be dated tentatively as early Rubio Peak. The manganese metallization is penecontemporaneous with, or later than, Rubio Peak time. The ores of the Macho and Old Hadley districts contain barite and vanadium minerals. No barite, and no vanadium minerals occur in the ores of the Cooks Peak district. It is especially surprising that barite, generally so typical of lead-zinc mineralization, is lacking in the Cooks Peak ores. Yet barite may be classed as characteristic in the vein deposits in andesite. The later (?) manganese ores also contain no barite.

The ores of the Lake Valley district combine features of two postulated epochs of mineralization. The lead-zinc-silver content suggests a relation to the Macho and Old Hadley deposits, and the manganese content a relation to the later period of manganese mineralization. It is probable, however, that both types of mineralization occurred contemporaneously in this area, as postulated by Harley (1934, p 177) . The ore-bearing solutions were probably related to sources similar to those which generated the ore-bearing solutions which metallized the Old Hadley and Macho districts.

Summary

Lake Valley quadrangle is in semiarid southwestern New Mexico, about 30 miles southeast of Silver City and 85 miles north and west of El Paso, Texas. The rocks range in age from Precambrian to Quaternary, but are chiefly Paleozoic limestones, Cretaceous clastics, and Tertiary lavas of great thickness. In Cooks Range Paleozoic sandstones, limestones, and shales lie unconformably on Precambrian granite and are overlain in various localities by Mesozoic shales, limestones, and sandstones. The range is a fault block intruded by a granodioritic mass of late Cretaceous or early Tertiary age. Correspondingly, the Lake Valley area is a large tilted fault block of Paleozoic sediments surrounded by volcanics of Tertiary age.

The Tertiary rocks include pyroxene andesites, amphibole latites, quartz latites, rhyolites, basalts, and their fragmental equivalents. Petrographic descriptions of all these rocks are given.

Faulting in the area follows a general northwest trend, though some northeast trending cross faults are present. Minor faults are not related closely to the general structural pattern.

Five important mining districts, the Cooks Peak and Jose districts (lead-zinc-silver) , the Old Hadley (Graphic) district (copper-lead-zinc-silver) , the smaller Macho district (lead-silver-zinc) , and the Lake Valley district (silver and manganese) are in the quadrangle. Several other, less important, deposits of metallic and nonmetallic minerals have been investigated.

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Appendix

EXPLANATION OF THE GEOLOGIC SECTIONS ACCOMPANYING THE GEOLOGIC MAP OF LAKE VALLEY QUADRANGLE

It should be noted that the thicknesses of the volcanic formations are not so consistent as they have been assumed to be for the purposes of making these sections. Variations in thickness have been noted on a regional scale. Local variations are also known to occur. Such differences are the result of the very nature of the deposition of volcanic rocks, which spread out from an eruptive center or centers. However, since there is no possibility of determining where such changes of thickness take place in the subsurface, or whether the formations become thicker or thinner at any given subsurface locality, the generalized type of presentation has been adopted.

The term "pre-Tertiary" is used to describe the rocks beneath the volcanic series, because there is presently no way of knowing what formations were exposed on the prevolcanic surface.

The feeder pipes or dikes of the Mimbres Peak rhyolite domes are shown diagrammatically. Their true nature is not known except by analogy with Dwyer quadrangle on the west, where pipelike masses of breccia are regarded as the eroded remnants of such feeders.

Section A-A', which extends from Cooks Range to the Macho mining district, provides a more graphic representation of the faulting in Cooks Range. The easternmost fault in Cooks Range may have parallel subsidiary faults on the downthrown side. However, as the fault line itself is covered by talus and alluvium, and much of the remaining part of the area is covered by later fanglomerate of Santa Fe (?) age, no evidence is present to substantiate the presence of subsidiary faults.

Section B-B' demonstrates the deposition of tuff in topographic lows in the Rubio Peak formation. The general dip of the formations to the west is the result of a large anticlinal structure whose axis is east of the end of the section.

Section C-C' covers a line between the headwaters of White Rock Creek and the northeast corner of the quadrangle. The main features shown are: (1) the intrusive nature of the rhyolites of the Mimbres Peak series; (2) filling of topographic lows by the Sugarlump tuffs; (3) the large fault in White Rock Creek; and (4) the main northwest-trending fault of the Lake Valley fault block.

The thinning of the Rubio Peak formation in the basins where Santa Fe (?) fanglomerates were deposited is postulated on the premise that the basins are erosional rather than structural. Although there is evidence of faulting in the Rubio Peak formation, it is almost impossible to trace faults along the strike because of the absence of marker horizons. Evidence that the basins are structural is therefore lacking. The author believes that the basins are at least partly erosional in any event.

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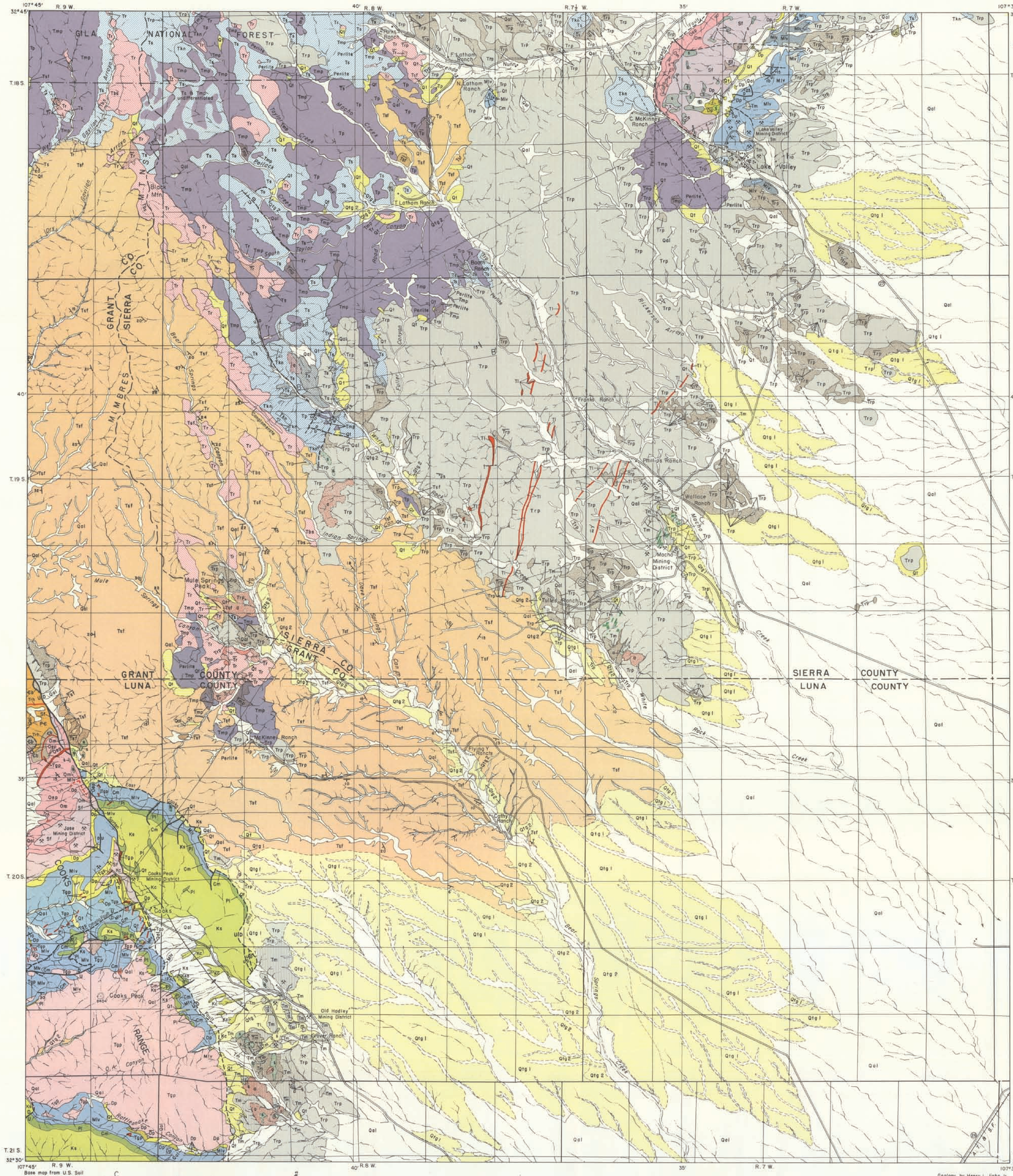
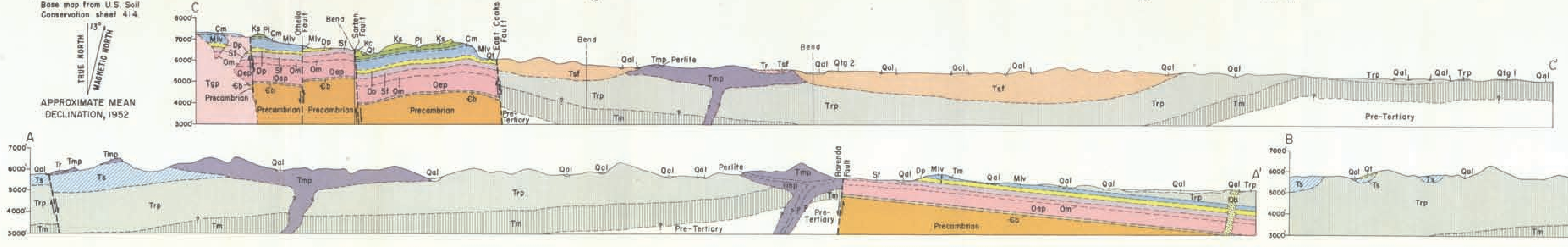
Numbers in *italics* indicate figures and plates; **boldface** indicates main references.



107°45' R. 9 W.
Base map from U.S. Soil Conservation sheet 414.



APPROXIMATE MEAN DECLINATION, 1952

Geology by Henry L. Jicha, Jr., Columbia University. Surveyed 1951-52 as part of Field Assistance Fellowship program.

GEOLOGIC MAP AND SECTIONS OF THE LAKE VALLEY QUADRANGLE, NEW MEXICO

Scale 1/48,000

1 0 2 3 MILES

EXPLANATION

QUATERNARY

Qal — Alluvium *sand and gravel*

Qt — Talus

Qtg 2 / Qtg 1 — Terrace gravels (Qtg2) High terrace and pediment gravels (Qtg 1)

Qb — Basalt

TERTIARY

Tsf Tsf — Santa Fe formation *fanglomerate*

Tbs — Bear Springs basalt

Tr Tr — Razorback formation *pyroxene andesite*

Tp Tp — Pollack quartz latite

Tmp Tmp — Mimbres Peak rhyolite

Tkn — Kneeling Nun rhyolite *welded tuff*

Ts Ts — Sugarlump quartz latite tuff

Trp Trp — Rubio Peak formation *pyroxene andesite, amphibole latite*

Tm — Macho pyroxene andesite

DIKES

Tl — Latite

Td — Diorite

Tgp Tgp — Cooks Peak granodiorite

Trh — Rhyolite

CRETACEOUS

Kc — Colorado shale *blocky black shale*

Ks — Sarten sandstone *light gray quartzitic sandstone*

PERMIAN

Pl — Lobo formation *red shale, sandstone & limestone*

CARBONIFEROUS

Cm — Magdalena group *limestone and chert conglomerate*

Mlv Mlv — Lake Valley formation *cherty and shaly limestones*

DEVONIAN

Dp Dp — Percha shale *black fissile shale*

SILURIAN

Sf Sf — Fusselman limestone *massive dolomitic limestone*

ORDOVICIAN

Om — Montoya group *limestone and dolomite, sandstone at base*

Oep — El Paso group *limestone with silica crenulations, upper part with algal biostromes*

CAMBRO-ORDOVICIAN

Єb — Bliss sandstone *dark colored hematitic and glauconitic sandstones*

PRECAMBRIAN

PЄ — Epidotized granite

(Unconformities occur between all the above units except between Bliss sandstone and El Paso group.)

a — Partly kaolinized and altered volcanics

s — Jasperoid

Veins

Bar over symbol (e.g., $\overline{\text{Trp}}$) distinguishes areas with soil cover from outcrop areas (e.g., brown dots over formation color).

Contact *dashed where approximately located*

Fault *dashed where approximately located* U, *upthrown;* D, *downthrown*

Anticlinal axis *dashed where approximately located*

Synclinal axis *dashed where approximately located*

Road

Intermittent stream

Strike and dip of bed

⚒ Mining area

Buildings

Location Map showing Lake Valley Quadrangle