Geology and Ore Deposits
of
Eagle Nest Area
New Mexico

Photo on title page:
Lake Fork valley from Frazer mine, Twining
Fairview Mountain at right

NEW MEXICO STATE BUREAU OF MINES AND MINERAL RESOURCES

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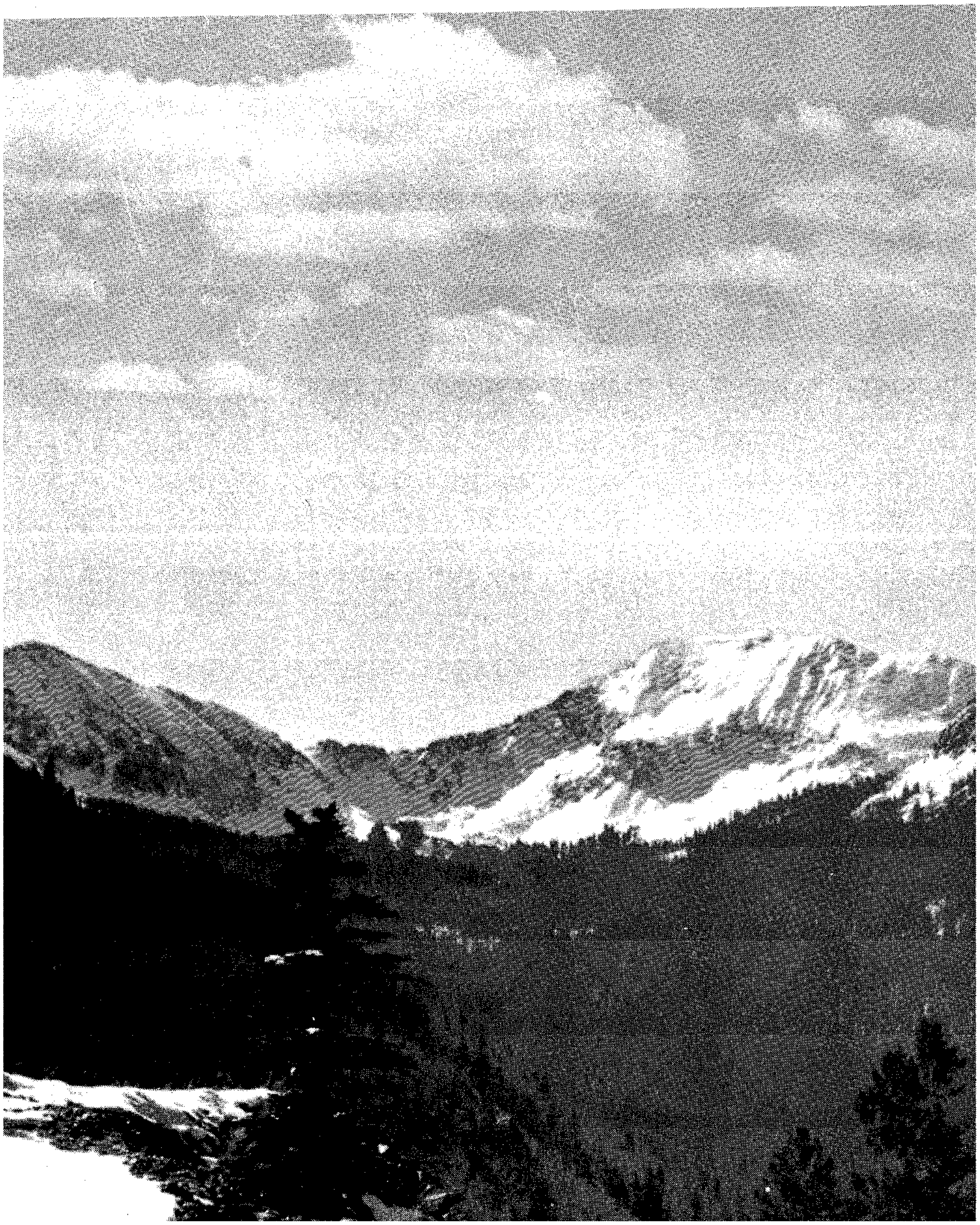

GEOLOGY AND ORE DEPOSITS OF EAGLE NEST AREA, NEW MEXICO

by KENNETH F. CLARK and CHARLES B. READ

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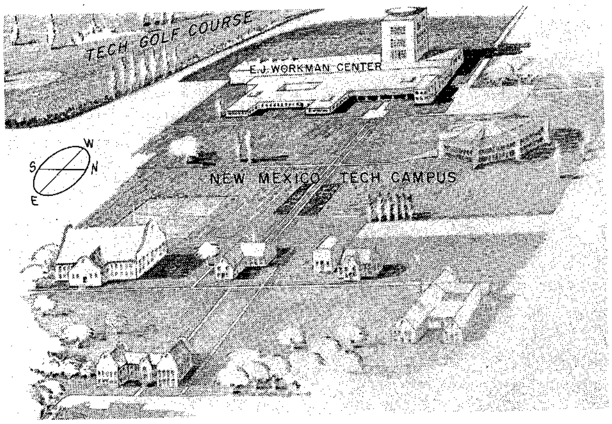

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Abstract

In the Eagle Nest area of the Sangre de Cristo Mountains, Precambrian sedimentary and minor igneous lithologies (metamorphosed to metaquartzite, mafic gneiss and granitic gneiss) attain a composite thickness of 18,000 feet. Apparently, emplacement of granite during the Elsonian (1,460-1,280 m.y.) and the formation of migmatites, occurred during the latter stages of regional metamorphism. Foliation is northeasterly.

The crystalline terrane, a positive area in early Paleozoic time, is partly overlain by a 13,000-foot section of Mississippian through Paleocene sediments. Repeated crustal warpings during Mississippian and also in Late Triassic and Late Jurassic times formed thin marine and continental deposits, respectively. An aggregate thickness of 711 feet is preserved. In contrast, trough deposition, during the interval between Pennsylvanian (Desmoinesian) and Early Permian accumulated 8,200 feet of marine arkosic 'and continental red-bed sediments. A deepening basin preserved 2,000 feet of Cretaceous marine strata.

The evolution of the southern Rocky Mountains geanticline during Laramide time was accomplished by deep-seated basement uplift along upthrust and flattened underthrust contacts with overlying strata. This orogeny is reflected in 1,000 feet of terrestrial Paleocene deposits. Lower to middle Tertiary volcanic units, nearly 3,000 feet thick, contain thin clastics, andesite, latite, and rhyolite. Intrusives include Eocene (51 m.y.) Rio Hondo hornblende granite, Oligocene (34 m.y.) quartz diorite porphyry, and early Miocene (23 m.y.) Questa mine biotite granite. Siliceous intrusives, emplaced along lines of weakness, contributed to uplift by doming.

Early Miocene granites produced widespread and locally intense hydrothermal alteration. Contemporaneously, metallization occurred in the Red River district in fissure veins and disseminations. The Questa open-pit stockwork molybdenum deposit, averaging 0.297 percent MoS_2, commenced production in 1965. Minor Precambrian quartz-copper mineralization occurs in the Rio Hondo district. In the Elizabethtown-Baldy districts fissure vein gold and contact iron deposits are Oligocene in age. Subsequently placer deposits formed in the Moreno Valley.

Middle to late Tertiary high-angle normal faulting dislocated a. mid Tertiary erosion surface. Structural and topographic relief of Laramide features were enhanced, producing several well-defined topographic, tectonic and lithologic features: the Taos horst, Red River graben, Moreno Valley and western flank of the Cimarron Range. Late Pliocene to early Pleistocene gravels accumulated in the Moreno Valley, and drainage integration followed. Radially disposed Wisconsin valley glaciation, coupled with fracture patterns, control drainage in uplifted areas.

Introduction

For many years systematic geologic mapping has been carried out in the Sangre de Cristo Mountain range. In New Mexico much of the range has been mapped yet some parts have received little or no geologic investigation. Although some aspects of the Eagle Nest Area still require more detailed examination, this report presents the general geology as a broad foundation on which future work may be based.

The area exhibits a multitude of geologic features requiring investigation. In particular, the Precambrian terrane has been subdivided; Mississippian, Pennsylvanian and Permian stratigraphic problems have received special treatment. The structural fabric has been described in detail because of anomalous implications arising from this interpretation. Finally, mineralization in three mining districts, one of which includes a large open-pit mine brought into production in 1965, summarizes the mineral resources.

METHODS

The field work started in 1948 and continued to 1950, when Charles B. Read mapped the Eagle Nest 15-minute quadrangle and compiled a preliminary geologic map. In 1964 and 1965, the senior author made an independent study of the quadrangle for a doctoral dissertation submitted to the University of New Mexico in 1966. Subsequently, he extended the mapping eastward to join with the Philmont quadrangle.

In this report, the chapters on stratigraphy, structure, and geologic history were written jointly; the remainder of the report reflects Clark's work.

Geology was plotted in the field on 1:32,000 aerial photographs flown in 1962 by the U.S. Geological Survey. The base map was compiled from 7½-minute topographic maps (scale 1:24,000, contour interval 40 feet) which allowed horizontal and vertical control. The U.S. Soil Conservation Service provided a controlled photomosaic of the area. The U.S. Forest Service planimetric map (scale 1:31,680) provided additional control for drainage, property lines, roads, and trails. Compass, tape, or staff methods were used in measuring sections, and some estimates of rock thicknesses were calculated from topographic maps.

PREVIOUS STUDIES

The first mention of the area was made in the Wheeler Surveys by Conkling (1876) and Stevenson (1881). Darton (1928) included the area on his geologic map of New Mexico, scale 1:500,000. This map indicates the general distribution of Precambrian rocks, some of the sediments, and the volcanics. Gruner (1920) did reconnaissance work on a small part of the southern edge of the quadrangle and the adjoining area to the south. Dane and Bachman provided more information with their geologic maps of northeastern New Mexico (1962), scale 1:380,160, and of the whole state (1965), scale 1:500,000. Further information, particularly in regard to the Moreno Valley, comes from the work of Wanek and Read (1956). Ellis (1931) and Ray (1940) studied some of the glacial deposits and Ray and Smith (1941) considered the geology and geomorphology of the Moreno Valley. Schilling (1960) presented further information pertaining to the geology around the mining districts as well as a brief road guide of a general nature (1956).

With regard to the adjoining quadrangles, similar information may be found in the publications of the federal and state surveys: McKinlay (1956) has described the Costilla and Latir Peak quadrangles to the north, and the Questa quadrangle to the west (1957); Smith and Ray (1943) described the Cimarron Range to the east, and Robinson and others (1964), the Philmont quadrangle. Quadrangle coverage for the area immediately to the south is not available. Elsewhere in the range, various other geologic investigations have a bearing on the present study. Among these are a description of the foothills near Las Vegas by Northrop and others (1946); the Picuris Range by Montgomery (1953); and the Truchas Peaks area by Miller, Montgomery, and Sutherland (1963).

GEOGRAPHY

The area comprises about 310 square miles of rugged mountainous terrain with intervening high valleys. Vertical relief is about 5,000 feet, embracing Wheeler Peak, highest point (elev. 13,173 ft) in New Mexico. The western part of the area is dominated by the Sangre de Cristo Mountains, known locally as the Taos Range; the eastern part includes the broad Moreno Valley and the west slope of the Cimarron Range. All these features are aligned north-south (fig. 1 and pl. 1).

The area may be approached from the east by a road from Las Vegas or Raton through Cimarron, and from the west through Santa Fe, New Mexico or San Luis, Colorado. The area is sparsely settled; Red River and Eagle Nest are the only important communities. They are connected to Taos and Questa by paved roads that

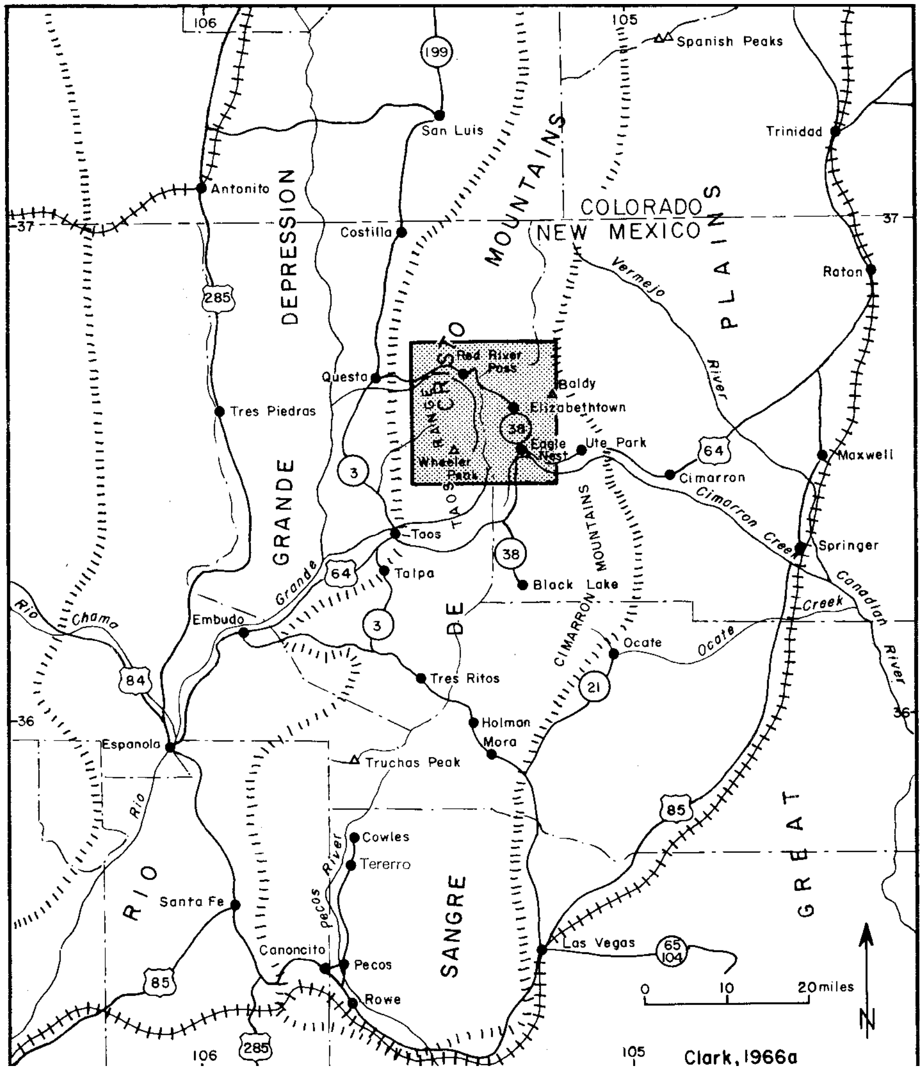


FIGURE 1—Location and index map.

form a circular route through and around the mapped area between the four villages. This route crosses the range between Red River and Eagle Nest at Red River Pass (elev. 9,856 ft) and again at Palo Flechado Pass (elev. 9,107 ft) between Eagle Nest and Taos.

The nearest railheads are at Antonito, Colorado, served by the Denver and Rio Grande western Railroad; and at Raton, Springer, Las Vegas, and various other stations on the Atchison, Topeka, and Santa Fe Railroad in New Mexico.

A sparse network of dirt roads and jeep trails makes more of the area accessible, although much of the high country can be negotiated only on horseback or by foot.

Most of the western part of the area, in Taos County, falls within the Carson National Forest and is open to the public. The eastern part, which lies in Colfax County, is privately owned, and was formerly held by the Maxwell Land Grant Corn-

TABLE 1—*Climatological Data for Taos, Red River, and Eagle Nest*
(Courtesy National Weather Service, Albuquerque, New Mexico)

Average Temperatures (° F.)

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Taos, elevation 6,952 feet													
1956	31.9	25.5	37.4	44.5	56.8	67.2	67.4	64.5	63.2	51.3	31.3	28.5	47.5
1957	28.8	37.8	37.8	43.5	52.1	64.3	68.9	66.6	59.7	49.7	31.5	28.4	47.4
1958	25.6	35.0	35.6	46.5	58.9	67.3	69.0	68.3	60.5	48.5	33.8	31.5	48.4
1959	28.0	31.1	38.0	47.9	56.2	67.4	70.0	68.6	60.1	48.6	35.8	31.9	48.6
1960	18.8	24.7	38.9	49.8	56.6	65.3	68.5	70.4	63.1	46.9	35.3	26.4	47.0
Red River, elevation 8,676 feet													
1956	26.4	16.6	30.2	34.2	48.1	56.2	57.2	54.1	53.4	42.1	23.0	17.7	38.3
1957	22.2	30.0	29.7	34.6	41.0	51.2	57.2	55.5	48.8	40.0	23.0	21.8	37.9
1958	17.9	25.2	22.4	33.5	46.7	54.3	57.9	58.5	51.8	41.1	29.4	26.1	38.7
1959	21.0	21.9	28.5	37.3	45.6	55.0	57.8	57.3	49.6	40.3	29.1	23.1	38.9
1960	13.5	16.1	29.5	38.5	42.6	54.4	57.3	57.8	51.6	39.6	31.1	19.6	37.6
Eagle Nest, elevation 8,220 feet													
1956	28.0	18.2	32.2	35.5	46.9	56.6	58.8	55.7	52.1	40.9	24.1	22.2	39.3
1957	26.6	33.8	32.1	37.9	43.9	54.1	59.6	57.8	48.3	41.6	23.6	23.9	40.3
1958	22.7	28.8	28.6	36.1	49.4	55.5	58.8	58.4	53.6	41.2	33.2	28.8	41.3
1959	20.7	27.2	29.2	39.9	46.6	55.8	58.6	58.5	49.9	41.5	30.8	25.0	40.3
1960	–	14.9	25.7	40.7	44.4	55.5	57.9	57.1	52.8	41.7	–	21.9	–

Total Precipitation (inches)

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Taos, elevation 6,952 feet													
1956	1.30	.72	.28	.21	.61	.41	2.59	1.17	T	.72	.56	.26	8.83
1957	2.66	.65	1.41	1.13	2.64	.12	3.39	5.13	T	4.69	1.49	.07	23.38
1958	.28	.92	1.05	1.08	.69	.08	.63	2.41	2.72	.67	.87	.00	11.40
1959	.37	.45	.60	.95	1.74	1.40	.81	3.09	.24	1.40	.33	1.96	13.34
1960	1.37	.80	.76	.61	.76	1.32	1.93	.30	1.57	1.11	.07	.76	11.36
Red River, elevation 8,676 feet													
1956	1.32	1.04	.67	.56	.76	.70	2.12	2.03	.10	1.07	.72	.55	11.64
1957	2.16	.45	.91	2.62	3.83	.57	3.42	6.55	.05	4.19	1.87	.22	26.84
1958	.44	.90	1.65	1.23	1.35	.43	1.47	2.73	1.36	1.02	1.40	.12	14.10
1959	.44	.91	.55	1.97	2.60	2.14	1.93	3.60	.67	2.06	.44	2.25	19.56
1960	2.38	1.19	1.33	.78	.82	1.18	2.51	.78	1.64	3.26	.71	1.02	17.60
Eagle Nest, elevation 8,220 feet													
1956	.59	.51	.25	.35	.94	.16	1.91	1.49	.05	.27	.32	.10	6.94
1957	2.73	.18	1.29	.99	2.42	1.07	2.83	3.85	.06	3.25	1.25	T	19.92
1958	.03	.37	1.03	1.32	1.54	.55	.96	1.38	.95	1.01	.67	.30	10.11
1959	.50	.30	.15	1.40	1.46	2.29	2.84	3.82	.26	1.27	.15	1.55	15.99
1960	–	1.17	.69	.61	.00	–	–	6.06	1.28	–	–	.50	–

pany. Part of the Taos Pueblo Indian Reservation along the upper reaches of Rio Lucero is located in the southern area. In the past this country has been jointly administered by the governor of the pueblo and the U.S. Forest Service. It is closed to the public between August 20 and 30 every year during pueblo ceremonial activities held at Blue Lake. However, in late 1970, Congress withdrew the area from the public domain. Immediately to the north, and adjoining the reservation, the country around Wheeler Peak has been designated a wildlife area by the Forest Service, as is part of the Cimarron Mountains east of Eagle Nest Lake.

The climate has marked seasonal variations locally modified by altitude. Field work was confined to the months of May through October, with a shorter period at the higher elevations. Average annual rainfall is about 17 inches at Red River and 13 inches at Eagle "Nest. Summer rains account for about one-third the annual rainfall; they are relatively short but intense afternoon thunderstorms, with some sleet storms at higher elevations. In winter, moisture from the Pacific is carried eastward by the prevailing westerly winds, whereas in summer, moisture is brought from the Gulf of Mexico. Surface heating of this moist air and its upward path on the slopes of the mountains results in the summer thunderstorms. During winter months, occasional cold Arctic air moves into northern New Mexico.

A light fall of snow can be expected in mid-September, but thereafter a pleasant Indian summer prevails throughout October. Winters are relatively severe (Eagle Nest and Elizabethtown have record low temperatures for the state for several months). Heavy winter snows come in middle November and, thereafter, all but the lowest elevations become impassable, although paved roads are kept open. Humidity is relatively low throughout much of the year; and the amount of sunshine received is great.

As in adjacent mountainous areas, the relationship between altitude, climate, and life zones is distinct. The upper three life zones of Merriam's classification (1890) are present. The Transition Zone is represented by the yellow (ponderosa) pine association, found in the valleys between 8,000 and 9,000 feet elevation. The Canadian-Hudson Zone, between 9,000 and 12,000 feet, is characterized by aspen in the lower part and by spruce and fir in the upper part, and forms the cover of densely forested slopes. The Arctic-Alpine Zone, in contrast, lies above timber line and is represented by grasses and sedges on the barren mountain crests.

The wildlife and natural physical features of the area continue to attract visitors in increasing numbers. Mountain stream and lake fishing, combined with the equable summer temperatures and majestic scenery, prove a natural vacation attraction for people from adjoining states, mainly Texas and Oklahoma. Many summer cabins have been built in and around Red River and at Idlewild and Lakeview in the Moreno Valley. Fall brings hunters to Red River and Eagle Nest, and in the winter, skiing at Taos Valley (Twining), Red River (fig. 2A) and Angel Fire (near Eagle Nest) compares favorably with other resorts in New Mexico.

ACKNOWLEDGMENTS

The writers acknowledge all those who have assisted them in any way and wish that every name could appear here in print, although space limitations make this impossible.

Part of the field investigations were made with the help of A. A. Wanek, George O. Bachman, and Pedro Verastegui Mackee, U.S. Geological Survey, in conjunction with Philip F. McKinlay, formerly of the New Mexico State Bureau of Mines and Mineral Resources. Gratitude is expressed to Stuart A. Northrop, University of New Mexico, who visited the field area and undertook the examination and identification of the

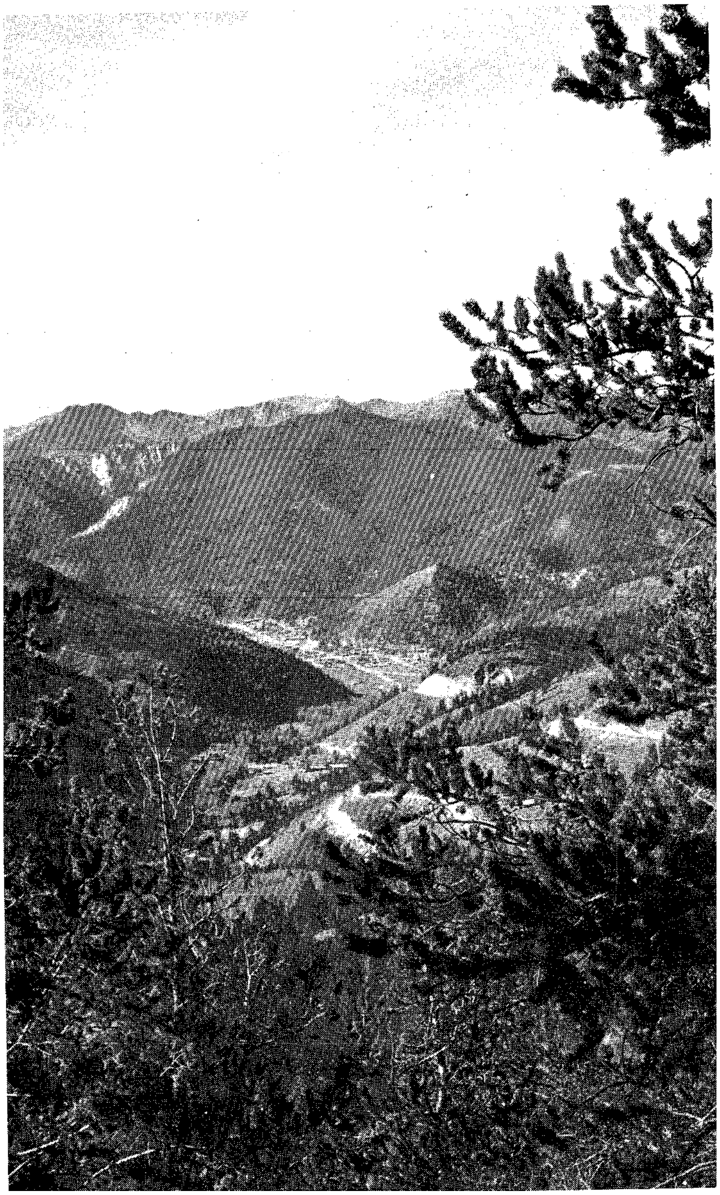


FIGURE 2A—Westward view of Red River valley from near Red River Pass. *Wide alluvium-covered* floor. The broad, flat part of the valley marks the former site of a small lake that may have been dammed behind a mudflow from the Hottentot alteration area, seen in the background. The triangular facet immediately north of the town indicates a fault along the length of the valley.

FIGURE 2B—Westward view of Red River valley toward head of East Fork. *Talus stream and moraine.* Thin-bedded Pennsylvanian siltstones are in the foreground. Flow ridges on talus stream below; the material accumulates from the steep slopes of Taos Cone. Above the well-defined lip at the head of the valley lie moraines of Wisconsin substages 4 and 5.

megafossils. Fusulinid determinations were made by H. V. Hollingsworth, Paleontological Laboratory, Midland, Texas. Elmer H. Baltz, U.S. Geological Survey, helped in discussing various field problems relating to stratigraphy and structure. Special thanks are due to Vincent C. Kelley, University of New Mexico, who accompanied the authors in the field on several occasions. We are indebted to Max E. Willard, Roy W. Foster, Frank E. Kottlowski, and the late Alex Nicholson, New Mexico State Bureau of Mines and Mineral Resources, who critically reviewed the manuscript, as well as to William E. Arnold, who prepared the colored geologic map.

General information regarding the Questa mine, Molybdenum Corporation of America, was provided by the geologic staff of that company. Gilbert R. Griswold, consultant, Albuquerque, made available his files on mining activities of the Elizabethtown district. Further information was provided on that district by M. W. Lowrey and Adolf Mutz, both of Eagle Nest.

To the landowners in the Moreno Valley, the writers acknowledge the generous cooperation received in gaining access to private property, in particular, Adolf, Emil, and George Mutz; Kenneth Danley, manager of the Moreno ranch; T. D. Gorman; and the lessees of Eagle Nest Lake, Tal Neil and William Gallagher.

Field expenses were partly defrayed during the summers of 1964 and 1965 by American Metal Climax, Inc., Denver, Colorado, through R. J. Wright, manager for western exploration. A grant from the Roswell Geological Society defrayed various expenses during 1965. The Society of the Sigma Xi covered the costs of reproducing the original manuscript and the maps. Field expenses were partly defrayed by Cornell University in 1967. Patricia Clark did the photographic work, and Virginia Gillespie and Dorothy Messenger typed the manuscripts.

Stratigraphy

Precambrian metamorphic rock comprises the highest topographic features in the western part of the area, and accounts for one-third the total surface. Igneous rocks are conspicuous in the relatively depressed Red River segment. But intrusive phases also occur elsewhere, particularly in the floor and flanks of the Moreno Valley. In contrast, the sedimentary section is mainly preserved in the Moreno Valley and the relatively gentle rounded northern flank of the Cimarron Range. From there the sedimentary section passes into adjacent parts of the Raton Mesas.

Ages of stratigraphic units range from Precambrian to Holocene (table 2). The thickness of Precambrian metasediments is probably no less than 18,000 feet. Sedimentary units varying in age from Mississippian to Recent have a composite thickness of about 13,000 feet. The Tertiary volcanic sequence has a thickness of less than 3,000 feet.

Many of the rocks found in the map area have been described previously in surrounding quadrangles or elsewhere in the Sangre de Cristo Mountains. Consequently, wherever possible, the terminology of previous workers is continued herein.

PRECAMBRIAN

Many Precambrian rocks in this area have been derived from regional metamorphism of pre-existing sedimentary and igneous rocks, although locally the effects of granitic intrusion are marked. Foliation generally trends northeastward and is present in most of the rocks to some extent.

Four major sequences have been mapped. They represent older sediments and igneous rocks that have been divided into the metaquartzite and mafic gneiss groups that were later intruded by granitic rocks represented now by granite and granite gneiss of the third group. A fourth group, made up of migmatites was derived to a large extent from the granitic intrusions. In addition, minor intrusions of granitic dikes, pegmatites, and veins are regarded as genetically related to the main granite bodies. Elsewhere, intrusive bodies of diabase are minor.

The petrographic classification used in this report is similar to that of McKinlay (1956, 1957); the proportions of minerals are visual estimates only (except those given in table 5).

Metaquartzite Group

Rocks of this group are found in several places, as in Rio Pueblo de Taos, Cabresto Creek, and an area between Red River Pass and Costilla Pass. The stratigraphic succession of the members within the group and their relation to rocks above and below are:

Granitic Group	granitic biotite gneiss, type 3 granitic biotite gneiss, type 2	
Metaquartzite Group		graphite mica gneiss
	mica quartzite	
		sillimanite mica gneiss
	muscovite-hematite granulite	
Granitic Group	granitic biotite gneiss, type 1	

TABLE 2—*Stratigraphic Units of the Eagle Nest Area. New Mexico*

Age	Stratigraphic Unit	Thickness (feet)
Quaternary	Alluvium, mudflow	–
	Moraine, terrace gravel	–
	Moreno Valley gravel fill	440+
	High-level gravel	–
	Monzonite porphyry	–
	Quartz porphyry	–
	Biotite granite, quartz veins	–
Tertiary	Rhyolite group	1,365
	Latite group	519+
	Quartz diorite porphyry	–
	Augite diorite porphyry	–
	Andesite group	1,494+
	Hornblende granite	–
	Conglomerate, pyroclastics, siltstone	97
	Poison Canyon Formation	(?)1,000
Cretaceous	Pierre Shale and upper part of Niobrara Formation	(?)900
	Fort Hays Limestone	21+
	Carlile Shale	297
	Greenhorn Limestone	22
	Graneros Shale	400
	Dakota Sandstone	150
Jurassic	Morrison Formation	162+
	Wanakah Equivalent	30
	Entrada Sandstone	100
Triassic	Dockum Group	342
Penn.-Permian	Sangre de Cristo Formation	5,300+
Pennsylvanian	Magdalena Group	2,921+
Mississippian	Tererro Formation	36
	Espiritu Santo Formation	41
Precambrian	Diabase dikes	–
	Migmatite	–
	Granitic Group	
	Pegmatites, quartz veins	–
	Pink biotite granite	–
	Gray granite and gneiss	–
	Granitic biotite gneiss	(?)6,000+
	Mafic gneiss group	7,000+
	Metaquartzite group	5,000

Muscovite-Hematite Granulite

The lowest stratigraphic member of the metaquartzite group is a metasediment and is herein referred to as muscovite-hematite granulite. Exposures extend from Hematite Creek northeastward across Moreno Creek and North Moreno Creek. Excellent exposures of a schistose variety appear in roadcuts along Moreno Creek. The estimated minimum thickness is 400 feet.

The muscovite-hematite granulite is a fine- to medium-grained leucocratic rock, spotted with grains of black hematite up to 7 millimeters in diameter. Hematite and magnetite occur in numerous bands, 5 to 10 millimeters thick. Locally, where the rock is schistose, the hematite is accompanied by knots of green mica 10 to 20 millimeters in size. Mica is also common along joints. Other major light-colored constituents are quartz and feldspar; the rock has an aplitic appearance in non-schistose varieties.

Thin sections reveal a granoblastic mosaic consisting of 35 percent microcline, 30 percent quartz, 25 percent plagioclase, and 2 percent muscovite, together with accessory hematite, sillimanite, and zircon. Grain size ranges from 0.1 to 1.0 millimeters; grain boundaries are interlocking but unsutured. Anhedral microcline is abundant and is a little altered. Quartz is associated with feldspars and commonly has undulatory extinction. Plagioclase (near An_{14}) occurs largely as sericitized and saussuritized grains, although the rim may be clear and unaltered. Relict polysynthetic twinning can be seen in a few specimens. Muscovite laths up to 0.5 millimeters long have a crude parallel arrangement, imparting a weak schistosity to the rock. The hematite grains are crowded with inclusions of quartz, feldspar, and muscovite, imparting a sieve texture to the host mineral (fig. 3A). Some included microcline grains are partially sericitized. Small grains of zircon are distinctly rounded. Magnetite grains 0.1 millimeter in diameter commonly appear at quartz grain boundaries, but, where concentrated into layers, the magnetite is included in quartz grains. Sillimanite occurs in aggregates of fine needles, intergrown with quartz and muscovite and partly developed from the mica. The fibers of the two minerals are associated in swirling bunches and knots.

Where the rock has been deformed, the potash feldspar has been altered to sericite, as noted elsewhere by Harker (1932, p. 173). The percentage of white mica increases, but that of plagioclase remains about the same. The resulting rock is a silvery-gray quartz-mica schist. This phenomenon was observed 2.8 miles southeast of Costilla Pass in a Big Ditch excavation near the contact with biotite gneiss on the leading edge of a high-angle thrust fault.

The granulite is considered to be metasedimentary; the original rock could have been a feldspathic sandstone similar to those described by Harker (p. 246). The significance of abraided zircons will be mentioned later. The occurrence of hematite with inclusions of other minerals is considered a metamorphic effect, due to regional metamorphism or the subsequent intrusion of Precambrian granites.

The granulite is regarded as being stratigraphically below the mica quartzite; however, it may be a lateral equivalent of the lower part of the mica quartzite found in Rio Pueblo de Taos.

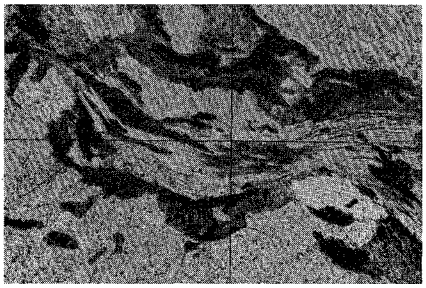
Mica Quartzite

Large exposures of mica quartzite crop out in the southern part of the area along the upper reaches of Rio Pueblo de Taos, in and below the cirques of Blue, Star (Ben Hur), and Waterbird Lakes (fig. 4A). Elsewhere, the quartzite is exposed on the high ridges along Cabresto Creek and in large areas of small hills and ridges north and east of Red River Pass. In the vicinity of North Moreno Creek, a distinct hogback marks the strike of the quartzite and the associated metasediments.

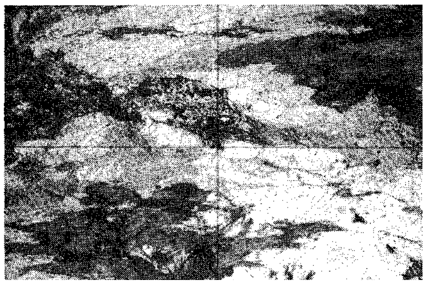
The rock is distinctive gray-white, coarsely crystalline, slabby, and locally massive. The quartz content is about 95 percent. Magnetite-rich layers are common; and parallel flakes of white mica are disseminated throughout the rock. The mica imparts a crude schistosity, not always a reliable indicator of original bedding.

Sutured quartz grains, 0.2 to 4.0 millimeters in diameter, form an interlocking granoblastic mosaic. The long dimensions of the grains are aligned with the long dimensions of the interstitial muscovite flakes. Most quartz grains have undulose extinction; a few are composite. The latter suggests a period of sedimentation and metamorphism recorded only in the presence of cobbles at a few exposures. Grains of magnetite, 0.2 millimeters in diameter, and occasional subrounded zircons, 0.2 millimeters in diameter, are scattered throughout. These minerals are found along quartz-

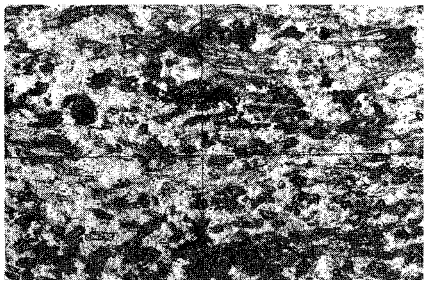
A. *Muscovite-hematite granulite.* Hematite grain under crosshairs has sieve texture. Microcline shows characteristic twins; quartz is light. Plagioclase and muscovite are also present. Texture is granoblastic. Crossed nicols, X 14.



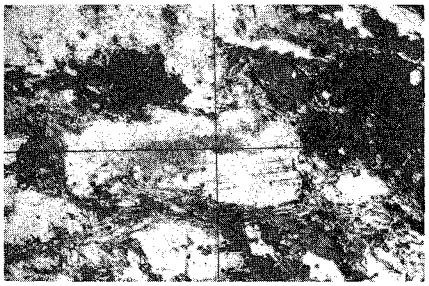
B. *Graphite-mica gneiss.* Dark plates of graphite are intergrown with muscovite under the crosshairs. Also present are quartz and plagioclase. Crossed nicols, X 14.



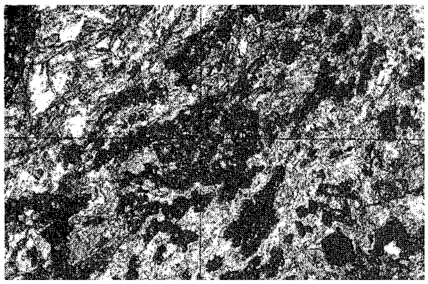
C. *Sillimanite-mica gneiss.* Gray, fibrous sillimanite is intergrown with quartz. Plane polarized light, X 56.



D. *Quartz-biotite schist.* Biotite is in fine gray laths, whereas epidote is dark gray and has higher relief. Light-colored mineral is mainly quartz with some feldspar. Plane polarized light, X 56.

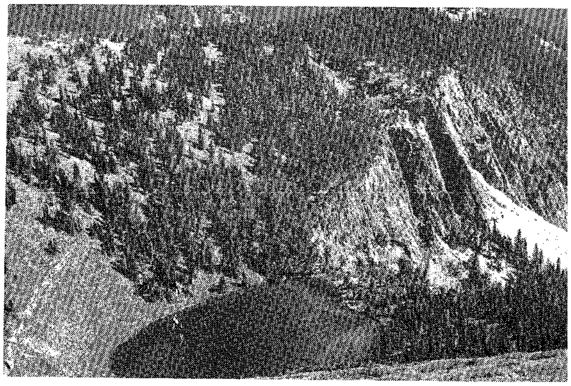


E. *Hornblende gneiss.* Plagioclase under cross-hairs is surrounded by trains of dark hornblende intergrown with some biotite. Light material is quartz and feldspar. Crossed nicols, X 14.



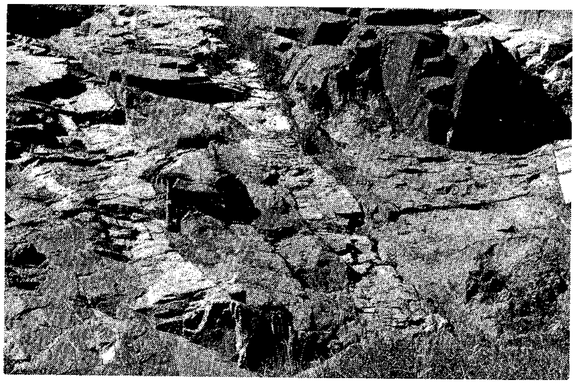
F. *Chlorite schist.* Chlorite is in fine laths intergrown with epidote, which has higher relief. Light material is quartz, and the opaque grains are magnetite. Plane polarized light, X 14.

FIGURE 3—Photomicrographs of metaquartzite and mafic gneiss groups.



A. *Mica quartzite. Star* Lake perched on strongly jointed mica quartzite that forms a precipitous lip to the cirque. The light-colored outcrop in the head of the cirque is the basal bed of the overlying Magdalena Group.

B. *Biotite gneiss.* Summit of Vallecito Mountain. Finely banded, alternating layers of mafic and leucocratic components. Dark patches are moss.



C. *Migmatite.* Head of South Fork. Fine-grained dikes, veins, and veinlets of granite intrude mafic gneiss. Commonly, the intruding material is more irregularly disposed in the host rock.

FIGURE 4—Metamorphic rocks.

grain boundaries or are enclosed within the grains due to recrystallization. Small stout fibers of sillimanite commonly occur between quartz grains. In deformed rock, the grain boundaries are crushed.

Graphite-Mica Gneiss

Graphite-mica gneiss is exposed at a few localities on the north side of Cabresto Creek near its confluence with Bonito Canyon. Overall, the rock is dark gray and has a fine foliated structure. It is composed predominantly of quartz, graphite, muscovite, and albite, in order of decreasing abundance.

This rock type is associated with the mica quartzite; and may be interbedded with the mica quartzite as interpreted by McKinlay (1956, p. 9; 1957, p. 5). In exposures more than 100 feet thick the graphite-mica gneiss commonly predominates.

Quartz grains, 0.5 to 2.0 millimeters in diameter, have sutured edges and commonly display strain shadows. Intergrown with quartz are irregular plates of black graphite, 0.2 to 1.0 millimeters long, that constitute 5 to 10 percent of the rock. These plates are associated with crenulated plates of muscovite and biotite up to 1.5 millimeters long. Some of the graphite occurs along muscovite cleavages (fig. 3B). Anhedral albite (near An_6) occurs in grains 0.2 to 0.6 millimeters in diameter and commonly is developed along quartz grain boundaries.

Sillimanite-Mica Gneiss

This gneiss is found along Cabresto Creek, at Cabresto Lake, and at the base of the mica quartzite between Hematite and North Moreno Creeks. The exposures in the vicinity of Cabresto Creek have an overall drab appearance but exhibit strong foliation and banding. Sillimanite is a distinctive gray white in hand specimens, but in the vicinity of North Moreno Creek, occurs in fine, regular, reddish-brown strands.

In thin section, specimens from Cabresto Creek contain 50 percent quartz, 20 percent sillimanite, 15 percent biotite, 10 percent muscovite, and 2 percent magnetite. Quartz grains, 0.1 to 1.0 millimeters in length, have sutured outlines, exhibit a little strain shadow, and show some cracks. Grains commonly occur in trains or as separate ragged grains surrounded by biotite. Magnetite is associated with and embedded in anhedral masses of biotite. Biotite, up to 1.5 millimeters in length, is commonly chloritized and intimately intergrown with small flakes of muscovite. Both micas are associated with swirling bunches of sillimanite, 2 to 3 millimeters, made up of a plexus of slender needles (fig. 3C). The sillimanite is gray in plane polarized light, has straight extinction, and appears to have developed from mica.

The structure of the sillimanite gneiss examined at the north end of the Moreno Valley is more regular. Trains of quartz, parallel to the plane of foliation, are separated by layers of equal width composed of muscovite and sillimanite. Magnetite is scattered throughout the rock. This gneiss has been mapped with the mica quartzite. Several feet thick, it is commonly overlain in succession by quartz-mica schist of similar thickness and the main body of the mica quartzite.

Also included within the mica quartzite unit are rare bands of garnet-biotite gneiss. One locality is above the Hornet mine in Cabresto Creek. Other constituents of this rock are sillimanite and magnetite.

The mica quartzite here described in Cabresto Creek can be directly correlated with the Cabresto Quartzite named by McKinlay (1956). The coarse-grained quartzite in other parts of the map area is identical in composition and texture, and the correlation is further continued so that the Pueblo Quartzite of Gruner (1920, p. 734) may be equivalent to the Cabresto Quartzite. We believe that a correlation may be possible between the Cabresto Quartzite and the coarse-grained quartzite of the Ortega Formation (Montgomery, 1956) and the quartzite in the Ortega Mountains described by Just (1937) and Bingler (1968). Both the Ortega Quartzite and the Cabresto Quartzite are coarse grained and micaceous and bear sillimanite horizons.

The mica quartzite is estimated to be at least 800 feet thick at the north end of the Moreno Valley and at least 5,000 feet thick in the vicinity of Blue Lake, although in the latter locality the possibility of repetition because of folding cannot be entirely eliminated. This last estimate is similar to that indicated by Gruner (1920). The distance between these localities is about 10 miles and no exposures intervene. Variation in thickness can be explained by a sedimentary facies change. The muscovite-hematite granulite found below the quartzite in the northern locality may be a lateral equivalent of the quartzite found at Blue Lake. Even so, a considerable thickness difference still arises, and one could question whether or not the granitic biotite gneiss below the granulite at the north end of the Moreno Valley is also of sedimentary origin and equivalent, in part, to the lower part of the Pueblo Quartzite. Other lines of evidence suggesting a sedimentary origin for the granitic biotite gneiss are presented later.

Elsewhere, estimates of thickness of the quartzite range from 400 feet in lower Cabresto Canyon (McKinlay, 1957), and between 200 and 1,000 feet in the Latir Peak and Costilla Peak quadrangles (McKinlay, 1956). Montgomery (1953) estimated the Ortega Quartzite to be at least 2,500 feet thick and indicated that the Ortega Formation as a whole has a minimum composite thickness of 6,600 feet. In the Petaca area, Just (1937) indicated an even larger thickness for the Ortega Quartzite; and in the more detailed studies carried out in Las Tablas quadrangle, Barker (1958) cited a thickness between 21,000 and 31,000 feet.

Rocks of this group are of sedimentary origin, in which large thicknesses of predominantly quartz sands, with subordinate shaly and feldspathic layers, have since been converted into mica quartzite, granulite, and sillimanite-mica gneiss respectively.

Mafic Gneiss Group

Quartz-Biotite Schist and Gneiss

Quartz-biotite schist and gneiss are interlayered with other units of the mafic gneiss group. Much of the biotite-bearing rock is found around Wheeler Peak and localities adjacent to Lake Fork, Rio Hondo, and places farther north. This unit is the most widespread lithology of the mafic group.

In the field, the schist is fine grained, dark gray and exhibits a micaceous sheen. The gneissic variety is coarse grained, having distinctly developed mafic and leucocratic bands and lenses rich in biotite and quartzofeldspathic material, respectively. Hornblende is conspicuously absent from these rocks. Seen under the microscope, the schist contains 35 percent quartz, 30 percent epidote, 25 percent biotite, and accessory amounts of plagioclase, apatite, magnetite, and garnet (?). Quartz grains, 0.05 to 1.0 millimeters, occur either singly or in lenticular mosaics alternating with parallel biotite laths that produce a fine regular schistosity (fig. 3D). More rarely, the biotite flakes are arranged in trains around quartz grains. Biotite laths, 0.1 to 0.2 millimeters in length, are pleochroic (X = light brown, Y = dark green). Epidote occurs as discrete grains associated with biotite or in irregular trains. Plagioclase is not everywhere present but has been detected as small grains, 0.2 to 0.3 millimeters in length, associated with quartz. Scattered apatite and magnetite occur throughout the rock. A few small grains of reddish brown garnet (?) were detected in the sections examined.

The quartz-biotite gneiss has a similar composition, although plagioclase is better developed and garnet (?) is absent. In the field, the rock can be recognized by the typical porphyroblastic development of plagioclase and associated quartz, surrounded by black trains of biotite.

Seen in thin section, the porphyroblastic structure consists of aggregates of small quartz grains, 0.2 to 1.0 millimeters, intergrown with and surrounding larger plagioclase grains up to 4.0 millimeters in length. The plagioclase porphyroblasts usually lie at a distinct angle to the plane of foliation and, on occasion, are nearly perpendicular to it. Surrounding the light-colored constituents are trains of biotite 0.1 to 1.0 millimeters in length. Epidote is embedded in and replaces plagioclase; elsewhere, epidote is associated with biotite. Alteration is mostly from biotite to chlorite, with the distinctive anomalous Berlin Blue color noticeable from time to time.

In areas where shearing stress continued after porphyroblastic development of plagioclase, a type of augen gneiss resulted—as at Bull-of-the-Woods, east of Twining. Here the feldspar has corroded edges and quartz has been redistributed in the corners of the "eyes." Elsewhere, quartz grains tend to be flattened and occur in curving trains around the augen or as discrete stringers. The mafic component is primarily biotite, with associated granular aggregates of epidote. Subsidiary quartz grains are interstitial to the mafic minerals. Another type of quartz-biotite gneiss was observed at the summit of Vallecito Mountain: a finely banded gneiss with regularly disposed alternating parallel layers of mafic and leucocratic components. The width of the bands average about 5 millimeters. The rock is fine grained but has a micaceous sheen due to the dark bands (fig. 4B).

Biotite, one of the major minerals, occurs as subhedral laths from the smallest discernible size to 0.2 millimeters in length. It is associated with an equal amount of epidote 0.2 millimeters in size and a few grains of plagioclase 0.3 millimeters in length. The leucocratic bands are composed of interlocking grains of quartz, anhedral microcline, and epidote, all 0.2 millimeters in size, and a few grains of biotite. Some cryptocrystalline material, perhaps clay, is between the grains.

Hornblende Gneiss and Schist

Subordinate to the biotite schists and gneisses are a series of units containing amphibole, in which biotite is present only in minor proportions. Hornblende gneiss is a coarsely foliated rock consisting of strands of dark green to black hornblende, alternating with lenses of gray-white leucocratic material. The gneiss is apparently interbedded with the biotite-rich rocks previously described.

The mineral composition consists of 30 percent hornblende, 25 percent quartz, 25 percent plagioclase, and 10 percent biotite, with accessory amounts of epidote and magnetite (fig. 3E). Hornblende occurs in subhedral laths up to 2 millimeters in length. Pleochroism is olive green to dark green. Quartz, in grains up to 0.8 millimeters is anhedral and associated with plagioclase. The laths of plagioclase are as much as 3 millimeters long and have a composition in the oligoclase-andesine range. Plagioclase is altered to sericite and clay. Accessory minerals include small laths of biotite and scattered grains of epidote and magnetite.

Outcrops of a massive, medium-grained, dark rock occur in the West Fork of Red River, adjacent to the Relica Peak rhyolite. They form cliffs with blocks of loose material below. Thin sections reveal hornblende, quartz, biotite, calcite, and magnetite. No feldspar was detected, but it may have been replaced by calcite. The matrix is inequigranular and consists of quartz grains with lesser amounts of biotite, hornblende, and calcite.

A similar rock is found in some cuts along the newly paved road above Red River. Here the mafic rock has been intruded by Tertiary latite. In this rock, however, calcite is absent. These two rock types could be called either hornblende schist or, perhaps more aptly, amphibolite.

Amphibolite

Areas of this unit appear on the high ridge immediately north of Rio Hondo, near Twining, and on the high drainage divide in Placer Fork, three quarters of a mile southwest of Gold Hill.

This lithologic unit occurs in massive outcrops, is dark in color, well jointed, and tending to break loose as angular blocks and pieces on hillsides and scree slopes. Hand specimens consist of black hornblende, 2 to 3 millimeters in size, intergrown with white plagioclase and quartz.

In thin section, euhedral laths of hornblende form about 45 percent of the rock and appear quite fresh. Plagioclase, up to 1.5 millimeters in length, is much altered to sericite and clay and tends to be replaced by minute grains of quartz. Subhedral grains have a composition of andesine, An_{35}-An_{43}. Quartz, up to 0.5 millimeters in size, occurs between hornblende and plagioclase. A little magnetite may be present. The texture is reminiscent of that in diabases and this, coupled with the uniformity of outcrop, suggests that the rock type developed from basic igneous rocks.

Hornblendite

There are two areas of this monomineralic rock: the first is near the summit but on the south side of Fairview Mountain; the second is high on a ridge one mile east-southeast of the Questa mine.

In the field, the rock is dark greenish black and massive. No minerals other than hornblende were seen in thin section. Ragged laths of hornblende, 0.5 to 6.0 millimeters in size, are randomly intergrown. Pleochroic colors are: Z = dark green to green, X = green to pale brown. This rock is probably a representative of ultrabasic intrusion.

Tremolite-Actinolite Schist

An area of this rock was found along the Gold Hill trail near the Commodore prospect. In hand specimen, it is fine grained and consists of a felt of greenish-black amphibole needles, together with small grains and lenticles of leucocratic material. The rock is schistose.

In thin section, the amphibole needles, up to 1 millimeter in length, have an extinction angle $Z^{A}C = 18°$, and are pleochroic in shades of green. They form about 40 percent of the rock and are regarded as intermediate in composition in the tremolite-actinolite series (Winchell and Winchell, 1959, p. 243, fig. 309). A little chloritized biotite, with ragged outlines, and magnetite form the other dark constituents. Quartz grains 0.1 to 0.2 millimeters in diameter, together with small grains of calcite, are present between the amphibole needles. Epidote is also present. The lenticles of leucocratic material are made up of larger grains of calcite and some quartz, together with a little euhedral plagioclase.

This rock is thought to have been derived from impure calcareous sediments, subsequently regionally metamorphosed and represented now by the minerals calcite, tremolite actinolite, and epidote.

Chlorite Schist

Outcrops of a fine-grained, dark-green, and locally contorted schist occur along the southeast bank of Rio Lucero near Larkspur Point. A somewhat similar rock was found in Italian Park, south of the old, unpaved road across Red River Pass.

The mineral constituents, as examined in thin section, include 40 percent chlorite, 25 percent epidote, 25 percent quartz, and 10 percent magnetite. Small veinlets and clots of calcite are believed to have been introduced at a later stage, as they cut across the plane of schistosity.

Chlorite is pleochroic from green to nearly colorless; extinction is parallel or nearly so. It occurs in fibrous linear trains with individual fibers about 0.2 millimeters in length sometimes joining to form larger masses. Epidote occurs in linear aggregates of grains 0.5 to 1.0 millimeters long. Magnetite is associated with chlorite and epidote and may be up to 0.5 millimeters in diameter. Together, these minerals tend to make up fine lenticular and discontinuous bands 0.2 to 0.5 millimeters wide. Quartz, the main leucocratic mineral, is associated with minor amounts of sericite with which it forms discontinuous light-colored bands containing minor amounts of chlorite, epidote, and magnetite (fig. 3F). The rock is believed to have been developed from noncalcareous sediments such as shale.

In the specimen from Italian Park, calcite grains occur in lenses up to 13 millimeters long. They are enveloped by mafic minerals, particularly chlorite, which occur in swirling masses. In smaller lenses, epidote commonly rims the calcite and appears to have developed from it. The calcite in these specimens seems to be an integral part of the rock.

In Cimarron Creek canyon, a quartz-sericite-chlorite schist lies partly within the map area. In the field, this variety is dark green, although it may have a characteristic sheen. The essential mineral components include 40 percent quartz, 30 percent light-colored mica, 15 to 20 percent chlorite, and 3 to 5 percent iron ore. The schist is very fine grained, with mica needles up to 0.1 millimeters long. The mica is aligned. To a lesser extent, chlorite trains around the small quartz grains.

The thickness of the mafic gneiss group as a whole is unknown because the base is not exposed, even in the most deeply incised canyons. Rafts found above Precambrian granite represent only a small part of the original thickness. The mafic gneiss does occur, however, over wide areas of considerable relief, and is estimated as at least 7,000 feet thick, perhaps much more. Within the map area, it is found above and below the metaquartzite group, perhaps with the greater thickness above.

McKinlay (1957) noticed similarities between these rocks and the Vadito Formation described in the Picuris Range by Montgomery (1953, p. 21-35). We support this suggestion, although apparently the conglomerate and quartzite at the base in the Picuris Range are absent in the Taos Range. Also, the metamorphic grade of the schists and gneiss is lower in the rocks described here and elsewhere north of the Picuris Range. Some differences in composition of the original sediments are probably also reflected in differences in the metamorphic rocks in these two areas.

Granitic Group

Gray Biotite Granite and Granitic Gneiss

Gray biotite granite has little or no foliation and tends to be massive. It is found only in areas of limited extent, but one of the larger outcrops lies along the north bank of Martinez Canyon. By comparison, the granitic gneiss has a similar color and composition and is regarded as a gneissic equivalent of the gray biotite granite. Within the map area this gneiss is widespread, being found north of Rio Hondo, around the upper part of Deer Creek, north of Gold Hill, and in the vicinity of the Questa mine.

In the field, the gray biotite granite is a massive inequigranular, medium- to fine-grained rock, composed of quartz and feldspar and sparse black biotite. Although the color is usually gray, it is less frequently pale pink. Foliation may be absent, although the gneissic variety has all gradations. Occasionally, it can be mistaken for Tertiary hornblende granite, but in hand specimens, the rock is not so fresh and usually not so coarse grained as the later granite. In addition, the absence of hornblende is distinctive. Association with the gneissic phase should be regarded as characteristic. Reasonably good outcrops occur along the south-facing slope of Martinez Canyon where the vegetation is stunted.

Seen under the microscope, the rock is typically composed of 35 percent microcline, 35 percent quartz, 20 percent plagioclase, and 5 percent biotite, with accessory amounts of magnetite. Minor amounts of garnet (?), epidote, muscovite, and zircon may also be present. Grain boundaries are commonly sutured and granulation is fairly common. Texture is allotriomorphic-seriate (fig. 5A). Microcline, 0..2 to 2.0 millimeters in diameter, is commonly microperthitic. Quartz, 0.1 to 0.5 millimeters in diameter, displays undulatory extinction. Plagioclase, An_6-An_{17}, is usually oligoclase. Biotite, 0.1 to 2.0 millimeters in size, is pleochroic, light to dark brown, and commonly in aggregates. It may be altered to chlorite when commonly associated with magnetite dust and occasionally coarse muscovite. Epidote, if present, occurs in granular masses intergrown with quartz and feldspar. Small grains of garnet (?) are rare.

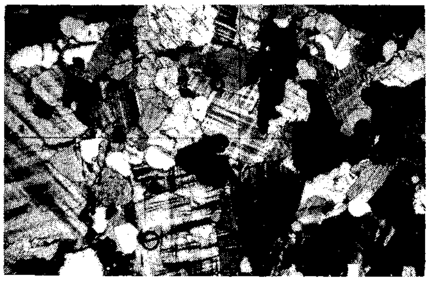
The granitic gneiss is characterized by strong foliation but has similar color and composition. Streaks of black biotite alternate with aggregates of light-colored felsic material. Thin sections reveal microcline, orthoclase, quartz, plagioclase, biotite, muscovite, and magnetite. Potash feldspar up to 2 millimeters long occurs in porphyroblasts with corroded edges. The long axis of the grain is commonly aligned parallel with the plane of foliation, although it may be at an oblique angle. Small included grains of quartz are common and the extinction of the feldspar may be undulatory. Quartz grains 0.1 to 0.4 millimeters in size occur in trains swirling around the potash feldspar porphyroblasts. The long axis of the grains is end to end and parallels the foliation. Anhedral grains of plagioclase, An_9-An_{12} , 0.1 to 0.4 millimeters long are oriented in various directions to the foliation but are believed to have porphyroblastic development. Occasionally, plagioclase appears to have partly replaced potash feldspar. Biotite flakes, 0.1 to 0.5 millimeters in size, are pleochroic light brown to green. Flakes are subparallel and occur in aggregates. Biotite is frequently associated with muscovite and magnetite and is intergrown with quartz. Epidote, where developed, occurs in granular aggregates or single subhedral grains. Small prisms of zircon are also present.

Extreme cataclastic deformation has caused mineralogical changes, as Harker (1932) noted elsewhere. The potash feldspar in some instances has been wholly destroyed, and the rock has become more like a quartz-mica schist. Quartz grains in such rocks are crushed and set in a fine matrix of smaller grains, producing a mortar structure. In hand specimen, these rocks are lighter in color and finer grained than the typical gneissic variety. Some have been formed by local intense shears in the gray biotite granite.

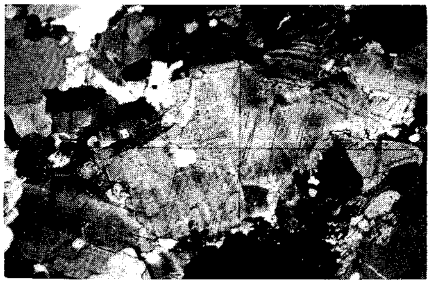
Pink Biotite Granite

Pink biotite granite, associated with the gray varieties described above, constitutes a third distinctive type. Outcrops occur in four areas. The first is in the highly dissected country in and around Wheeler Peak wildlife area. Exposures were observed on the west side of Lake Fork; on the east side of the same valley between Frazer Mountain and Mount Walter; along the drainage divide between Middle Fork and East Fork of Red River; near Bear Lake; and on the drainage divide between Rio Lucero and Rio

A. *Gray biotite granite.* Intergrowth of microcline, plagioclase, and quartz. Irregular and sutured grain boundaries are typical of this granite. Crossed nicols, X 14.



B, *Pink biotite granite.* Microcline, with polysynthetic twinning in two directions, is abundant. Plagioclase shows twinning in only one direction. Laths of gray biotite are in southeast quadrant; quartz grains are light and dark. Crossed nicols, X 14.



C. *Granitic biotite gneiss.* Large grains of microcline at center of the field are flanked by small laths of biotite on the horizontal crosshair. Plagioclase is in northwest quadrant; quartz is gray and white. Typically, grains have mutual boundaries. Crossed nicols, X 14.

FIGURE 5—Photomicrographs of granitic group.

Pueblo de Taos. Farther west, this granite is found on the southern bank of Rio Lucero and is associated with the gray granite on the drainage divide between Rio Lucero and Martinez Canyon, near the confluence of the two streams. The second area is on the west side of the Moreno Valley at Lakeview. The third area is on the east side of the Moreno Valley along the southeast side of Eagle Nest Lake. The fourth area is in and around Tolby Creek in the extreme southeast corner of the map area. The varieties at the last three places are similar.

In the field, the rock is easily recognized by its strong pink color. In the Wheeler Peak wildlife area, most exposures are above timberline and unusually good. Along the flanks of the Moreno Valley, contacts tend to be obscured by forest, although isolated cliffs of the granite can be found. Hand specimens show a medium- to fine-grained, roughly equigranular, pink, biotite granite. Biotite plates are small and shining. Characteristically, the granite is massive, particularly in the Moreno Valley, but on occasion a faint foliation is apparent. The red color is apparently due to microcline as noted in the Picuris Range by Montgomery (p. 45) although the same mineral is present in the gray granite and granite gneiss.

Thin sections reveal a hypidiomorphic-seriate texture. Grain size ranges from 0.1 to 0.5 millimeters (fig. 5B). The essential components include 30 percent microcline, 35 percent quartz, 25 percent plagioclase, and 3 percent biotite, with accessory magnetite and rare apatite and zircon. Untwinned potash feldspar is fairly common in the sections examined and is regarded as orthoclase. Subhedral to anhedral grains of microcline and string-type microcline microperthite .occur throughout the rock. Quartz grains are irregular in shape and are associated with microcline and plagioclase. Undulatory extinction is common. Plagioclase laths tend to have stronger idiomorphism and have a composition in the albite-oligoclase range, An_6-An_{14}. Small biotite flakes, 0.2 millimeters long, with light-brown to dark-brown pleochroism, grow along grain boundaries of the other minerals. Specimens from the Moreno Valley show that both potash feldspar and plagioclase have undergone little or no alteration and that cataclastic effects are negligible. Elsewhere, deformation has been recorded in some sections examined where quartz and feldspar grains tend to be aligned in trains separated by fine masses of light and dark mica accompanied by a little epidote. Biotite may be partly chloritized. Where deformation is extreme, a mortar structure prevails; biotite is completely replaced by chlorite and is disposed in irregular shreds associated with finely comminuted felsic material, all of which occur between larger angular grains of quartz and feldspar. A micaceous variety is common along Tolby Creek and Cimarron Canyon and apparently is associated with faulting. It occurs with intervals of gray quartz-mica schist. This schist is composed of 70 percent quartz, 15 percent muscovite, and 5 percent microcline, with accessory amounts of hematite and zircon. Quartz grains are often cracked, and fragments break off and form a matrix between the larger quartz and mica grains.

Many examples of the intrusive effects of the granites into the mafic gneiss group were observed, but only a few are described here. At the contact in Gavilan Canyon, on the south side of the granite body, the mafic rocks are silicified and sheared. On the high ridge west of Long Canyon is a gradational contact over a distance of 15 to 20 feet; whereas opposite Twining, a zone of hybrid rock having a width of one foot or more contains streaks of mafic material on the granite side of the contact. Elsewhere at this last locality the contact is distinctly migmatitic.

On the trail from Bull-of-the-Woods to Wheeler Peak, a sharp contact between granite and mafic gneiss lies about 1,000 feet north of the summit of Mount Walter. Only one or two veins of granitic material intrude the gneiss. At other places above timberline, dikes and apophyses of granite invade the dark host rocks. Where this phenomenon is intense, migmatites are formed.

On the west side of Rio Lucero, exposed in the high wall of the valley, and immediately south of Bear Lake, a large granite sill is believed to have been injected into the mafic gneiss. A later east-west fault has brought down the rocks on the south side, and the plane of the fault has been occupied by a diabase dike approximately 80 feet wide. The lower contact of the granite sill with chlorite schist is sharp, although the rocks are sheared and silicified. The diabase dike has a sharp contact where it intrudes the granite. At a later period, rhyolite dikes intruded the pre-existing rocks. These relationships are shown on the geologic map (pl. 1).

Because of similarities of composition, texture, and structure, the three varieties of granite and granite gneiss described in this group are believed to be equivalents of the Embudo Granite (Montgomery, p. 37). The leucocratic phase in the Picuris Range is more coarse grained than the pink biotite granite in the Eagle Nest area. Otherwise they are similar.

The granites intrude the mafic gneiss group and are themselves intruded by diabase dikes, probably late Precambrian. The granites are unconformably overlain by sedimentary rocks of Upper Paleozoic age in the southern part of the map area and by Tertiary volcanics in the vicinity of Goose and Pioneer Creeks.

The pegmatites of the Picuris Range are believed related to the Embudo Granite which was first dated by Ahrens (1949, p. 225) as 800 m.y. However, Aldrich, and others (1958) and Herzog and others (1960) have dated this pegmatite as 1,250 to 1,350 m.y. using the strontium-rubidium and potassium-argon methods. Thus, by analogy, the granites of the Taos Range may have a similar Precambrian age, and correspond to some of the younger granites of the southern Rocky Mountains (King, 1969). These were emplaced in times corresponding to the Elsonian (1,460-1,280 m.y.) and Grenville (1,150-800 m.y.) events. Among them are the Sherman, Silver Plume (1,450-1,350 m.y., late tectonic to post tectonic) and Pikes Peak (1,000 m.y.) granites in Colorado (Tweto, 1968).

Granitic Veins, Pegmatites, and Quartz Veins

Granitic veins are distributed around Precambrian granite, particularly at Vallecito Mountain, and at other localities in the southwestern part of the area. The veins vary in width from a few inches to a few feet; only the largest are shown on the geologic map. The veins at Vallecito Mountain appear to be dipping at a shallow angle, and some are regarded as formed by intrusion rather than by segregation from the surrounding gneiss; contacts with the mafic gneiss are sharp.

The granitic veins resemble the gray granite, are medium to fine grained, and consist of quartz, orthoclase, plagioclase, and magnetite. Grain boundaries are sutured, and mineral grains may be aligned. Most of the feldspar has been sericitized. Plagioclase is in the albite-oligoclase range. Accessory amounts of magnetite and chlorite are also present.

Relatively few pegmatites are found associated with the granites in the western part of the map area. Coarse aggregates of pale-pink microcline, quartz, and greenish muscovite are the major constituents of these simple pegmatites. In general, they are only a few feet wide and may be much less. The largest observed had an apparent width of 60 feet and was traced from a point one mile south of the Questa mine intermittently over a distance of about 7,000 feet. The strike is east-northeast. Usually lengths vary from 200 and 300 feet to 1,000 feet. The trends noticed are northwest, northeast, and east-northeast.

As indicated previously, the pegmatites may be genetically related to the granites of Precambrian age. They cut these granites in addition to the mafic schist and gneiss. As far as could be ascertained, the pegmatites do not contain any minerals of value; only a few in the Hematite Creek district have been prospected.

Some, if not most, of the quartz veins in the map area are believed to be Precambrian in age. The veins trend between northwest and northeast. Overall distribution is in areas of Precambrian granite and granite gneiss; but the veins intrude all other major Precambrian rock types. A few veins intrude the volcanic rocks and must necessarily be Tertiary in age, possibly related to the Questa mine and Red River stocks. Dimensions are variable. Width is usually a few feet and length may reach 400 or 500 feet. The larger veins are usually barren and are almost exclusively made up of milky-white quartz. In the northeasterly striking veins around Gold Hill, magnetite is common. Copper mineralization is associated with veins in northeasterly shears in the Twining district. In addition, Park and McKinlay (1948, p. 18) noted that pyrite and tourmaline also occurred in veins of Precambrian age. In contrast, the gold-pyrite and molybdenite-bearing veins in the Red River district belong to the Tertiary period of mineralization.

Granitic Biotite Gneiss

A large area of granitic biotite gneiss is exposed over the northern part of the Moreno Valley and Costilla Pass. The biotite gneiss is described herein by reference to three types believed to be closely related. Their composition is granitic, very similar to the gray granitic gneiss previously described; they differ by being apparently unrelated to, or associated with, intrusive granite bodies.

The first type is a medium- to coarse-grained granitic gneiss, containing pink potash-feldspar, cream-colored plagioclase, colorless quartz, and streaks of black biotite. It occurs in numerous outcrops in the low, wooded slopes on the west side of the Moreno Valley, south and west of Moreno Creek. At some localities south of Hematite Creek, a few red garnets were observed. The overall color of the rock is pink to pale pinkish-brown, although not nearly so intense as the pink biotite granite. Foliation is generally well marked.

Seen under the microscope, the texture is an interlocking mosaic of mineral grains, with mutual and sutured grain boundaries (fig 5C). Essentially, the minerals present include 40 percent quartz, 30 percent microcline, 20 percent plagioclase, and 5 percent biotite. A few grains of an untwinned feldspar (a = +11°) suggest orthoclase is present in small quantities. Grain size varies from 0.3 to 2.0 millimeters. Microcline is anhedral but quite fresh. Quartz grains are very irregular and show some undulatory extinction. A few minute grains are intergrown with the feldspars. Plagioclase has a stronger crystal outline and displays weak zoning; it is oligoclase, near An_{14}, and there is little or no alteration. Biotite with pleochroic colors ranging from light brown to dark brown occurs in laths 0.3 to 1.0 millimeters in length. There is no alteration. Accessory minerals include hematite occurring in grains up to 2.0 millimeters in diameter and may display a sieve texture. Also a few minute grains of magnetite and a few subrounded grains of zircon are present.

The second type of biotite gneiss, north of the metaquartzite group, is exposed in a belt between Hematite and North Moreno Creeks. It has a fine gneissic structure and weathers brown. The major constituents are microcline, quartz, plagioclase, and biotite, in decreasing order of abundance. Subrounded grains of zircon are fairly numerous. Occasionally, large grains of magnetite, up to 1.5 millimeters in diameter, are present and may incorporate other small mineral grains. Oglioclase, An_{17}-$An_{22,}$ commonly shows a rim of more sodic material. In rare instances, there is a myrmekitic intergrowth with quartz. The texture is hypidiomorphic-granular, and grain boundaries are mutual but not sutured. Minor layers of mafic schist appear within this gneiss. A thin but persistent layer occurs immediately above the mica quartzite ledge where it crosses North Moreno Creek. Similar layers are found within the gneiss on the southern limb and around the nose of a large synclinal fold. These mafic layers appear identical with the biotite schist previously described.

These two types of biotite gneiss are quite close in essential mineral composition, and both contain large grains of iron ore and rounded zircons. Texture and structure are also similar.

The third type of biotite gneiss lies along the axis of the large synclinal fold. Outcrops appear in North Moreno Creek half a mile south of Costilla Pass and along the drainage divide to the northeast. This lens-shaped area is three miles long by about three quarters (20f a mile wide at its maximum development.

The essential constituents are microcline, quartz, plagioclase, and biotite. Microcline occurs in grains up to 3 millimeters in size, and quartz grains are irregularly shaped. Plagioclase is a calcic oligoclase, An_{28}, found in laths about 0.5 millimeters. Biotite may be altered to chlorite and magnetite, and occurs in irregular masses. This type is believed to be migmatitic in part and consists of irregularly shaped masses of granitic material, some of which are quite angular, within a host gneiss containing more biotite, hence is more mafic.

Whether the granitic biotite gneisses are metasedimentary or metaigneous facies is unknown. The mineralogy, especially in the first two types, is similar to the pink biotite-granite at Lakeview and on the eastern side of the Moreno Valley. The location of the first type of gneiss on the western side of the Moreno Valley is analogous to that occupied by the pink biotite-granite at Lakeview. This observation, coupled with the common pink color, could lead to a conclusion that the biotite gneiss is a foliated equivalent. However, the presence of rounded zircons suggests a sedimentary origin, although their recognition in thin section is in some doubt according to Poldevaart (1956, p. 529). The presence of grains of hematite, similar to those seen in the muscovite-hematite granulite, is considered another factor in favor of a metasedimentary origin. The layers of biotite schist in the second type must also lend further support to this conclusion, particularly because igneous rocks do not occur within the area. The migmatitic character of the third type does show that the rocks were related to igneous activity to some extent, although the outcrop pattern suggests that the host material was controlled by sedimentary structures, and, in fact, occupies the core of the large synclinal fold. The original sediments were quartzofeldspathic, although these minerals may have been introduced by granitization phenomena adjacent to meta-quartzite and mafic gneiss groups of sedimentary origin in a manner similar to that envisaged by Ramberg (1952, p. 238).

In conclusion, a sedimentary origin is tentatively advanced. By so doing, the first type becomes the lowest metasedimentary rock in the entire area mapped. It occurs below the metaquartzite group, whereas the second and third types are stratigraphically higher. Markers are lacking in the first type, and its attitude, other than the position it occupies in the metasedimentary sequence, is unknown. The probable thickness of the two other types is about 5,000 feet. Therefore, the combined total thickness probably reaches 6,000 to 7,000 feet.

Migmatite Group

Migmatites occur around the margins of Precambrian granite bodies. The term as used here is similar to that of Turner and Verhoogen (1960, p. 370) in which a granitic component and a metamorphic host rock are mixed so as to be recognized megascopically . In the Eagle Nest area, the Precambrian granites intruded rocks of the mafic gneiss group, thereby producing migmatites.

A northeast-trending belt of this rock crosses Lake Fork. Commonly, migmatite zones map out as transitions between mafic gneiss and granitic rocks, as in Lake Fork. Smaller areas of migmatite were again seen on the drainage divide between Martinez Canyon and Rio Lucero. Areas of mixed rock appear more commonly associated with the pink biotite-granite than with the gray granite and granite gneiss.

In the field, the mixing of the two rocks is on various scales. At Frazer Mountain, bands of leucocratic and mafic gneiss vary in width from a few inches to several yards. Within these bands, the two components may be further mixed, but one type predominates over the other. At other places, the mixing is not so regular; the mafic gneiss is silicified and intruded by small tongues of pink-granite material similar to that found in the main body of the pink granite. Both types of migmatite are, however, believed to conform to the migmatite production outlined by Turner and Verhoogen (p. 373) shown in Figure 4C.

On the western bank of the East Fork of Red River, tongues of granite have intruded brecciated mafic gneiss. Reddish-pink potassic feldspar introduced into the gneiss is easily seen in hand specimen. In a thin section of the mafic gneiss, the main constituents of the original rock are believed to have been biotite, quartz, and plagioclase. Alteration effects produced are the chloritization of biotite and epidotization and sericitization of plagioclase. Orthoclase has replaced plagioclase. Quartz, also believed to have been introduced, is associated with orthoclase; quartz invades and transects all the other minerals. These effects are believed to represent the hydrothermal alteration that accompanies potash metasomatism and silicification during the formation of migmatites. Similar effects were observed by Park and McKinlay (1947) during work in the Red River and Twining mining districts. They state that bright, salmon-colored feldspars with quartz were noted along narrow cracks, either parallel or transverse to the foliation of the mafic metamorphic rocks. The process became more intense until the resulting rock resembled a gneissic granite. The same authors (1948) referred to a "contact" zone between Precambrian granite and country rock that has a width of more than one mile. The present writers believe that Park and McKinlay were referring to the migmatitic and metasomatic effects outlined here.

Although these effects are easily recognized near the granitic bodies, they become increasingly difficult to distinguish at a distance from the intrusive centers. The limit of the migmatite zone has been mapped where no obvious intrusion of granite material could be detected and where no pink potash feldspar was seen developing in the mafic gneiss.

In the undisturbed mafic gneiss, porphyroblastic development of feldspar is common, together with banding brought about by segregation of light and dark components within the gneiss during metamorphism. These rock types are not considered migmatites, as no intrusive effects were noticed, and are referred to as banded gneiss.

Diabase Dikes

Although diabase dikes occur in Precambrian terrane in the southwest part of the area, they are noticeably absent from the large tracts of biotite gneiss in the northeast part.

These dikes are readily recognized by their dark-brown to black color, medium grain size, blocky fracture, and high specific gravity. Float is readily identifiable in talus slopes and can be traced to the exposed rock outcrop. The dikes vary in width from a few feet to a maximum of about 80 feet. Length ranges from about 500 feet to more than a mile. The latter figure is based on estimates where the dikes cross cirques at the head of Lake Fork, appearing in the walls but disappearing under moraine in the cirque basin. A preferred trend is east-northeast, although many are randomly oriented.

In thin section, the ophitic, diabasic texture is immediately apparent, being produced by the random orientation of plagioclase laths. Other minerals recognized were pyroxene, biotite, quartz, magnetite, ilmenite, apatite, and sometimes pyrite. Alteration minerals are sericite, chlorite, and calcite. Plagioclase occurs in subhedral laths 0.1 to 0.3 millimeters in length, and is in the oligoclase-labradorite range, An_{29}-An_{46}. Alteration is partial to fine sericite. Pyroxene has been determined on morphological evidence alone. In the sections examined, it has been replaced by chlorite, sericite, and calcite. Quartz up to 1 millimeter in size, occurs in irregularly shaped grains partly resorbed. They are interpreted as xenocrysts, caught up during emplacement of the dike in a manner similar to that described by Hatch, Wells, and Wells (1949, p. 300). Ore minerals are magnetite, ilmenite, and occasional pyrite. Magnetite grains are commonly scattered throughout the rock; apatite is rare. Wedge-shaped areas between the plagioclase laths are greenish and are believed to represent alteration products, possibly uralite after pyroxene.

The dikes intrude the granitic rocks but not the overlying Mississippian rocks and hence may be very late Precambrian in age.

Metamorphism

The Precambrian mafic rocks have been subjected to low-grade regional metamorphism, in places approaching medium-grade. The metaquartzite group, on the other hand, appears to have certain characteristics of high-grade regional metamorphism. Contact metamorphism, related to the emplacement of granite in batholithic proportions, soon followed. The exact relationship is not clear, but the development of foliation in some of the granite bodies suggests that the compressive forces of regional metamorphism had not entirely relaxed during the later period of intrusion.

Regional Metamorphism

Rocks of the mafic gneiss group belong to the chlorite and biotite zones of regional metamorphism in the classical sense. The lowest grades are in the chlorite schist, which is characterized by chlorite, epidote, and quartz, and by the tremolite-actinolite schist that contains tremolite (actinolite), epidote, calcite, and quartz, as indicated by Turner and Verhoogen (p. 533-541). These rocks have well-developed schistosity, characteristic of low-grade regional and dislocation metamorphism.

Of somewhat higher grade are the biotite schists and gneisses represented by biotite, quartz, and epidote (and plagioclase). The hornblende gneiss contains hornblende, plagioclase, epidote, and quartz (and biotite); and the amphibolite is represented by the association of hornblende and plagioclase (and quartz).

In the metaquartzite group, a high grade of regional metamorphism is indicated by sillimanite, but, curiously, no other high-grade indicators are present.

In the Picuris Range, Montgomery (p. 71) recognized in the Ortega Formation the presence of sillimanite that he believed had a hydrothermal origin, as well as that formed under strong regional stress. Using the same criteria, both types of sillimanite are recognized in units of the metaquartzite group in the map area. Sillimanite, in swirling bunches that partly cross the foliation, possibly hydrothermal in origin, is found in the muscovite-hematite granulite and the sillimanite gneiss. On the other hand, the small stout laths of sillimanite found parallel to the foliation, as seen in the mica quartzite and in the sillimanite gneiss horizon below, in the vicinity of Hematite and North Moreno creeks, is considered a product of regional metamorphism. The absence of other high-grade indicators is puzzling, although they may have been destroyed after formation.

Montgomery (p. 71) demonstrated the classical principle that the stratigraphically lowest rocks in the Picuris Range alone contain the high-grade metamorphic minerals. Since temperature and pressure are the main physical conditions governing metamorphism, some general connection between depth of burial of rocks at the time of transformation and the mineral assemblages produced is to be expected, as Fyfe, Turner, and Verhoogen (1958, p. 4) indicated.

Possibly the quartzite was one of the stratigraphically lowest horizons within the metasedimentary rocks. The mafic gneiss group would then be considered stratigraphically higher by virtue of its lower metamorphic grade and is in an analogous position to the Vadito Formation in the Picuris Range. The two types of sillimanite strengthen the proposed correlation of the Cabresto Quartzite with the Ortega Quartzite.

The metamorphic grade of the granitic biotite gneiss is less easily explained. Garnet was infrequently observed in hand specimen and none was seen in thin section. Its presence, though, would suggest only a medium grade, although potash feldspar indicates a high grade. This is compatible with the stratigraphic position of type 1 below the metaquartzite group and possibly type 2, which is above. The migmatitic type at the core of the fold is problematical; its hybrid character suggests that it may represent a contamination of the lowest part of the overlying mafic gneiss group. Harker (p. 247) showed that the regional metamorphism of quartzose-feldspathic sediments is often arrested at the biotite and garnet-granulite stage, or a variety rather rich in magnetite. Obviously more data are needed before a rigorous interpretation can be attempted.

Contact Metamorphism

The production of migmatites around the lobes of granite bodies at the contact with mafic gneiss has already been discussed, mainly from a structural point of view, although the accompanying metasomatic effects were indicated. The principal materials introduced were potash and silica, accompanied by alteration phenomena that include the chloritization of biotite and the replacement of plagioclase by sericite and epidote. Boron also appears to have been introduced into the surrounding rocks. One locality near Amizette contained a little muscovite-tourmaline schist, and there is evidence of tourmaline associated with Precambrian quartz veins (Park and McKinlay, 1947, p. 1215; 1948, p. 18). The possibility that boron became concentrated into tourmaline by metamorphic differentiation of boron-carrying sediments cannot be overlooked. Ramberg (p. 268) suggested such a mechanism.

In addition, sillimanite possibly of hydrothermal origin, formed in the sillimanite gneiss and the muscovite hematite granulite. Large intrusives are not associated with the granulite but pegmatites are fairly common. The alteration effects in Precambrian granite itself consist mainly of the chloritization of biotite, which may have been produced by retrograde metamorphism.

MISSISSIPPIAN

Pre-Pennsylvanian rocks directly overlying the Precambrian crystalline rocks in New Mexico were first recognized by Thompson (1942) from exposures seen in Gallinas Canyon, near Las Vegas, and on the northwest side of the Sandia Mountains. Read and others (1944) did the first mapping in north-central New Mexico and the rocks were designated as the lower limestone member of the Sandia Formation of the Magdalena Group. They suggested the possibility of a pre-Pennsylvanian age of the member. Similar units of limestone were mapped as the lower limestone member elsewhere in

New Mexico, and each investigation reiterated the possibility of a pre Pennsylvanian age. Henbest (1946) found foraminifera in the limestones of the Sandia Mountains and correlated them with the Leadville Limestone of Mississippian age in Colorado.

Armstrong (1955, p. 3, fig. 26) described Meramec (Mississippian) microfossils and megafossils from these rocks in the Nacimiento, San Pedro, and Sangre de Cristo Mountains and named these rocks the Arroyo Peñasco Formation.

Fitzsimmons, Armstrong, and Gordon (1956) published macrofaunal lists for the type section of the Arroyo Peñasco Formation at Pinos Canyon, Nacimiento Mountains, and for the exposure on the northwestern flank of San Pedro Mountains, northeast of Cuba, New Mexico. The macrofossils were collected from the upper part of the Arroyo Peñasco Formation at both localities and indicated a Meramec (St. Louis) age.

Armstrong (1958, p. 971) described and illustrated the microfauna in the Arroyo Peñasco Formation in northern and central New Mexico. He believed this fauna clearly indicated a Meramec age for the Arroyo Peñasco Formation in the Nacimiento, San Pedro, Sandia, and southern Sangre de Cristo Mountains of north-central New Mexico.

Baltz and Read (1960, p. 1750) recognized a similarity in lithology between the units in the Sangre de Cristo Mountains and southwestern Colorado. They set up a type locality at Holy Ghost Creek and named the Devonian (?) rocks the Espiritu Santo Formation and the Mississippian rocks the Tererro Formation, the latter with three members which are, in ascending order, the Macho, Manuelitas, and Cowles Members. Wanek and Read (1956, p. 83) first mentioned these units in the Eagle Nest area.

Espiritu Santo Formation

Isolated exposures of these rocks occur at Bear Lake, Old Mike, Wheeler Peak, Horseshoe Lake, and Lost Lake. The maximum total thickness, exhibited by six or seven recognizable units, is only 58 feet (fig. 6). The units are folded by drag of Laramide thrust faults, hence true thicknesses are questionable in some localities.

The basal unit is a well-cemented, brown, medium grained sandstone containing angular fragments believed to be derived from the underlying Precambrian terrane.

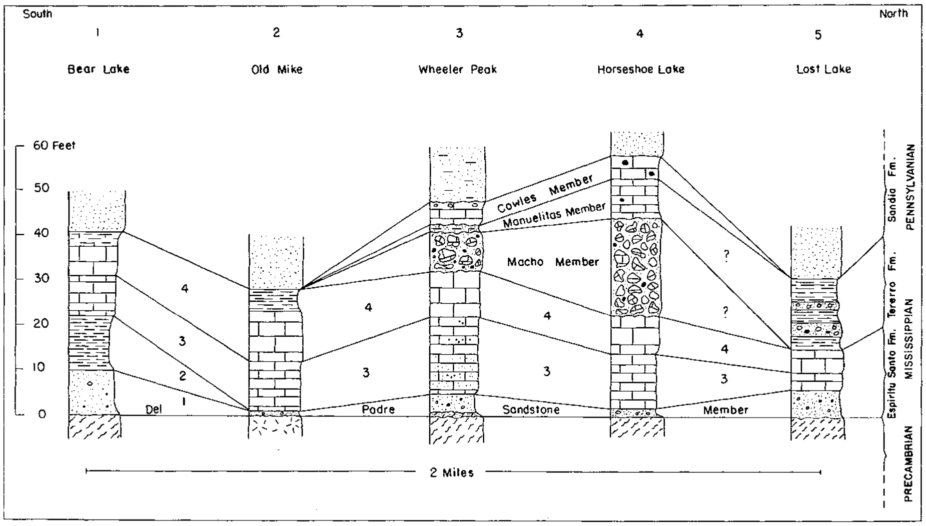


FIGURE 6—Stratigraphic correlation of Mississippian rocks in the Eagle Nest area.

Thickness of the unit ranges from 6 inches at Old Mike to about 10 feet at Bear Lake. Limited exposures do not allow lateral tracing, but such thickness variations are not unexpected in such a major unconformity, where changes in thickness of the basal unit reflect relief on the old erosion surface. The contact in the remnant on the northwest side of Wheeler Peak is marked by a weathered surface at the top of the Precambrian mafic schist. Cracks are filled with sandy material to a depth of a few inches, indicating a sedimentary contact. Miller, Montgomery, and Sutherland (1963, p. 22) proposed the name *Del Padre Sandstone* for this unit, from localities in the southern Sangre de Cristo Mountains.

Limestone of the second unit conformably overlies the basal clastics. At Bear Lake, a dark siltstone interval below the limestone is not represented in the other sections. The limestone is sandy in places and weathers dark brown, suggestive of a dolomite, in part. Typically, the limestone is medium to thin bedded. In thin section, it is a micrite. Some recrystallization has occurred, as developed in dark-brown masses of carbonate. Fossil fragments are few and could not be identified. The thickness ranges from 9 to 17 feet, averaging 11 feet.

The uppermost unit is represented by a light-gray, sandy limestone that may become shaly near the top. A suggestion of a slightly uneven surface at the base of the upper limestone may indicate erosion prior to its deposition. Thickness of the upper limestone varies but usually ranges between 10 and 11 feet.

No identifiable fossils have been found in the Espiritu Santo Formation at this locality, but the lithology suggests a shallow marine environment of deposition. Evidence of uplift following deposition shows in the irregular contact with the overlying Tererro Formation, noticed in some of the sections examined. The relief on this old surface is about one foot. On the cirque wall south of Lost Lake, structures are developed in the upper limestone; sinkholes are filled with limestone breccia of the overlying Macho Member of the Tererro Formation (Clark, 1966a, pl. 5A).

The shallow-water deposition of the Espiritu Santo Formation took place on an area that may have been above sea level since Precambrian time, although early Paleozoic sediments are found in southern New Mexico and south-central Colorado and may be absent here because of various periods of pre-Upper Devonian erosion. The age of these limestones has tentatively been indicated by correlation with rocks of Late Devonian age in southwestern Colorado (Baltz and Read, 1960, p. 1958). They noted a similarity in lithology between the sandy dolomitic limestone and interbedded shale with the Elbert Formation and Ouray Limestone of the San Juan Mountains (Baars and Knight, 1957, p. 118-121). This correlation is not accepted by Miller, Montgomery, and Sutherland (1963, p. 27). According to Baltz and Read (1960) the Percha Shale in southern New Mexico may be in part the equivalent of the Espiritu Santo Formation; but Armstrong and Holcomb (1967, p. 421) described and illustrated a microfauna of upper Osage and Meramec age, collected from Baltz and Read's type section of the Espiritu Santo Formation.

Tererro Formation

Macho Member

This member of the sequence is a distinctive massive ledge of limestone breccia. Breccia is persistent although in discontinuous outcrops from the type locality northward into the Picuris Range and can be recognized in the Eagle Nest area. In the field, the unit makes a prominent rounded ledge that weathers light gray. It was found north and south of Horseshoe Lake, and again south of Lost Lake.

The Macho Member is composed of limestone breccia set in a sandy matrix that also contains chert fragments. The limestone fragments are similar in appearance to those of the underlying limestones of the Espiritu Santo Formation. In the other erosional remnants, the remainder of the Mississippian section seems to be absent and is likely to have been removed by erosion. On the north side of Lost Lake, the stratigraphic position of the Macho Member is occupied by conglomeratic sandstones containing chert and by interbedded pale-green and maroon shales. Whether or not these lithologies represent the upper part of the Tererro Formation or the lower part of the Magdalena Group is not definitely known. The situation at Bear Lake is analogous. There, the limestones are overlain by a feldspathic sandstone, which, seen in thin section, contained microcline and plagioclase similar to that in rocks of Pennsylvanian age. The contact between the feldspathic sandstone and the underlying limestone is largely obscured by the tight overturning of the beds.

Where the upper part of the Tererro Formation is preserved, the contact between the Macho Member and the overlying Manuelitas Member is interpreted as an erosional unconformity, because the upper surface of the Macho Member is slightly irregular in the exposures adjacent to Horseshoe Lake and south of Lost Lake. Thickness of the Macho Member ranges from 9 to 19 feet.

Manuelitas Member

The Manuelitas Member is composed of thin beds of sandstone, calcareous shale, and thin-bedded limestone. The calcareous shales are sometimes reddish or green. The limestone is medium gray and cherty in places.

Thickness variations from 1.5 to 9 feet are probably due to erosion. This member is believed to be unconformably above the Macho Member. Exposures do not allow an interpretation of the upper contact with the overlying Cowles Member, but the variation in thickness suggests a period of erosion prior to renewal of sedimentation.

Cowles Member

The uppermost member of the Tererro Formation is represented by medium-bedded, fine-grained limestone of the Cowles Member. This limestone is medium to light gray or pale green to olive. Fragments of jasper may be present. Total thickness is about 5 feet. It becomes brecciated near the top. Within the map area, this member is overlain by beds of the Magdalena Group, the basal unit of which is a ferruginous, medium- to coarse-grained feldspathic sandstone or a dark shale. At Lost Lake, movement has occurred between the pre-Pennsylvanian and the Pennsylvanian strata.

Armstrong and Holcomb (1967) considered Baltz and Read's (1960) Cowles Member to be the final phase of Meramec sedimentation in the region and a facies of the regional sedimentation at this time. A Mississippian age of at least part of the pre-Pennsylvanian rocks in northern New Mexico appears acceptable to all previous investigators. Henbest (1946, p. 730), Armstrong (1955, p. 3-6), Baltz and Read (1960, p. 1765), Miller, Montgomery, and Sutherland (1963, p. 28), and Armstrong and Holcomb (1967, p. 421) submitted paleontologic evidence for a Mississippian age. Baltz and Read favored an Early Mississippian age at least for the lower two members of the formation, based on megafossil evidence. The upper member they considered Meramec. Others tend to favor a Late Mississippian (Meramec) age for the whole formation, based on the presence of *Endothyra.*

Thus, Armstrong and Holcomb (1967, p. 421), specifically show that all three members of the Tererro Formation can be assigned a Meramec age. Consequently, in the Eagle Nest area, field recognition of the lithologic subdivisions of the Arroyo Penasco Formation equivalent made by Baltz and Read should all be tentatively correlated with Mississippian (Meramec) units elsewhere in the Sangre de Cristo Mountains. Conformation must await paleontological evidence.

The deposition of limestones of the Tererro Formation was probably accomplished in a shallow marine environment over wide areas in New Mexico and Colorado. Arching in central New Mexico produced times of marine regression, so that the upper parts of the Macho and Manuelitas members were exposed to subaerial erosion.

The outcrops described here are believed to be the northernmost occurrences of Mississippian rocks in the Sangre de Cristo Mountains in New Mexico. Thus, the limit of the pre Pennsylvanian area of sedimentation given by Brill (1952, pl. 2) can be extended northward some 20 miles.

PENNSYLVANIAN

Distribution

The term Magdalena Group is retained to distinguish those strata of Pennsylvanian age from beds in the Sangre de Cristo Formation, the lower part of which may also be in the same system (Read and Wood, 1947, p. 223; Brill, p. 822). Lithologic and paleontologic basis for this designation is presented later.

Pennsylvanian rocks are found on the western slope of the Moreno Valley from Comanche Creek to the southern limit of the mapped area. This includes most of an isolated wedge that is the northernmost representative of this system in the Sangre de Cristo Mountains of New Mexico (Bachman and Dane, 1962). Further south the main mass of Pennsylvanian strata is continuously exposed to the limits of the uplift in the vicinity of Santa Fe. In addition in the Eagle Nest region, small outliers of these rocks remain as either erosional remnants, adjacent glacial cirques or are preserved structurally at the crest of the Taos Range. Poor exposures on a forest-covered dip slope, plus the preliminary nature of the work make it impossible to subdivide the Pennsylvanian strata, despite the presence of some marker beds.

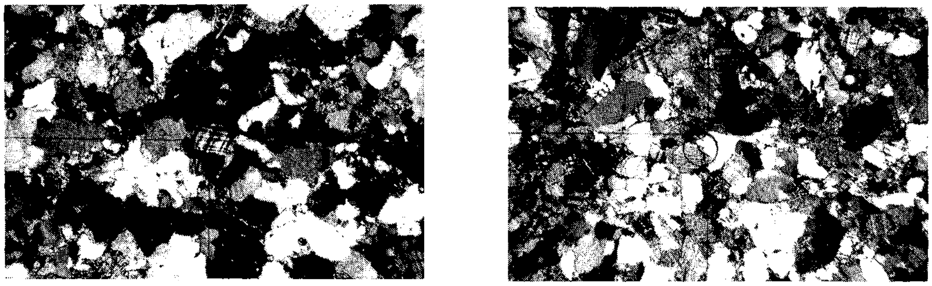
Lithology

The Pennsylvanian is represented by an alternating sequence of coarse-grained sandstones, shales, and minor intervals of limestone. Descriptions of individual beds observed in measured sections (chart 1, in pocket) are given in the Appendix.

Sandstones are medium to coarse grained and feldspathic in the lower intervals. In outcrop, they weather to a light-gray white or gray brown. The feldspar content is usually higher where the color is brown. Small flakes of muscovite are common. Bedding is variable; where the sandstones are impure and shaly, thin beds are usual; elsewhere, medium- to thick bedded ledges are common.

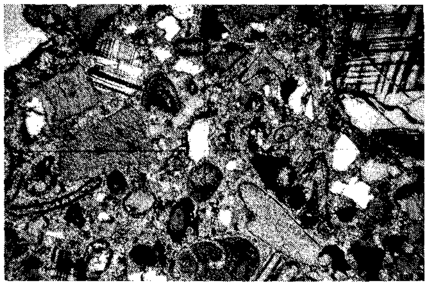
In thin section, grain size ranges from 0.1 to 2.0 millimeters. Quartz grains are poorly rounded, being subangular to curvilinear in outline, and are in point contact. Some have undulatory extinction. The interstices are typically filled with very fine aggregates of sericite, in which are embedded some flakes of muscovite up to 0.5 millimeters long. Feldspar is present in the form of anhedral grains of microcline or small, rare, grains of plagioclase. The rocks are regarded as immature to submature, based on poor sorting and appreciable amounts of "clay" cement (fig. 7A).

Sections of arkosic sandstone higher in the sequence are thought, in general, to fall into the medium grain sizes. Visual estimates of feldspar content in the field proved to be unreliable. Thin sections showed the same mineral assemblage described above, with the exception that muscovite occurred in larger shreds. Sorting is better, but there is still much cement between the grains, consisting mainly of clay, sericite, and chlorite. Quartz grains are typically curvilinear in appearance (fig. 7B). Sandstones are com-

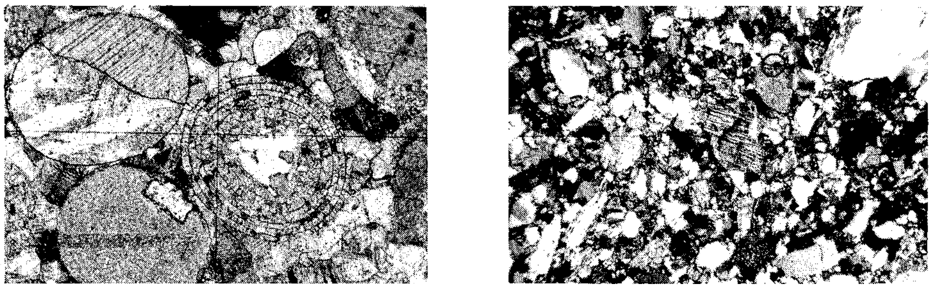


A. *Feldspathic sandstone, Magdalena Group.* A few grains of microcline are scattered in the quartz particles. Rounding is poor, and clay fills the interstices. Crossed nicols, X 14.

B. *Arkosic sandstone, Magdalena Group.* Abundant microcline and smaller amounts of plagioclase are present. Rounding is poor. Crossed nicols, X 14.



C. *Arkosic limestone, Magdalena Group.* Grains of microcline and quartz set in a matrix of fine-grained calcite. Microfossils and fragments of larger forms are present. Crossed nicols, X 14.



D. *Oolitic limestone, Magdalena Group.* Concentric layering is apparent around the quartz nucleus. Other types are rounded grains made up of one or two grains of calcite, all set in an interlocking matrix of carbonate. Crossed nicols, X 14.

E. *Arkose, Sangre de Cristo Formation.* Feldspars are scattered among the quartz particles. Rounding is poor; the cement is hematitic. Crossed nicols, X 14.

FIGURE 7—Photomicrographs of upper Paleozoic rocks.

monly pebbly within single ledges and pass into conglomerates, or they have shaly partings and pass into shale. The feldspathic sandstones contain few fossils.

Thick sequences of shale are interbedded with sandstones and limestones. In areas of little outcrop, shale is probably bedrock but fails to make any appreciable topographic expression. Color ranges from drab brown and gray to black, where calcareous, and either purple, pale red, or greenish gray in the upper parts of the section. Where fossiliferous, limonite imparts a characteristic rust color.

Limestones are arkosic and bedding thickness is variable. Color is usually gray or dark gray, but weathered surfaces are commonly lighter. The most common limestone types have a speckled appearance in hand specimen, because of glassy quartz and cream to light-brown feldspar grains. Fossil fragments may be present. Calcite occurs as large sparry grains or as minute grains in the matrix and in fossil fragments.

In thin section, quartz grains are subangular to subrounded, and microcline and plagioclase have similar outlines. Sericite flakes are present in places, as are microfossils (fig. 7C). The matrix is made up of minute grains of calcite 0.01 to 0.1 millimeter in diameter. Fossil remains include fusulinids, arenaceous foraminifera, bryozoan fragments, crinoid fragments, pieces of brachiopod shell, and echinoid spines (R. Y. Anderson, personal communication, 1965).

Oolitic limestone, found in widely scattered areas, is usually dark gray, containing gray to black rounded oolites 0.3 to 0.7 millimeters in diameter, which give the rock a "birdseed" appearance. Oolites occur in bands one or two inches thick.

The oolites are roughly spherical, but a few are flattened, with nuclei of angular quartz grains 0.1 millimeter in size, or, less commonly, feldspar grains. The oolites have a concentric layered structure, made up of elongate calcite grains aligned end to end. Layers of these grains commonly number 6 to 7, and each is up to 0.05 millimeter thick. A subsidiary radial structure is produced at the boundary of grains in the same layer (fig. 7D). Between the nucleus and the first layer, usually an intermediate zone consists of randomly disposed calcite grains. In a few oolites, the concentric structure is absent and is replaced by a mass of calcite in optical continuity that envelops the nucleus.

The matrix consists of interlocking anhedral calcite grains about 0.1 millimeter in size. This cement completely fills the interstices between the oolites. In some specimens, the proportion of oolite and single rounded grains of calcite is equal. Others are made up of two or three interlocking calcite grains that form a rounded oolite. A pisolitic type was seen on occasion. Its flattened shape appears to result from parallel growth around an elongate nucleus rather than flattening after formation. In addition, some grains of quartz and feldspar, similar to those seen in the arkosic limestone may be present. Sericite shreds are rare. Fossil content is the same as described above, with the addition of productid brachiopod spines.

Fine-grained to aphanitic limestones (micrite) are the least common type, although they are by no means rare. They are usually dark gray when seen in the field. In thin section, the bulk of the limestone is made up of cryptocrystalline calcite and contains a few rounded pellets about 0.1 millimeter in diameter. Indistinct aggregates may be due to recrystallization. The limestones are commonly veined by sparry white calcite.

Dolomitic limestones are present but entirely subordinate to those already de-scribed.

A few nodular limestones and limestone conglomerates are indicated in the measured sections. These types are found high in the section at Larkspur Point (Gruner, p. 739); in the Sawmill Park Trail area, where crinoid stems make up part of the fragments; and high in the section designated "Upper East Fork, Red River" (chart 1).

Conglomerate is fairly common but only a few feet thick in most localities, although, at Larkspur Point, beds are as much as 60 feet thick. In general, the conglomerate contains rounded cobbles and pebbles of Precambrian rocks, most of which are mica quartzite, granite, and granitic gneiss. The matrix is sandy and feldspathic.

At Larkspur Point, conglomerate is exceedingly coarse and contains angular fragments up to boulder size. A striking characteristic is the presence of angular fragments of weathered, dull-green, chlorite schist. They are believed to have formed quite locally, as chlorite schist is well exposed below the measured section and farther west on the flank of Rio Lucero. The angularity of the fragments indicates a nearby source and furnishes the best evidence for a bordering positive area at this time. Gruner (p. 740) first described this sequence (chart 1, col. 1) He drew attention to five intervals of coarse elastics, aptly referred to as puddingstone conglomerates. Smaller intervals interbedded with red and greenish-gray micaceous shale and siltstone are also present, together with arkosic sandstones and thin limestones. Overall, the color is dark red and may suggest a Late Pennsylvanian or Permian age. Exposures are good throughout the entire section, as in the fault block immediately to the north where similar beds are exposed. Brill (p. 828) considers these rocks part of the Sangre de Cristo Formation.

Contacts

The wedge of Pennsylvanian rocks described is in fault contact with Precambrian rocks on the north and west sides and in thrust contact with younger rocks on the east side. At one locality near Graney Creek, the Pennsylvanian is believed to be transitional with the Sangre de Cristo Formation.

On the west side, a fault contact can be seen on the high divide between the East Fork of Red River and Rio Pueblo de Taos. This fault strikes northward and is largely buried by Cenozoic deposits along the East Fork of Red River. The Pennsylvanian sediments are more than 1,000 feet above the floor of the valley east of Wheeler Peak Village. A sedimentary contact is recognized there; its relationship to the nearby Taos Cone fault will be dealt with in a later section. In the eastern part of sec. 31, T. 28 N., R. 15 E., on a spur, the following section was measured, in descending order:

Lithology	Thickness (ft)
Gray limestone, thin-bedded, with a highly fossiliferous layer (locality 452)	15
Covered interval	n.a.
Pebbly arkose, thin bedded with limestone fragments in first few inches	n.a.
Thin-bedded, light-gray-weathering limestone with crinoid columnals and corals (locality 585)	14
Covered interval	38
Brown conglomerate sandstone, with small mafic gneiss pebbles	1
Precambrian mafic gneiss	base

The upper fossiliferous limestone is definitely Pennsylvanian and is characterized by *Fusulina* and a corresponding megafossil assemblage. Whether the lower limestone, containing unidentified solitary corals, is Pennsylvanian or Mississippian in age is uncertain. The basal sandstone unit is apparently in sedimentary contact with the underlying gneiss.

The remainder of the Pennsylvanian beds—some are small outliers—occur along the crest of the range. They will be briefly described in order from south to north.

High on the ridge south of Rio Lucero, Pennsylvanian strata are exposed between several small cirques, but the contact with the underlying Precambrian is obscured by vegetation and talus. The lowest beds seen were dark limestone or iron-stained feldspathic sandstone.

The Pennsylvanian (?) conglomerates near Larkspur Point are preserved in faulted segments by both high-angle normal and reverse faults.

Farther to the northeast, the lowest beds are probably in sedimentary contact with the Underlying mica quartzite on which they rest. The contacts are poorly exposed and pass into the cirques of Blue and Star Lakes, perched high on a steep lip floored by quartzite (fig. 4A). On the ridge east of Blue Lake, a small outlier of brown angular conglomerate overlies the mica quartzite.

Earlier Read believed that rocks of Mississippian age were present in and around the cirques. Clark (1966a) disagreed on the grounds that the distinctive limestones of the Espiritu Santo Formation and the overlying Macho Member of the Tererro Formation could not be recognized; and suggested that pre Pennsylvanian erosion may be responsible for their absence. The upper part of the interval is cut out by a thrust fault that brings mafic gneiss over the sediments in Taos Cone.

Erosional remnants of Mississippian and Pennsylvanian rock are found on Old Mike, on the northeast flank of wheeler Peak (south of Horseshoe Lake), and around Lost Lake. At the last locality, evidence of movement of the Pennsylvanian over the Mississippian will be detailed later.

Finally, a few very small outcrops of arkose and limestone in this general area are far too small and poorly exposed to allow further interpretation, other than that they resemble erosional remnants.

Thickness

Wanek and Read (p. 84) arrived at an estimate of 7,200 to 8,500 feet, based on a consideration of sequences adjacent to the Moreno Valley where the section is better preserved.

Thus, at the junction of Flechado Canyon and Rio Pueblo in the Mora Valley-Tres Ritos area, resting disconformably on the old Mississippian karst surface or directly on the Precambrian, are dominantly clastic rocks nearly 4,000 feet thick. They consist of coarse arkosic sandstones and siltstone beds with a few beds of limestone. These basal sandstones and shales were believed equivalents of the Sandia Formation. Various representatives of the genus *Fusulinella* occur in the lower part of the section: in the upper part, *Fusulina* occurs.

Overlying this dominantly clastic sequence north of Tres Ritos is the lateral equivalent of the lower limestone member of the Madera. It consists of marine lime-stones, siltstone and shale, and sparingly fresh feldspathic sandstone. The complete thickness of this unit is about 3,500 feet. In general, the sequence may be referred to as part of the zone of *Fusulina.*

In the hogbacks east of Mora, overlying the top of the sequence just mentioned, are siltstones and coarse arkose with some interbedded impure limestones. Although dominantly gray or buff, many of the beds of shale are red. Limestones become less abundant upwards and the section grades into nonmarine strata. Nearly 1,000 feet of nonmarine sediments are preserved here and are believed to be the equivalent of the upper arkosic member of the Madera Formation and appear transitional with the succeeding Sangre de Cristo Formation.

Traced northward from the vicinity of Mora and Tres Ritos, the composite sequence just described is preserved in part below the summits of the mountains, and the lithologic equivalents can be recognized in the west flank of the Moreno Valley.

In the Eagle Nest area, Clark (1966a) determined the minimum thickness of the Pennsylvanian at not less than 4,500 feet. To this, he added an estimated 500 feet to include the folded upper part of the Sawmill Park section. Here the limestones become thin and widely separated, although they still contain marine fossils. The last marine limestone is partly dolomitic and has been traced around the east side of the Dakota hogback in Graney Creek. Above this unit, the characteristic color of the Sangre de Cristo Formation comes in strongly, and the transition is marked by the appearance of a thin, reddish-colored, fresh water limestone. Thus, the total minimum thickness was estimated at not less than 5,000 feet, although the actual amount deposited may have exceeded this figure (based on addition of sections measured in two structural blocks). The base of the section is recognizable in the Red Dome section, and no apparent overlap is evident with the stratigraphically higher Sawmill Park section (chart 1) and its transition with the Sangre de Cristo Formation. Exactly how large an interval was originally present between these two sections may never be known. In the event that overlap should be present in the two sections used, the Sawmill Park interval alone indicates a minimum of 2,921 feet. Partial correlation, using marker horizons with other sections, tends to substantiate this minimum thickness.

Eight stratigraphic columns are presented in chart 1. The base of the Pennsylvanian is above Mississippian limestones in column 3. These limestones may be present at the base of column 2, although the lithologic correlation is barely apparent. The section at Larkspur Point has been included with the Pennsylvanian, although this is open to question. The remaining four columns have been correlated on the appearance of oolitic limestone and major intervals of red- or purple-colored siltstones.

In conclusion, thickness of the Pennsylvanian in the Eagle Nest area is complicated by poor exposure, structural dislocation, missing intervals, and facies variation with more complete sections elsewhere in New Mexico. At least 2,921 feet are present, although circumstantial evidence suggests much greater thicknesses.

Regionally, Baltz (1965, figs. 4, 5) showed several thousand feet of Pennsylvanian strata north and south of this area. To the west, the sediments are generally absent because of removal by erosion in the Taos Range, although in nearby Taos Canyon, Miller, Montgomery, and Sutherland (p. 45) indicate a section assigned to the Atokan and early Desmoinesian interval. To the east, the Pennsylvanian thins and wedges out over the Sierra Grande Arch, so that the Sangre de Cristo Formation and younger Permian rest directly on Precambrian rocks (Foster, 1966). In Cimarron Canyon, Robinson and others (1964, pl. 3) showed the Permian and Triassic systems resting directly on a crystalline basement. Absence of the Pennsylvanian here may be due to an arch in the basin of deposition, postulated by Baltz (p. 2,045). Whether or not this omission is based upon sedimentation or structure is discussed later.

Paleogeography

According to Brill (1952, p. 810) the Permo-Pennsylvanian zeugogeosyncline of southern Colorado and northern New Mexico received detritus from the adjacent positive areas. The map area falls very near or at the margin of the Uncompahgre-San Luis positive axis (fig. 8). The Rowe-Mora basin earlier described by Read and Wood (p. 227) is now included in this geosyncline. Apparently its development was progressive. During Early Pennsylvanian time, the northern end downwarped first, but only in Middle Pennsylvanian times did the southern and middle parts develop. This would appear to be true in the Eagle Nest area, as indicated by the faunal evidence discussed below. However, the southern end also appears to have received sediments in Early

Pennsylvanian time, according to Read and Wood (1947, p. 235), Baltz, Wanek, and Read (1956, p. 17), and Miller, Montgomery, and Sutherland (1963, p. 33).

Fauna

A fossil list of 79 forms (62 localities), for the Magdalena Group is given in table 3 (localities designated on map 1, in pocket). Northrop (personal communication, 1965) identified the megafossils. Fusulinids not identified by H. V. Hollingsworth are listed as undetermined.

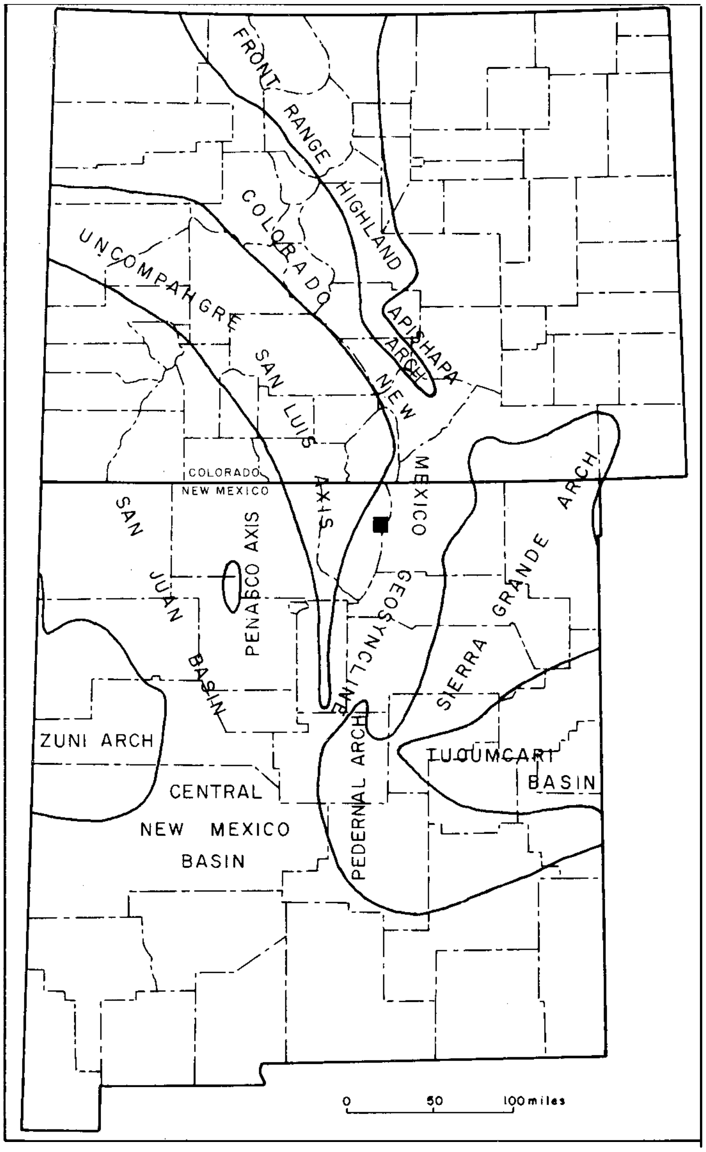


FIGURE 8—Early Desmoinesian paleogeography of New Mexico and southern Colorado.

(compiled from Read and Wood, 1947; Brill, 1952; and Baltz, 1965)

***Table 3**-Distribution of Pennsylvanian Fossils by Locality in the Eagle Nest Area (localities designated on map*

localities→	264	335	344	362	363	364	365	366	370	371	373	376	377	379	384	385	390	393	395	398	402	409	410	411	414	419	421	422	424	425	428	430	431	432	434	437	444	447	452	454	470	471	472	473	474	475	476	477	506	544	547	548	549	555	559	561	565	579	580	582
ALGAE																																																												
Leptophycus ? sp.																	x																																											
Several undet. sp.							x		x														x																				x			x														
FORAMINIFERA																																																												
Eoschubertella sp.									x																																																			
Fusulina sp.													x			x							x			x				x	x	x							x											x	x						x		x	
Fusulinella sp.									x																																																			
"Fusulinella-Fusulina"																x															x																				x									
Wedekindellina									x																																									x							x			
Undet. fusulinids	x				x		x		x		x	x		x	x												x						x						x						x	x														
Undet. arenaceous foraminifera	x					x																																																						
ANTHOZOA																																																												
Lophamplexus ? sp.																																								x																				
Lophophyllidium ? sp.																																										x	x	x												x				
Pleurodictyum ? sp.																																									x																			
Syringopora cf. multattenuata																																							x																					
Thamnopora ? sp.																																										x																		
Undet. corals		x	x	x											x			x																x	x			x			x		x									x	x	x	x					
BRYOZOA																																																												
Prismopora sp.																																									x		x																	
Fenestelloid bryozoans										x									x	x				x																		x	x	x		x	x	x												
Massive hemispherical bryozoan																																									x		x																	
Ramose bryozoans																			x																						x					x														
Rhomboporoid bryozoans					x													x	x																							x	x																	
Undet. bryozoans	x					x																							x												x		x																	
BRACHIOPODA																																																												
Anthracospirifer opimus																																										x	x		x		x													
A. cf. opimus																							x		x																			x				x												
A. cf. rockymontanus																																														x														
Antiquatonia coloradoensis																					x					x													x						x															
A. cf. hermosana																							x																																			x		
A. sp.				x	x						x																																																	
Composita elongata																																									x	x	x	x												x				
C. subtilita																			x																						x	x	x	x	x	x										x				x
Condrathyris perplexa																																																x										x		
C. ? sp.																																															x													
Derbyia crassa																																																								x				
D. sp.																																																								x				
Echinaria semipunctata																																					x																			x				
E. sp.																																																								x				
Juresania nebrascensis																					x																					x																		
Linoproductus cf. prattenianus																																															x													
L. sp.								x												x			x		x																	x			x	x										x		x		
L. ? sp.																				x																																								
Neospirifer goreii																																																								x				
N. latus																																																												x
N. sp.				x	x																	x																																x				x		
Productid brachiopod								x																					x														x																	
Undet. fragments	x			x		x																																			x																			

PELECYPODA																															
Acanthopecten cf. carboniferus																					x					x					
Annuliconcha interlineata																								x							
A. sp.															x						x										
A. ? sp.																									x						
Anthraconeilo ? sp.																													x		
Astartella ? sp.																					x					x					
Aviculopecten sp.																										x					
Edmondia ovata																			x												
E. sp.																															x
Lima retifera																															x
L. sp.																					x										
Myalina sp.																					x										
Parallelodon sp.																					x					x					
P. ? sp.																					x										
Pleurophorus ? sp.														x																	
Pteria longa																										x					
Schizodus sp.																					x										
S. ? sp.												x												x							
Wilkingia terminale													x																		
W. ? sp.												x																			
Pectinoid pelecypod														x																	x
Undet. forms											x			x						x	x	x	x		x	x		x			
GASTROPODA																															
Amphiscapha subquadrata													x																		
Euconospira ? sp.							x																								
Euphemites nodocarinatus																													x		
Glabrocingulum ? sp.												x																			
Bellerophontid gastropods																											x				
Undet. forms								x						x	x			x		x	x	x	x		x	x					
CEPHALOPODA																															
Megaglossoceras sp.														x																	
Mooreoceras ? sp.																									x						
Pseudometacoceras sp.																															x
Undet. nautiloid																								x		x					
CRINOIDEA																															
Delocrinus sp. (spine)																						x									
Columnals and fragments	x	x	x	x	x		x	x	x	x	x			x	x	x	x			x	x	x		x			x	x			
ECHINOIDEA																															
Echinoid spine																		x													
PROBLEMATICA																															
Star-shaped object																														x	

Northrop noticed the absence of the coral *Chaetetes milleporaceus* and of the following brachiopods:

Beecheria bovidens
"Chonetes," now subdivided into *Chonetinella*
Lissochonetes, Neochonetes
Crurithyris planoconvexa
Hustedia
Leiorhynchus rockymontanus
"Marginifera," now subdivided into *Desmoinesia*
Hystriculina, Kozlowskia, Retaria
Meekella striatocostata
Mesolobus
Wellerella

Most of these occur to the north in Colorado and to the south in the Mora-Las Vegas-Pecos area, Sandia-Manzano mountains, and Jemez-Nacimiento mountains. Absence may be due in part to incomplete collecting but also in part to ecologic control. Table 4 presents correlations made between the fauna listed above and those of adjacent areas.

Age

The Pennsylvanian rocks are confined to a lower or middle Des Moines (upper Cherokee) age, as indicated by an examination of the fusulinids collected from scattered localities (written communication, R. V. Hollingsworth, 1965). Supporting this assignment is an indication of a similar age for the megafossils (written communication, S. A. Northrop, 1965). However, Northrop drew attention to the fact that some forms might be more readily assigned to an early middle Pennsylvanian (Atoka) age.

Correlation

Table 4 shows that the best correlation based on faunal assemblage is with Pennsylvanian strata in New Mexico in the Sandia-Manzanita-Manzano mountains (Des Moines to Virgil), Nacimiento Mountains (Morrow to Virgil) and Pennsylvanian of Colorado (early Des Moines, middle Des Moines, and Atoka).

A correlation with faunas to the north and south is not unexpected, considering the paleogeography and the extent of the basin of deposition. However, the two areas in New Mexico lie outside the Colorado-New Mexico zeugogeosyncline proper, although a restricted connection with the central New Mexico basin, of which they were a part (Brill, p. 826, figs. 3, 4), was probable.

Of more interest is the weak correlation of faunas between the Eagle Nest area and other areas in the southern Sangre de Cristo Mountains, which were a part of the same basin. A possible explanation, found in the work of Read and Wood (p. 227), is the increase in thickness of Pennsylvanian strata in the Rowe-Mora basin from south to north. Associated with the increase of thickness is a facies change, which, in our view, may have been accompanied by faunal variation. Brill (p. 826), and Baltz and Bach-man (1956, p. 99), noted similar views with regard to northward thickening. The clastic-to-limestone ratio changes from dominantly calcareous to dominantly elastic from south to north. In the sections measured in the map area, this ratio was 8:2. Miller, Montgomery and Sutherland (fig. 10) concur in this respect and from paleontologic evidence presented in the previous section apparently faunal zones B to F inclusive, recognized in the southern Sangre de Cristo Mountains, are represented in the Eagle Nest area.

TABLE 4—*Pennsylvanian fossils of the Eagle Nest area compared with 15 adjacent areas in New Mexico and Colorado*

Other areas →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Algae							x	x							
Eoschubertella sp.														x	
Fusulina sp.	x	x	x	x				x		x			x	x	x
Fusulinella sp.		x							x						
Wedekindellina sp.	x	x						x		x					x
Lophamplexus ? sp.															x
Lophophyllidium ? sp.			x			x							x	x	x
Pleurodictyum ? sp.	x	?	x												
Syringopora cf. multattenuata	x								x				x		
Prismopora sp.	x	x			x						x	x	x	x	x
Anthracospirifer opimus	x	x							cf.		cf.		cf.	x	x
A. cf. rockymontanus	x	x	x		x	x			x	x	cf.	x	x	x	x
Antiquatonia coloradoensis		x		g.			x	g.	g.	g.	x	x	x	x	
A. cf. hermosana		x										x			x
Composita elongata	x	?			x	x									x
C. subtilita	x	x	x		x	x			x	x	x		x	x	x
Condrathyris perplexa	x	x	x				x			x		x	x	x	x
Derbyia crassa	x	x	x		x	x				g.	x	x	x	x	x
Echinaria semipunctata	x	x		x	x	x		g						x	x
Juresania nebrascensis	x	x									x			x	
Linoproductus cf. prattenianus	x	x	x	g.		x				g.	x	x	g.	g.	g.
Neospirifer goreii				x						g.		g.	cf.		
N. latus	x								cf.				cf.		
Acanthopecten cf. carboniferus	x	x									x		x	x	
Annuliconcha interlineata	x										x	?			
Anthraconeilo ? sp.		x													
Astartella ? sp.	x	x		x						x	x			x	x
Ariculopecten sp.	x	x		x						x		g.	x	x	x
Edmondia ovata	g.	g.									g.			g.	g.
Lima retifera	x													g.	
Myalina sp.	x	x		x									x	x	x
Parallelodon sp.	x														x
Pleurophorus ? sp.	x	x												x	x
Pteria longa	x														
Schizodus sp.	x	x												x	x
Wilkingia terminale	x	x	x											x	x
Amphiscapha subquadrata		g.												g.	
Euconospira ? sp.	x		x										x		
Euphemites nodocarinatus	x	x				g.								?	g.
Mooreoceras sp.	x	?												x	
Delocrinus sp.	x	x													
Totals	31	29	10	8	6	8	3	5	7	11	12	10	17	25	23

Other areas:

1. Magdalena Group, Sandia-Manzanita-Manzano Mountains, Northrop (1961)
2. Magdalena Group, Jemez-Nacimiento Mountains, Northrop (1961)
3. Madera Formation, near Las Vegas, Brill (1952)
4. Arkosic Limestone Member, near Mora, Brill (1952)
5. Arkosic Limestone Member, near Guadalupita, Brill (1952)
6. Arkosic Limestone Member, southern Moreno Valley, Brill (1952)
7. Flechado Formation, near Tres Ritos, Miller and others (1962)
8. Alamitos Formation, near Tres Ritos, Miller and others (1963)
9. Deer Creek Formation, Huerfano River, Colorado, Bolyard (1959)
10. Madera Formation, La Veta Pass, Colorado, Bolyard (1959)
11. Belden Formation, Glenwood Springs, Colorado, Bass and Northrop (1963)
12. Paradox Formation, Glenwood Springs, Colorado, Bass and Northrop (1963)
13. Atoka of Colorado, Chronic (1958)
14. Early Des Moines of Colorado, Chronic (1958)
15. Middle Des Moines of Colorado, Chronic (1958)

In the southern part of the basin, the Magdalena Group ranges in age from Morrow to Virgil but is relatively thin. Baltz and Bachman (p. 100) considered the Madera Limestone Member as Middle to Late Pennsylvanian and suggested that farther north the formation may be no younger than Des Moines because of lateral replacement of the upper parts of the arkosic limestone member by the lower part of the Sangre de Cristo Formation. This observation may be borne out by the Des Moines age of the section in the map area and its transition into the Sangre de Cristo red beds.

The oolitic limestone developed in a zone with a maximum thickness of 92 feet. Using this zone as a datum, the red siltstones appear between 50 and 150 feet higher in the section (chart 1). Red siltstones, equivalent to the upper arkosic member of the Madera, were rioted at Mora by Wanek and Read (p. 84).

The oolitic limestone is similar to the whiskey Creek Pass Limestone described by Brill (p. 818). It occurs some 45 miles farther north in southern Colorado in a zone 150 feet thick. Brill recognized an equivalent of the limestone at the south end of the Moreno Valley, and used it as a datum throughout the whole trough of deposition. In short, the limestone should be present in the Eagle Nest area and. a tentative correlation is hereby suggested. Both have a Desmoinesian age. However, according to Brill, the zone should occur some 350 to 400 feet below the base of the Sangre de Cristo Formation, although Clark considered it more nearly 1,000 feet below the base in the map area. While this discrepancy might appear to cast doubt on this correlation, the section at the south end of the Moreno Valley is structurally complicated (Brill, p. 827) obscuring the true position of the datum.

Below the oolitic limestone, Brill indicated a thickness in excess of 3,000 feet to the base of the section in this part of the trough, substantiating the thickness measurements cited in this report. Furthermore, the lithofacies map Brill presented (his pl. 3), generally agrees with the results of this investigation.

The foregoing supports correlation between the upper part of the sequence in the map area and the Madera Limestone member in adjacent areas, although the gross aspects of the lithology have changed in some respects. The overlying red and purple siltstones in the Eagle Nest area may be correlative with those further south, and thus equivalent to the upper arkosic member of the Madera. In the lower part of the sequence, fusulinid determinations are lacking for the Red Dome section, but because of the proximity of the underlying Precambrian and Mississippian rocks, some of the Sandia Formation equivalents may be represented.

PENNSYLVANIAN

Sangre de Cristo Formation

The Permian rocks in this vicinity are wholly contained in the Sangre de Cristo Formation, the lower part of which may be Late Pennsylvanian in age.

The Sangre de Cristo Formation lies in the low hills and slopes along the western margin of the Moreno Valley—almost continuously exposed from Hollenback Creek southward to the limit of the quadrangle. Elsewhere, small outliers of reddish conglomerate lie along the crest of the range and have been tentatively assigned to the Magdalena Group, although possibly they are part of the Sangre de Cristo Formation. Two remnants were found on the drainage divide between the Middle and East forks of the Red River. In addition, coarse conglomerates associated with red siltstones in the vicinity of the Questa mine, Goose Creek, and Placer Creek are identical to those described in the Questa quadrangle by McKinlay (1956) who tentatively assigned them to the Sangre de Cristo Formation. We consider these rocks either Precambrian or

Tertiary in age, based on field relations alone, although evidence from thin section examination suggests that they are most likely early Tertiary in age. The exposures near Larkspur Point may also be Permian in age (Brill, p. 828).

The Sangre de Cristo Formation consists of a series of red arkose, siltstone, conglomerate, and thin nonmarine limestone. The color of the rocks, a dominant characteristic, is most aptly described as blood red. With a little practice, one can detect an appreciable difference in color between this formation and the red siltstone of the upper part of the Magdalena Group, the overlying Triassic shale and the Poison Canyon Formation. The color, coupled with other physical properties, makes the field recognition of this sequence of rocks a little easier than would otherwise have been expected. The feldspars in the Sangre de Cristo arkose in the Eagle Nest area are rather white and contrast with the red color of the rest of the rock. The Pennsylvanian red siltstones are finer grained, so the feldspar is not obvious, and, in addition, the silt-stones are more fissile. The Triassic siltstones are plastic and the Poison Canyon Formation is invariably conglomeratic and much less consolidated.

Thick ledges of Sangre de Cristo conglomerate exposed in Comanche Creek and northward to Hollenback Creek contain boulders, cobbles, and pebbles of Precambrian rocks, mainly quartzite, granite, and granitic gneiss. The matrix is arkosic, but the rock can easily be broken with a geologic pick—quite unlike the hard conglomerate in the vicinity of the Questa mine. Ledges of conglomerate range from a few feet to a few tens of feet in thickness. Rounding of the pebbles, cobbles, and boulders varies from subangular to subrounded, although not as angular as the conglomerate at Larkspur Point. Where loose, the coarse clastic constituents acquire a distinctive red or black sheen on the weathered surface.

Interbedded with, and grading into the conglomerates both laterally and vertically, are layers of siltstone and medium-to coarse-grained arkose. Buff and green horizons occur from time to time. The arkose is characterized by the dull-white feldspar grains distributed throughout the dark grains of quartz and other minerals heavily coated with hematite. Arkose tends to be friable, and current bedding and cross bedding are infrequently observed.

Shale underlies the shallow slopes between the more resistant ledges. Siltstones are usually deep red and commonly micaceous. Mica is usually finer than that in the Pennsylvanian sediments.

In thin section, specimens of arkose are composed of quartz, microcline, plagioclase, muscovite, and magnetite (fig. 7E). Grain size in the sections examined ranges from 0.1 to 1.2 millimeters in diameter. Quartz grains, subangular to curvilinear in outline, sometimes may have undulose extinction. Feldspars are anhedral and cloudy in plain polarized light. White mica occurs in contorted shreds between the grains of other minerals. Also present are appreciable quantities of magnetite distributed throughout. The cement, largely hematite, coats the grains and imparts the deep red color seen in hand specimen. Minor amounts of clay, sericite, and calcite make up the remainder of the cement. Submaturity is indicated by the relatively poor sorting and rounding and the presence of clay in the interstices.

Limestone beds are rare but, where visible, are thin and aphanitic with a reddish-purple sheen; some are nodular. They are unfossiliferous and are probably nonmarine. In general, they appear confined to the lower parts of the interval.

Seen under the microscope, the limestone is cryptocrystalline (micrite) and red in oblique reflected light because of the presence of finely disseminated iron oxide. Sparse grains of sparry calcite and quartz and rare grains of feldspar may be present. Overall, a decrease is apparent in the arkosic component of Sangre de Cristo limestone compared with that in arkosic limestone of the Magdalena Group, a point made by Brill (p. 821).

No fossils, other than a few plants, were found in the Sangre de Cristo Formation. Wanek and Read (p. 85) identified *Callipteris conferta* along with other fossil plants of Permian age in at least the lower part of the interval. Since the lower part of the Sangre de Cristo Formation is likely to be upper Pennsylvanian, this genus may be prenuncial in this part of the basin, or the Pennsylvanian marine faunas may be relict. We cannot subscribe to a disconformity and a hiatus at the boundary of the Sangre de Cristo and the underlying Pennsylvanian. Continuous infilling of the Rowe Mora basin precludes this possibility.

North of Graney Creek, the Sangre de Cristo Formation has a transitional contact with the underlying Magdalena Group. The base of the Sangre de Cristo Formation has been drawn where the blood-red color comes in above the last marine limestone. Elsewhere, the older rocks have been thrust over the red-beds. To the west of Scully Mountain, the Sangre de Cristo Formation has been thrust over rocks of Mesozoic age, although farther south it underlies the Dockum Group with little apparent angularity.

Red beds of the Sangre de Cristo Formation are continental in origin, the material derived from the Uncompahgre-San Luis highland to the west (Bolyard, 1959, p. 1932). Coarseness of the conglomerates indicates that the deposits formed in an environment not too distant from the source area. In fact, if the small outliers between the Middle and East forks of the Red River and the conglomerate at Larkspur Point are part of the Sangre de Cristo Formation, obviously the formation has overlapped the older beds and rests directly on the Precambrian. Melton (1925b) noted similar overlap in an area in southern Colorado.

Deposition was mainly in an environment of strong oxidizing conditions, prior to deep burial. The basin of deposition must have been rapidly subsiding as Brill (p. 821) reported at whiskey Creek Pass. The materials were probably deposited on a flood-plain or piedmont alluvial plain adjacent to the Uncompahgre-San Luis highland.

Thickness of the formation in the Eagle Nest area is at best 4,800 feet (chart 1, in pocket). The base of this section is in fault contact with Precambrian biotite gneiss. Because of the high angle of this fault, and the similarity in configuration of this contact with a depositional contact with the Magdalena Group north of Graney Creek, the loss of section is estimated at not more than 500 feet. The total thickness, there-fore, may be as much as 5,300 feet (Wanek and Read, p. 85, estimated 5,000 feet). Within the section measured, 2,623 feet were exposed; the remainder is concealed under the alluvium of Comanche Creek, although the contact with the Dockum Group is exposed in the western flank of Scully Mountain. Under the alluvium, the formation is cut by a transverse fault. Because of its high angle and the near-vertical attitude of the beds, little of the section is lost.

Plants indicate a Permian age for the beds. To the north in Colorado, bones of pelycosaurs and of the cotylosaur *Didactes sp.* have been found, indicating an Early Permian (Wolfcamp) age by analogy with adjacent areas (Brill, p. 834).

In the Pecos region, the Sangre de Cristo Formation is underlain by beds of Late Pennsylvanian (Virgil) age but, farther north, by beds of Des Moines age (Miller, Montgomery, and Sutherland, p. 38). A similar situation obtains in the Eagle Nest area. Both areas contain a gradational contact, and the Sangre de Cristo Formation replaces the upper part of the arkosic limestone equivalent of the Madera Formation. Bolyard (p. 1923) made similar interpretation in southern Colorado, although Brill (p. 819) assumed that the Upper Pennsylvanian rocks were truncated by a pre-Wolfcamp unconformity, but cited no clear evidence.

Along the Mora River and overlying the Sangre de Cristo Formation are the Yeso and Glorieta formations. These strata can be traced north along the hogbacks to the vicinity of Guadalupita. About five miles south of Guadalupita, however, the Yeso becomes coarse and arkosic apparently like the Sangre de Cristo. Also, strata at the base of the Glorieta are conglomeratic; apparently both the Yeso and Glorieta lose their identities, and the top of the Sangre de Cristo becomes younger toward the Eagle Nest area. The northernmost outcrop of the Glorieta is 10 to 15 miles north of Guadalupita near the village of Black Lake. Baltz and Bachman (1956) made a similar interpretation. However, an increasingly downward beveling of Permian strata, as a result of pre-Upper Triassic erosion, could account for the absence. of the Glorieta and the Yeso Formations.

TRIASSIC

Dockum Group

Strata of Late Triassic age in northern New Mexico are referred to as the Dockum Group. These rocks occur in the Moreno Valley along the western flank, where they overlie the Sangre de Cristo Formation. A small interval, in fault contact with pink Precambrian granite, occurs east of Eagle Nest Lake. Other small inliers near Tolby Creek are in normal contact with the same granite.

In the vicinity of the Sangre de Cristo Mountains, the group has been mapped as one unit, although as far north as Turkey Mountain, the basal Santa Rosa Sandstone has been differentiated from the overlying Chinle Shale (Bachman and Dane, 1962). In the Eagle Nest area, the equivalents of the lower sandstone and the upper sequence of shales are only locally apparent.

In hand specimen, the sandstones tend to be somewhat friable and contain finely distributed dark material throughout that imparts a "dirty" appearance. The sandstones are fine grained, and form ledges that weather brown.

In thin section, grains of quartz 0.02 to 0.2 millimeters in diameter have a sub-angular to curvilinear outline. The grains are in point-to-point contact, and for the most part the cement completely fills the interstices. A few warped laths of sericite, 0.2 millimeters long, may be present. The cement is fine sericite and clay, mixed with limonite and hematite(?), which produces the dirty appearance in hand specimens. Bedding can be detected, and the long axes of the quartz grains are subparallel to the bedding plane. The sandstone is fairly well sorted, but the poor rounding and large amounts of clay suggest that the rock is not yet mature. The absence of feldspar, however, contrasts with the underlying Permian and Pennsylvanian. We infer that the source areas were no longer predominantly Precambrian terrane.

A characteristic feature of the Dockum Group is thin beds of limestone pebble conglomerate. Rounded pebbles and granules of gray limestone are set in a limey matrix. The conglomeratic nature of the rock is best observed on weathered surfaces where the slightly different color of the pebbles is in contrast to the matrix. Beds are little more than a few feet thick and commonly occur near the base of the interval, together with light-colored laminated sandstone.

In thin section, pebbles and granules are composed of well-rounded, cryptocrystalline carbonate and contain minute grains of quartz. Hematite dust is apparent in oblique reflected light. The rounded pellets are set in a fine-grained matrix of sparry calcite 0.05 to 0.5 millimeters- in size and small angular grains of quartz 0.5 millimeter in size. Larger limestone granules are made up of radially disposed calcite grains that produce a crude "spherulitic" structure. The diameter of these masses is 2 to 4 millimeters. Similar rounded granules have large peripheral grains of calcite and quartz, randomly oriented around a nucleus of small calcite grains. They resemble the oolites described in the Pennsylvanian limestones.

The equivalent of the Chinle Shale may be represented in the upper part of the Dockum Group in the Moreno Valley. It consists of intervals of bright-red shale with minor ledges of sandstone and rare limestone pebble conglomerate. The shale contains minute plates of white mica and is quite plastic when wet. Shale is rarely well exposed and does not have any positive topographic expression. Where folding has occurred, the overall thickness of the Dockum Group is largely reduced, mainly at the expense of the red shale interval which becomes pinched out between the more competent beds. An example of this lies in the north bank of Six Mile Creek, immediately below the Entrada Sandstone.

The contact with the overlying Entrada is one of small angular unconformity. The Triassic beds overlie the Sangre de Cristo Formation, but in the area examined, little or no evidence for an angular unconformity between the two systems appears. The lower part of the Triassic is not represented, therefore, a hiatus is postulated (Baltz, Wanek, and Read, p. 19).

The Dockum Group is well in excess of 1,000 feet thick in the southern part of the Sangre de Cristo Mountains and in the Las Vegas basin, but has thinned and in some places is absent in southern Colorado. Wanek and Read consider this thinning due chiefly to pre-Entrada erosion, mainly at the expense of the Chinle Formation. Baltz (p. 2058) indicated a thickness of 300 to 400 feet in the subsurface of the eastern limb of the northern Raton Basin. Further thinning northward and westward occurs toward the Apishapa arch and the northern Sangre de Cristo uplift (Oriel and Mudge, 1956, pl. 1). Apparently Triassic rocks finally wedge out in the subsurface. Robinson and others (pl. 2) showed a thickness of 400 to 500 feet in the Cimarron Mountains, whereas Simms (1965, p. 17) cited a thickness of 310 feet in the Rayado area. Where measured in the Eagle Nest area, the Dockum Group is 342 feet thick. The lower 166 feet are probably the equivalent of the Santa Rosa Sandstone; the upper 176 feet are regarded as the equivalent of the Chinle Shale.

No fossils were found in the Triassic beds, although at some localities in north-eastern New Mexico, the Chinle Shale has yielded phytosaurs, probably of Late Triassic age.

Faults have brought rocks of widely differing ages in contact with the Triassic. At Lakeview, the Dockum Group is adjacent to Precambrian granite; between Idlewild and Graney Creek, the Dockum is overlain by and in thrust contact with Pennsylvanian rocks; and west of Scully Mountain, the Dockum has been covered by a thrust plate of the Sangre de Cristo Formation. East of Eagle Nest Lake, a normal fault has dropped Triassic rocks against Precambrian granite.

The source terranes from which these sediments were derived was, again, the Uncompahgre highland (McKee and others, 1959). Some materials were derived by reworking Permian rocks. Pebbles in the limestone conglomerate are similar to those in the nonmarine limestones of the Sangre de Cristo Formation. Possibly rocks of both Pennsylvanian and Permian age eroded along the margin of the highland area and contributed to materials incorporated in the Dockum Group. Certainly, the lack of feldspars inthe sandstones suggests that some of the materials are second cycle.

An extensive shallow water continental environment of deposition is indicated by the deposits of sandstone, shale, and thin limestone conglomerate, widely spread throughout the southern Sangre de Cristo Mountains and in the Raton basin. The overlying red shale is also continental in origin and was probably deposited in a floodplain environment to the east of the highland area.

JURASSIC

Upper Jurassic strata cropping out in the Moreno Valley include three units: the Entrada (Ocate) Sandstone, an equivalent of the Wanakah Formation and the Morrison Formation.

The areas of outcrop are similar to those of the underlying beds and can be traced along the west side of the Moreno Valley from a point one mile west of Elizabeth-town, southward to Lakeview, and beyond. Other outcrops occur on the south side of Scully Mountain, where the rocks are exposed around a quartz diorite porphyry body of Tertiary age.

Renewed sedimentation began in late Middle Jurassic time with the deposition of the Entrada Sandstone, which is continental in origin. By Late Jurassic (Oxfordian) time, the seas had transgressed farther, although the Eagle Nest area still had a transitional environment during the deposition of the Wanakah equivalent. Shallow water nonmarine conditions probably resulted in the deposition of the Morrison silts and shales. The source of materials now lay to the south, as the low hills of the old highland had been submerged by early Kimmeridgian time. However, later the sea withdrew and partial erosion of the Upper Jurassic rocks took place (McKee, and others, 1956, pl. 8).

Entrada Sandstone

The basal unit forms a distinct ledge in the field that can be traced on aerial photographs. The sandstone is gray white to buff, fine to medium grained, and clean in appearance. The beds have a medium thickness, and locally display crossbedding. Maximum overall thickness is nearly 100 feet, as recorded in Scully Mountain, although in most localities it is nearer half that figure. In the measured section near Scully Mountain (chart 2, in pocket) a dike has cut out most of the sandstone.

Thin sections confirm the clean aspect of this sandstone. The quartz grains are subrounded, 0.05 to 0.2 millimeter in diameter, and in point contact, with some cement in the form of sericite and silt. Rounding and sorting are far better than any formation so far described, and the sandstone is regarded as mature.

The relative decrease in the amount of cement present as compared to other clastic units so far described, contributes to the friable nature of the rock which quickly weathers to a light sand.

Wanakah Equivalent

Above the Entrada Sandstone is a poorly exposed sequence of red and buff shales and thin limestones. The presence of small angular fragments of red jasper in some of the limestones suggests that this sequence is an equivalent of the Wanakah Formation. In some localities, thin limestone overlying the Entrada does not contain jasper, and Wanek and Read have considered this an equivalent of the Todilto Limestone. How-ever, the characteristics of the Todilto Limestone were not recognized within this map area. Thus, at Romeroville Gap, south of Las Vegas, the Todilto is a very thinly laminated, dark-gray crinkled limestone (Baltz, Wanek, and Read). In contrast, how-ever, in the Moreno Valley, limestones above the Entrada, other than those containing jasper, are thin bedded and medium gray. In thin section, they contain wedge-shaped aggregates of sparry calcite up to 1.2 millimeters in length, made up of individual grains of calcite 0.1 millimeter in diameter. The bulk of the rock is made up of microcrystalline granular calcite, in which a few quartz grains are embedded.

Thickness varies. In places, this type of limestone is absent, although limestone containing red jasper may still occur. The presence of red jasper is variable in rocks assigned to the Wanakah Formation (Elmer H. Baltz, personal communication, 1966).

The Todilto Limestone is only present in the southern part of the Sangre de Cristo Range and has not been observed north of Sapello (Baltz and achman). In a later paper, Baltz (p. 2060) stated that the Todilto tongued out northward and eastward into a sequence of reddish to waxy-green shale, with thin, medium-grained sandstones and red chalcedony beds. Apparently, Bachman (195 3), wood, Northrop, and Griggs (1953) and Johnson and Stephens (1954) correlated this sequence with the Wanakah Formation of southwestern Colorado. Thus, the consensus of available data derived from the map area and adjacent regions suggests that the Todilto Limestone is not present. The fine-grained limestone here described may be a Todilto equivalent, but the red shales and jasper-bearing limestone above are more easily assigned to the Wanakah Formation.

This interval, where measured, is less than 30 feet thick, and has been mapped with the Entrada Sandstone.

Morrison Formation

The highest beds of the Jurassic System are assigned to the Morrison Formation and consist of an alternating series of fine-grained sandstones, and predominant nodular siltstones. The sequence is poorly exposed in the field; some of the best exposures were seen in the side of a steep gully 3,600 feet east-southeast of the G. Mutz Ranch in the line of the measured section (chart 2). There, sandstones have a light to buff or tan color, are thin bedded, and usually have appreciable quantities of clay cement. Silt-stones, in intervals up to 40 feet, interbed with the sandstones and also form partings in the sandstone ledges. Color of the siltstones varies from purple, maroon, and red to shades of green.

Maximum thickness of the Morrison Formation where measured was 162 feet, but part of the section is cut out by a fault; so the true thickness may be nearer 310 feet, cited by Simms (p. 19) in the Rayado area. No angularity was detected with the underlying Wanakah equivalent.

Correlation of these beds with the Jurassic in adjoining areas must be made on a lithologic basis alone, because fossils were not found, and few have been recorded in areas nearby. As part of the belt of sedimentary rocks along the eastern front of the Sangre de Cristo Mountains, these sediments can be correlated with those in areas to the north and south of Eagle Nest; to the east, where they are exposed in the Cimarron Mountains, and in the Raton basin, where they have been recorded in the subsurface (Baltz, 1965, fig. 2).

The clean nature and bedding characteristics of the Entrada Sandstone suggest that it was deposited on or near beaches. Sedimentation continued in a shallow-water environment with the deposition of the Wanakah and Morrison Formations. Materials were derived from low hills that were part of the old Uncompahgre highland (McKee, and others, 1956).

As the Glen Canyon Group of Lower Jurassic and Upper Triassic age is absent in the map area, Wanek and Read interpreted this as pre-Entrada (Ocate) erosion.

After deposition of most of the strata included in the Glen Canyon Group and prior to Entrada deposition, gentle folding or warping took place over large parts of New Mexico. Although the structural relief is not great, folding is sufficient to notice the angularity east of Raton.

CRETACEOUS

Dakota Sandstone

Many hundreds of feet of Cretaceous rocks are represented in the Eagle Nest area. The Dakota Sandstone is the earliest of the strata present and forms a distinctive hogback along the western flank of the Moreno Valley, marking the base of the Cretaceous sequence. South of Six Mile Creek, gravel and alluvium preclude further exposure, although an isolated rocky outcrop of the Dakota Sandstone can be seen 1,000 feet west of U.S. 64 near the southern end of Eagle Nest Lake.

Elsewhere, a small outcrop of Dakota Sandstone was found in the west bank of North Moreno Creek, approximately one mile north of the Moreno (LeSage) Ranch. Additional exposures cap Scully Mountain.

The Dakota Sandstone crops out as well-developed ledges of gray- or buff-weathering sandstone that are medium grained and medium to thin bedded. Cross-bedding is observed on occasion. The buff to brown color may be due, in part, to limonite after pyrite recognized at one or two places. Two other characteristic features are the beds of small, gray, weathered, angular chert fragments and the resistant ribs of white quartz that crisscross the weathered surface. These characteristics, aside from stratigraphic position, help to distinguish the Dakota Sandstone from the Entrada Sandstone.

On the southwestern side of Scully Mountain, a lower ledge of sandstone appears to be separated from a second ledge by a small interval of gray shale. The lower ledge may represent the Purgatoire Formation, as suggested by Wanek and Read. Evidence of this second ledge was also seen west of Elizabethtown and at Idlewild.

In thin section, the Dakota Sandstone is composed of closely packed, subrounded quartz grains 0.1 to 0.5 millimeter in diameter, with some silty cement. Overall, the sections show that the sandstone is quite mature and, like the Entrada Sandstone below, suggest that the materials were reworked from earlier beds.

The thickness of the Dakota Sandstone is, in general, about 100 feet; a maximum of 150 feet includes both ledges and the intervening shale. Angularity with the underlying Morrison Formation is little evidenced, although the contact is infrequently exposed. The contact with the overlying Graneros Shale is probably conformable.

Graneros Shale

The Graneros Shale is poorly exposed in grass-covered slopes above the Dakota Sandstone on and around Scully Mountain.

In general, it consists of dark-gray shales that are predominantly noncalcareous, although one or two minor calcareous horizons are present in places. A few thin, cream-colored beds of bentonite were found about one and a half miles south of Elizabethtown. The Graneros Shale is estimated at nearly 400 feet thick in parts of the map area. Simms (p. 21) recorded a thickness of 192 feet in the Rayado area.

Greenhorn Limestone

The Greenhorn Limestone forms a distinctive lithologic unit poorly exposed south and west of Elizabethtown but well exposed in a roadcut of U.S. 64 two miles east of Eagle Nest. Locally, it is disrupted, faulted, and cut out by quartz porphyry diorite dikes resulting in discontinuous outcrops and variable strike.

Exposures consist of a dark-gray, fine-grained, blocky, light-gray-weathering, medium- to thin bedded limestone interbedded with dark-gray calcareous siltstone and shale. *Inoceramus labiatus* has been collected from this stratigraphic unit.

In thin section, the limestone comprises of grains of sparry calcite 0.05 to 0.5 millimeter in diameter in interlocking, rounded aggregates, with long axes parallel to the bedding planes. The matrix is formed of rather opaque calcite ooze.

A maximum thickness of 22 feet has been measured. The Greenhorn Limestone is probably conformable with the formations above and below.

Carlile Shale

The Carlile Shale conformably overlies the Greenhorn Limestone. The Carlile crops out west of Elizabethtown, adjacent to a small earth dam, approximately 1,800 feet south of the road leading to the G. Mutz ranch. More extensive exposures were found along the trail leading to Mills Divide, one and a half miles east of the LeSage ranch.

The Carlile Shale is dark gray to black and calcareous and contains lenticles of dark limestone up to 4 inches thick. Brown-weathering, septarian concretions are composed of dark, fine-grained limestone. The septa are formed of white calcite. The size of the concretions varies from less than one foot to about 4 feet in diameter.

As measured at Mills Divide, the minimum thickness of the Carlile is 297 feet. If the fine shale at the base of the section is included, the thickness is more. The concretions are in a zone more than 100 feet thick located 50 feet from the top of the section (chart 2, col. 4). In the Rayado area, Simms (p. 23) measured a thickness of 278 feet.

Niobrara Formation

Fort Hays Limestone Member

The Fort Hays Limestone is poorly exposed in the Eagle Nest area. Two localities were mapped, both in the vicinity of Elizabethtown. Outcrops are discontinuous. West of Elizabethtown, the limestone is in contact with a Tertiary sill and is brownish. Along New Mexico 38, the limestone is dark gray and medium to thick bedded and weathers to slabs 1 to 3 inches thick. Nearby sills of quartz diorite porphyry may have had some baking effects on the limestone.

Specimens of *Inoceramus* sp. were collected from this interval. The thickness at this locality is 21 feet, although immediately above, an additional 15 feet of thin limestone and dark calcareous shale should perhaps be included in the member.

The outcrop pattern and contacts of this limestone have been modified by the presence of numerous sills, but the unit is probably conformable with the formations above and below.

Pierre Shale and Upper Part of Niobrara Formation

The youngest strata of Cretaceous age in the map area overlie the Fort Hays Limestone on the slopes of Iron Mountain. They comprise an interval of dark, calcareous shales and thin, fine-grained limestone ledges up to 10 inches thick and contain numerous large pelecypods. Near the base, 75 feet of black, sparingly calcareous, platy-weathering siltstone commonly form a black sand below the outcrop. The thickness of the lower part of the interval attains several hundred feet. In the upper part, the shales have been modified by Tertiary sills. There, the resulting rock is hard, aphanitic, silicified, and streaked light and dark gray along the bedding; it will be referred to as hornfels representing the Pierre Shale.

A similar sequence, near Mills Divide at a large earth dam, contained a species resembling *Inoceramus involutus.* According to Northrop (written communication, 1965), this form first appears in the Smoky Hill Marl of the Niobrara Formation.

Elsewhere on Iron Mountain, noncalcareous gray shales represent the Pierre Shale. Exposures are meager, and no distinction has been drawn between this unit and the underlying calcareous beds of the Smoky Hill Marl.

High on the slopes of Baldy Mountain above the west portal of the Deep Tunnel mine, along the northwest shoulder, and just below the peak at the Mystic mine, outcrops of a buff, fine-grained sandstone interbedded with shaly hornfels probably represent the upper 200 to 300 feet of the Pierre Shale. The sandstone is quartzitic because of partial recrystallization by intruding igneous sills. According to Johnson, Dixon, and Wanek (1956), these sandstone beds grade and intertongue with the lowermost beds of the overlying Trinidad Sandstone in the Raton basin, although the Trinidad is not recognized as such west of Ute Park.

Griggs and Northrop (1956) gave the thickness of the Smoky Hill Marl (Shale) in the Raton basin as 900 feet. If a similar thickness is present in the Moreno valley, several hundred feet of Pierre Shale must also be represented above.

Continued epeirogenic downwarping throughout Cretaceous time resulted in the accumulation of at least 2,000 feet of sediments in the area occupied by the Moreno Valley. Rocks of late Late Cretaceous age are missing because of the onlap of the Raton Formation.

Uplift at the end of Morrison time may have resulted in land conditions in early Early Cretaceous time (Heaton, 1933, p. 61). Base leveling was followed by a wide-spread marine transgression from the south and west, resulting in the formation of the Dakota Sandstone. Much of the material comprising these sediments was derived by reworking the underlying rocks, as reflected in the thin sections examined. During Late Cretaceous time, the dark marine shales of the Raton basin and adjacent areas were derived from upland areas in southwestern New Mexico and adjoining areas to the west, while, at the same time, the San Luis-Uncompahgre positive area had been temporarily submerged.

PALEOCENE

Poison Canyon Formation

By Late Cretaceous time the seas had retreated to the east signaling the initiation of a further period of crustal unrest. The terrestrial rocks formed as a result of degradation of the rising mountains to the west are only partly represented in the map area. The most complete record is in the northern part of the Raton basin.

The Poison Canyon Formation crops out in and adjacent to the Moreno Valley. The unit represented on the geologic map is undifferentiated from the Raton Formation which has lithologic similarity, age, and distribution. Furthermore, the uppermost beds of the Raton Formation grade vertically and laterally into the lowermost beds of the Poison Canyon Formation (Johnson, Dixon, and Wanek, p. 128).

In general, equivalents of the Raton Formation (?) are represented by coarse gray-white sandstone, pebbly sandstone, conglomerate, and minor amounts of gray shale. They unconformably overlie the Dakota Sandstone at Idlewild, the Carlile Shale near Mills Divide, and the Smoky Hill Marl and Pierre Shale at Elizabethtown and in Grouse Gulch.

At least 250 feet of these sediments are present at Idlewild and perhaps more in the subsurface of the Moreno Valley.

A coarse and reddish-colored facies occurs near the Gallagher ranch at Idlewild and northward for about one mile. North of Mills Divide, this type predominates over the light-colored variety and is representative of the Poison Canyon Formation. Pebbles, cobbles, and boulders predominantly consist of Precambrian mica quartzite, granite and granite gneiss. The formation is usually characterized by pale-orange to red-colored sediments, including arkosic and micaceous siltstones and sandstones, and coarse boulder conglomerate. Feldspars in the rocks weather gray white, a feature interpreted by some as characteristic of the Raton Formation. Johnson and Wood (1956) suggest that between Eagle Nest and Ute Park, the lowermost beds of the Poison Canyon Formation are the age equivalents of the basal conglomerate of the Raton Formation. Read believed the lower few hundred feet of the Raton Formation to be Late Cretaceous.

The most extensive area underlain by the Poison Canyon Formation lies north and east of Mills Divide. Here, the hillsides are covered with pebbles, cobbles, and boulders of metaquartzite and Precambrian granite weathered out from a conglomeratic facies. These materials appear to have been derived from the vicinity of North Moreno Creek, because the boulders increase in size toward this locale. More rarely, fragments of Pierre Shale have been included in the basal conglomerate. Elsewhere, discontinuous outcrops and ledges show that the formation comprises beds of arkosic conglomerate; olive, thin bedded pebbly arkose (which predominates); and lesser amounts of drab micaceous siltstone and shale. Crossbedding in the coarser clastic units is common.

In thin section, the arkosic variety consists of 80 percent quartz, with lesser amounts of feldspar, biotite, and sericite. The cement consists of broken, angular grains of quartz, shreds of mica, iron ore, and small zircons (?). The cement contains in part fragments of larger quartz grains. These grains, 0.1 to 0.4 millimeter in diameter, have subangular outlines and commonly are represented by a fractured mosaic.

A distinct ridge of these deposits marks the line between Taos and Colfax counties along the east side of Valle Vidal and continues in a southerly direction. Over much of its length, this ridge parallels the fault contact with Precambrian rocks on the west. No thickness measurements were made of the Poison Canyon Formation, but an estimated 1,000 feet are probably present in the area. Maximum thicknesses of the Raton and Poison Canyon formations recorded in the Raton Mesa region and Huerfano Park are 1,700 and 2,500 feet, respectively (Johnson, Dixon, and Wanek, fig. 2).

The Raton Formation is considered a swamp or flood plain facies because of its dark-colored shales and thin coal seams that occur in places throughout the Raton basin. It grades and intertongues with the coarser piedmont facies of the Poison Canyon Formation. The angular unconformity between the Raton and the underlying Cretaceous testifies to the uplift of the Sangre de Cristo Mountains forming at the western margin of the ancient Colorado-northern New Mexico geosyncline. Thus, in the Eagle Nest area, much of the Precambrian detritus was probably derived from local sources.

TERTIARY IGNEOUS COMPLEX

A Tertiary igneous complex is much in evidence in and around Red River. Though diverse in age, composition, and texture, the lithologies probably are genetically related. The complex includes both extrusive and intrusive rock types. A fact not sufficiently emphasized previously is that the volcanics form only one part of this complex. Stevenson (1881, p. 321) made the first mention of igneous rocks in this area, referring to what is now the Red River as Colorado Creek.

Basal Sediments

Gray conglomerate, red and buff feldspathic sandstones, and red tuffaceous silt-stones occur in several small lenses between andesite above and Precambrian below.

The conglomerates are found near the Questa mine, at the mouth of Placer Creek, near the Purkapile prospect, and in Pioneer Creek. Thin, red tuffaceous siltstones, feldspathic sandstone, and a thin nonmarine limestone were found at the Stella prospect, whereas conglomerate and siltstone occur farther along Pioneer Creek toward the Anderson prospect. Red siltstone and conglomerate are found at the base of the andesite northwest of Tetilla Peak, and lenses of red siltstone appear inter-bedded with the andesite breccia higher in the interval.

Small patches of sediment north and east of Tunnel Hill are of interest. One mile to the north, a patch of pebble-granule conglomerate is made up of chlorite schist particles with lesser amounts of quartz and feldspar, all set in a calcite matrix. The color of the rock is mottled green and purple, the green derived from the included chlorite schist and the purple from hematite in the matrix. Bedding is weakly displayed, and although contacts are poor, the conglomerate appears to overlie the mafic gneiss unconformably and to be conformable with the nearby andesite. The rock is similar to the facies at Larkspur Point and for this reason is tentatively assigned to the Magdalena Group, even though its stratigraphic position appears the same as the early Tertiary sediments here described.

About 1,000 feet northeast of Tunnel Hill, another patch of conglomerate is problematic in that it contains sheared rhyolitic material. Contacts are not exposed. It has been assigned to the early Tertiary mainly because of the included material.

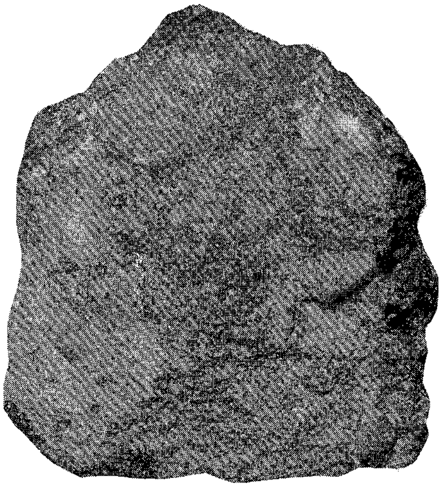
The conglomerate near the Questa mine comprises rounded pebbles and cobbles of Precambrian mica quartzite, granite, and mafic gneiss set in a hard, sandy, feldspathic matrix (fig. 9A). The matrix is medium gray, except in the immediate vicinity of the Questa Mine intrusive, where it assumes a dark-gray or greenish tinge and is accompanied by flakes of white mica a quarter inch in size. The texture of the matrix in thin section is inequigranular and consists of quartz, plagioclase, potash feldspar, mica, and iron ore. Quartz grains 0.5 to 6.0 millimeters in size are subangular and have undulatory extinction. Potash feldspar consists of orthoclase and microcline, which, like plagioclase, occur in grains 0.5 to 3.0 millimeter in size. Small amounts of chloritized biotite may be present, and in the vicinity of Sulfur Gulch, sericite and chlorite are well developed. Here the rock is intensely hard and cannot be easily broken with a hand pick. This effect, plus the production of platy minerals, is attributed to propylitization accompanying the intrusion of the Questa mine stock.

The fine-grained clastics consist of sandstones and dull-red and buff siltstones. Above the mouth of Placer Creek and near the jeep trail, fine-grained, dark-red silt-stone occurs with conglomerate. The siltstone tends to be massive and jointed at this locality. Microscope examination of the rock reveals quartz, feldspar, sericite, and magnetite. Quartz grains, 0.1 to 0.6 millimeter in diameter, are quite angular, with curving edges (fig. 10A). Plagioclase, about 1.0 millimeter in size, is altered to fine sericite shreds. The matrix is a cryptogranular mass stained by hematite. The angular shape of the quartz grains suggests that the siltstone is tuffaceous.

At the base of the exposed east-dipping sequence of andesite, northwest of Tetilla Peak, are poor exposures of conglomerate, arkosic sandstone, and red siltstone. Similar sediments in which the conglomeratic part contains Precambrian fragments are found north of Costilla Pass. They seem to grade into gray and green andesite. Between these two localities, red siltstone is intercalated with andesite breccia.

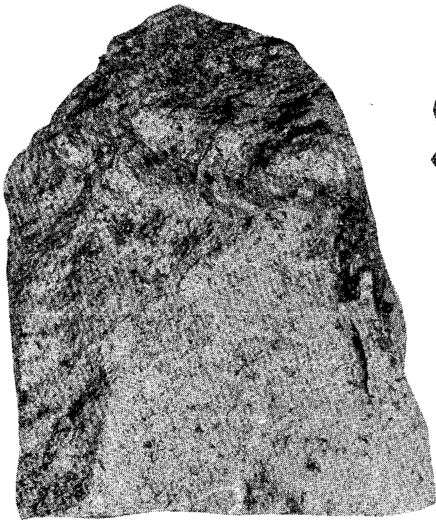
At the Stella mine, a sequence of fine-grained, purple, gray and red clastics interbedded with arkose and thin white, nonmarine limestone is intruded by sills and dikes of intermediate composition. A measured section at this locality is shown in fig. 11. A thin section of one of the finer clastic beds, obtained about 80 feet above the base of the section, shows that quartz grains 0.05 to 1.5 millimeters in dimension are again angular and curved. Plagioclase is present in rare grains, 0.2 millimeter in size, together with shreds of muscovite and small magnetite grains. The fresh water lime-stone occurs at the top of the sequence and is light gray and aphanitic. It contains a few quartz grains 0.02 to 0.05 millimeter in diameter set in a mosaic of sparry calcite of about the same grain size.

The age and correlation of these sediments from several different localities are not certain. These sediments were first described in the Questa mine area by Vanderwilt (1938, p. 612), who drew attention to the problem of assigning them to a particular system of rocks. Further outcrops in the mine area were described by Schilling (1956) and McKinlay (1957), both authors indicating a tentative correlation with the Sangre

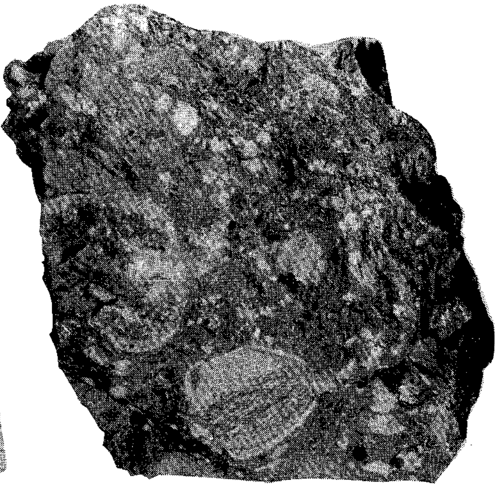


A. *Conglomerate.* Quartzite-pebble conglomerate with medium- to coarse-grained, hard pyritized matrix. X 0.5.

B. *Hornblende granite.* Rio Hondo. Large porphyritic potash feldspars are set in a coarse groundmass which contains abundant mafic minerals. X 0.5.

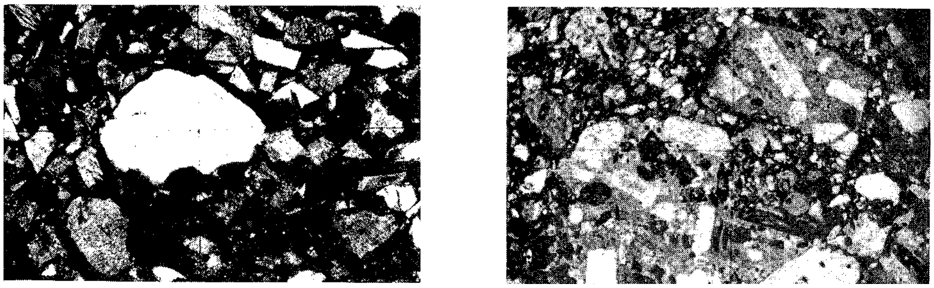


C. *Biotite granite.* Questa mine stock. Inequigranular to aplitic type. The mafic mineral is biotite that occurs in small flakes sparingly throughout the rock. X 0.5.



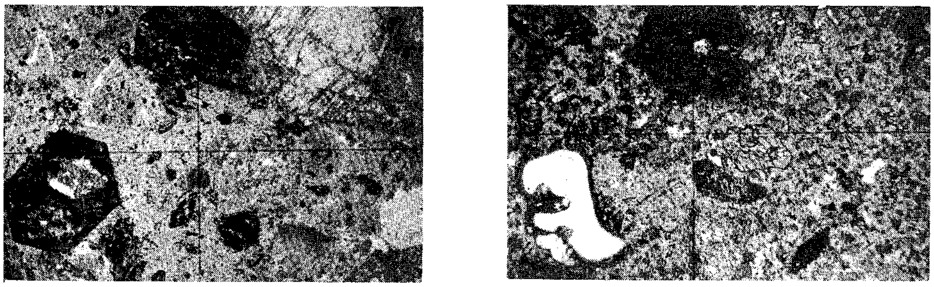
D. *Monzonite porphyry.* Large potash feldspar phenocrysts, small plagioclase, and black plates of biotite are set in a dark-gray groundmass. X 0.5.

FIGURE 9—Tertiary rocks.



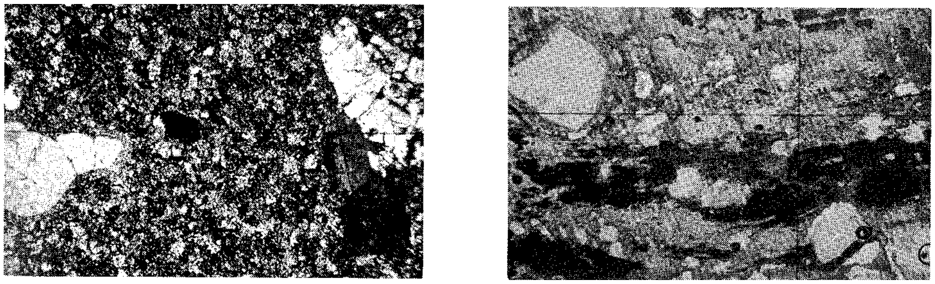
A. *Tuffaceous siltstone. Quartz is* white and angular. Feldspar is gray and has been sericitized. The matrix is hematitic cryptogranular. Plane polarized light, X 56.

B. *Andesite breccia.* Lithic fragments of porphyritic andesite contain white plagioclase and black hornblende and biotite, all set in a matrix of similar material, with some plagioclase altered to clay. Plane polarized light, X14.



C. *Quartz latite porphyry flow.* Euhedral biotite plates with small gray grains of quartz characterize the texture of this rock. A large potash feldspar grain is in the northeast quadrant. Crossed nicols, X 14.

D. *Quartz diorite porphyry.* This rock is similar in composition to latite but the groundmass is coarser. Biotite is euhedral, as is hornblende, but quartz grains are embayed and resorbed. Feldspars are small in this section. Plane polarized light. X 14.



E. *Relica Peak rhyolite porphyry.* Large quartz grains are rounded but not embayed in this specimen. Groundmass consists primarily of fine-grained interlocking granular quartz and feldspar. Crossed nicols, X 14.

F. *Welded tuff* Black lenses are devitrified collapsed pumice fragments. Quartz is white, and feldspar has been completely replaced by sericite. The gray material is quartz, sericite, and other alteration materials. Plane polarized light, X 14.

FIGURE 10—Photomicrographs of the volcanic series.

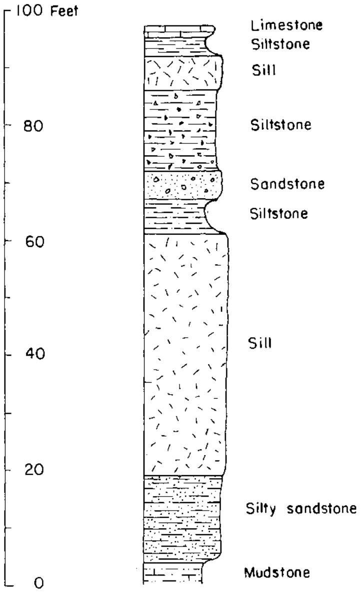


FIGURE 11—Stratigraphic column of early Tertiary sediments at the Stella mine.

de Cristo Formation. However, the hard conglomerate is nowhere seen in the main exposures of the Sangre de Cristo Formation in the Moreno Valley. Furthermore, the splinter form of quartz grains does not appear in the finer-grained clastics of typical late Paleozoic sediments in this region.

A suggestion of Precambrian age occurs near the Questa Mine stock, but mica and chlorite in the matrix appears due to propylitization alone. Further, these sediments are always associated with Tertiary andesite, commonly at the contact with the Precambrian. In Rio Arriba county Bingler (1965, p. 10) described a well-cemented conglomerate in an analogous stratigraphic position in La Madera area and assigned an early Tertiary age.

The lithologies described seem to correspond most nearly to the clastics found below and interbedded with andesite, described by McKinlay (1956, p. 12), near Little Latir Creek. He tentatively assigned to them an early Tertiary age and suggested possible equivalence with El Rito Formation of late Paleocene to early Eocene age. Frequently overlooked is the relation of the Precambrian surface to the overlying volcanics. Erosion in early Tertiary time stripped the sedimentary cover following Laramide orogenesis, similar to the record in the San Juan Mountains (Atwood and Mather, 1932, p. 16). This erosion resulted in a surface of slight relief, referred to as the Telluride peneplain, upon which the Telluride Conglomerate formed in Oligocene (?) time. Analogy appears applicable between the San Juan and Sangre de Cristo mountains, or between other conglomeratic formations of early Tertiary age elsewhere in the Sangre de Cristo Mountains and the deposits described here. For example, some of the coarse clastic beds of the Poison Canyon Formation on the northern slopes of Baldy Mountain, where intruded and metamorphosed by dikes and sills, are not unlike this problematical unit.

The finer-grained facies grade up from the basal conglomerate. However, the tuffaceous red siltstones and thin, fresh water limestones subsequently become buried by the main body of the volcanic series described below.

VOLCANIC SERIES

Andesite Group

Igneous activity was initiated by extrusion and deposition of andesite tuff, breccia, and flows, representing the earliest members of the volcanic series. In mid-Tertiary time, volcanic activity began with the extrusion of materials over a surface cut predominantly on Precambrian rocks. Only one area was recognized where late Paleozoic sediments were directly overlain by Tertiary volcanics: on the divide one mile east of Wheeler Peak village. There, in a fault angle, quartz latite porphyry overlies Pennsylvanian arkose and limestone, which in turn unconformably overlie mafic gneiss.

Along Red River Valley above and below the town in Goose and Placer creeks, the basal andesite unit overlies mafic gneiss. At Red River Pass this basal andesite overlies granite gneiss. Farther northeast, in the vicinity of Tetilla Peak, the basal unit again occurs' above granitic gneiss and quartzite.

In the field, these rocks are usually a distinctive purple, green, or brown, which helps to distinguish them from the latite unit. Color alone, however, is not diagnostic. Where alteration has occurred in the vicinity of the Tertiary intrusives, andesite and latite both have the same color. In such instances, the distinction is made on a textural and compositional basis.

Breccia and Tuff

The best example of andesite breccia was seen along the roadside one and a half miles above Red River. Fragments and blocks of purple and green andesite flow material, more than one foot across, lie in andesite tuff. Bedding of the tuff varies in thickness and is disturbed above and below the blocks. About 45 feet of exposed breccia dip 20°E, but on the west side of the river, the dip is 41°E; 800 feet higher and still farther west, the dip is as much as 73°E. Farther south, coarse breccia can be seen in both banks of Red River at the narrows, near the mouth of Foster Park Canyon. In the summer of 1964, the .Bureau of Reclamation considered the narrows as a possible dam site. Seven holes, each about 100 feet deep, were drilled across the canyon profile. All started and ended in breccia, although a slick plane was encountered about 50 feet below the river bed. This was interpreted as slumping from the canyon walls, and the proposed Zwergle dam was abandoned. We support this interpretation but point out that the reason for the slumping and the difference in attitude of the easterly dips at the first locality is a line of weakness caused by a high-angle, north-south fault along Red River.

Higher on the east bank of the river, breccia is largely replaced by purple andesite flows, commonly 3 feet thick, whereas beds of breccia are only 1 foot thick. A measured section at this locality revealed at least 1,186 feet of andesite, not including the upper part of the mountainside where there are structural complications. Another measured section on the north bank of Black Copper Canyon indicated a thickness of at least 1,494 feet; here, the andesite underlies latite, but the base is concealed by alluvium of Red River.

Tuff, breccia, and thin flows can also be seen in the vicinity of the Caribel mine in Pioneer Creek, at Cabresto Lake, and on the drainage divide between Goose Lake and

Bear Canyon. Northeast of Tetilla Peak, similar units contain small lenses and partings of red siltstone. In this area, the thin-bedded nature of the tuffaceous material is locally well displayed. Tuff and fine breccia are similar in appearance to flow material, especially as phenocrysts can be observed in both types. However, the finely fragmented nature and the powdery weathering of tuff is quite distinctive.

In thin section, the true nature of the particles was recognized as the components of a lithic tuff (fig. 10B). The particles range up to 20 millimeters in size and have an andesite composition, as shown by the presence of plagioclase, hornblende, biotite, magnetite, and rare quartz all set in a cryptocrystalline groundmass. The plagioclase is andesine, An$_{27}$-An$_{50,}$ with strong rhythmic zoning. Some of the untwinned feldspar and other grains exhibiting Carlsbad twinning may be orthoclase, but refractive index tests, using the method of Tsuboi (1923) showed most of the untwinned feldspar to have an index between 1.54 and 1.55, indicating a composition in the oligoclase-andesine range. Mafic minerals are chloritized, and small rounded quartz grains are rare. Hematite dust and chlorite were recognized in the groundmass.

The matrix in which the lithic particles are embedded varies from cryptocrystalline to microcrystalline. The material is composed of small rock particles and crystal grains. Rare microcline, together with composite fragments of quartz, suggests that some of the basement rocks were included in the pyroclastic debris. Zoned plagioclase, mostly andesine, An$_{t\ 5}$ -An$_{4}$ s , is partly altered to clay. Mafic minerals are also badly altered, but morphological evidence suggests the presence of hornblende and biotite. Magnetite grains and hematite dust occur throughout.

Flows

Flow material is a purple or gray porphyritic hornblende andesite that has a fine-grained to aphanitic groundmass. Flow structures and flow breccia are uncommon. Individual flows were not followed for any distance because of poor exposure and variability of the rock types. Hand specimens are characterized by phenocrysts of white plagioclase and dark hornblende laths.

The main porphyritic constituents are 25 to 30 percent plagioclase, 5 to 10 percent hornblende, and 5 to 10 percent biotite; quartz is rare. The groundmass commonly accounts for 50 percent of the rock. Plagioclase is andesine, An$_{31}$-An$_{40}$, and occurs as subhedral to euhedral laths 0.3 to 3.0 millimeters long. Zoning is common, and although reversals were noticed, the rim is usually more sodic. Some untwinned feldspars could be orthoclase, but none was positively identified. Moderate alteration of feldspar to sericite is common. Prismatic laths of hornblende reach 1.5 millimeters in length and may be lamprobolite in part. Alteration products are chlorite and some replacement by biotite. Elsewhere, the latter mineral occurs in hexagonal plates and has brown pleochroism. Morphological evidence suggests the rare presence of a much altered pyroxene. The groundmass is fine-grained to cryptocrystalline and consists of minute grains of plagioclase, hornblende, quartz, chlorite, and sericite and copious amounts of magnetite. The purplish or brown color in hand specimen comes from scattered hematite dust. Flow structure, indicated by crude parallelism of feldspar and hornblende microlites was rarely observed.

Dikes

Andesite dikes are confined to an area north and east of Red River Pass. In the vicinity of upper North Moreno Creek, the strike is northwest, in common with rhyolite and monzonite porphyry dikes. Dikes of andesite are usually only a few feet thick but may be as much as 3,000 feet long. They intrude Precambrian rocks but none of later age. Composition tends to vary, and little microscopic work was done.

One or two dikes in this area are distinctive light gray and speckled with small laths of white plagioclase and needles of black hornblende. In thin section, these microphenocrysts are arranged in a cryptocrystalline groundmass so that a flow structure is apparent, suggesting that the dike was a feeder for extrusive equivalents.

The source of the andesite is not known, although it may be near Latir Peak where McKinlay (1956) recorded a thickness of 2,500 feet. As previously mentioned, the minimum thickness is 1,494 feet, but may be as much as 1,700 feet in the vicinity of Foster Park. Vanderwilt (1938) suggested the possibility of vents at the head of Sulfur Gulch and west of Red River because of the absence of bedding and the accompanying alteration at these localities. Detailed mapping in and around the Questa mine showed that some of the andesite has intrusive characteristics, according to geologists of the Molybdenum Corporation of America.

Age and Correlation

The andesite, definitely the lowest member of the volcanic series, is intruded by dikes and bodies of latite and rhyolite. The absolute age is more difficult to determine because the andesite overlies only Precambrian rocks in the Eagle Nest area. However, if the conglomerate and tuffaceous red siltstone below are early Tertiary, then the age of the andesite may be late Oligocene to early Miocene, because the upper limit is fixed by the emplacement of aplite granite stocks and Miocene faulting. McKinlay (1956) stated that andesite may interfinger with the Amalia Formation, believed to be middle or late Tertiary in age, as the upper beds grade into late Tertiary gravel and are overlain by basalt flows. These flows are believed equivalent to the upper basalts of the Hinsdale Formation, which is Pliocene or late Pliocene (Cross and Larsen, 1935, p. 100). Consequently, the igneous volcanic rocks of the Red River area may be early mid-Tertiary in age and possibly equivalent to the andesites, latites, and rhyolites of the San Juan Mountains, Colorado.

Latite Group

Intrusive and Extrusive Phases

Quartz latite porphyry constitutes the middle unit of the volcanic series. The principal areas of outcrop are north of Cabresto Creek, along the northern bank of the Red River Valley between Sulfur Gulch and Mallette Creek, along the middle reaches of Mallette and Bitter creeks, in Pioneer and Goose creeks, and high on the walls of the upper Red River Valley. With the exception of occurrences in the altered area, this rock type has a distinctive color, as well as characteristic texture and composition.

In the field, fresh latite is recognizable by its white feldspar porphyritic texture, small rounded dark grains of quartz, and black shining plates of biotite all set in a medium-gray, fine-grained to aphanitic groundmass. Hornblende is entirely subsidiary to biotite. Quartz porphyry latite occurs in dikes, sills, and flows.

The mineral composition consists of 30 percent plagioclase, 5 percent biotite, 2 percent quartz, and 2 percent hornblende, all as phenocrysts. Staining tests suggest a much greater proportion of orthoclase in the groundmass than in the andesite, although phenocrysts are rare. The groundmass contains 50 to 60 percent of the rock. Small amounts of apatite and magnetite are also present, together with the alteration minerals chlorite, epidote, sericite, carbonate, and pyrite. Plagioclase occurs in subhedral laths that are commonly 1 to 2 millimeters long, although a few are much longer, usually with polysynthetic or combined polysynthetic and Carlsbad twinning. Composition is mostly oligoclase, with some andesine, An_{10}-An_{36} , and zoning on occasion. Biotite occurs in euhedral hexagonal plates 0.5 to 2.0 millimeters in size and commonly is partly chloritized (fig. 10C). Quartz appears as distinctive, clear, rounded grains and is often partly resorbed. Other smaller grains of intermediate size have the same habit. Myriad microcrystalline quartz grains form at the periphery of the grain and grade into the surrounding groundmass. The width of the peripheral zone bears witness to the amount of assimilation that the grain has undergone. The presence of biotite and quartz is diagnostic. Slender hornblende laths may be up to 2 millimeters long but were not present in every section examined. Similarly, the appearance of orthoclase is unpredictable; it occurs in euhedral grains up to 4 millimeters in length, the extinction, angle is a $P\wedge^{\infty}$ or $x = 8^{\circ}$, and the refractive index is less than that of balsam. It is usually less altered than plagioclase. The groundmass is microcrystalline to cryptocrystalline consisting of feldspar, quartz, and chloritized mafics, with lesser amounts of epidote, magnetite, sericite, and carbonate. Rare grains of apatite may intergrow with the other minerals. In some of the altered areas, quartz predominates, and pyrite may be introduced.

The form of the latite bodies is not fully understood, inasmuch as intrusive as well as extrusive relations can be observed without much change in the texture or composition.

Thus, in the upper Red River Valley on the divide to the east, latite apparently overlies andesite breccias and flows, while farther south, in one area of limited extent, the latite overlies sediments of the Magdalena Group. But on the west side of the valley, the contacts sweep up the steep mountainsides, a phenomenon also observed along Mallette and Bitter creeks. In Bear Canyon, andesite overlies latite. Some of these contacts might be explained by assuming a dissected surface prior to the emplacement of the latite flows, the depressions of which became filled with greater thicknesses of material. Elsewhere, bodies of latite probably intruded the pre-existing andesite volcanics. Later structural deformation and erosion produced the pattern now seen in plan. Further evidence of the partial intrusive nature of the latite is provided by the numerous dikes of similar composition and by a small body of latite breccia.

Larger intrusive bodies should be present, such as those mentioned in the San Juan Mountains (Cross and Larsen, p. 19).

Coarse latite breccia occurs in one small area high on the drainage divide between Red River and Cabresto Creek at the head of Bobita Gulch. This rock type forms a small topographic feature known as Elephant Rock and is largely composed of medium-gray breccia made up of fragments of latite 1 to 3 inches in size. The fragments are closely packed and brecciated along their edges. Smaller pieces and mineral grains make up the matrix. The composition of the fragments is similar to that described above, although quartz phenocrysts are much less abundant, and the matrix differs in containing additional amounts of hematite and calcite.

Surrounding the main exposure of latite are finer-grained materials similar in texture to the lithic tuffs previously described. In all, the intrusive nature of this body, as determined from the evidence available at the contacts, is uncertain; although intrusive contacts have been reported in other areas west of Sulfur Gulch for similar rock types. Ishihara (1964, p. 17) acknowledged that the origin is problematical but interpreted the body as a volcanic agglomerate.

Dikes of latite definitely intrude andesite, as on the south side of Goose Creek and elsewhere. In the area of Goose Creek, the dike trend is north-south. South of Comanche Creek the trend becomes northwesterly, where the Pennsylvanian is intruded; and definitely northwesterly along North Moreno Creek where the country rocks are Precambrian.

Dikes of latite are more common than those of andesite. Widths are ordinarily 5 to 10 feet and may be much more. The dikes can be traced up to half a mile; in one instance, up to 2 miles. They are recognized by their medium- to dark-gray color, jointed character, and prominent outcrops. Texture and composition are much the same as previously described, consisting chiefly of phenocrysts of plagioclase, biotite, and quartz. Plagioclase ranges from $An_{10}An_{40}$ but averages near An_{30}. Quartz phenocrysts, where present, are resorbed. Biotite occurs in hexagonal plates and exhibits medium to dark-brown pleochroism. Hornblende laths are pleochroic in shades of green. Both the mafic minerals are moderately chloritized and may be associated with magnetite grains. The groundmass is composed of microcrystalline quartz, plagioclase, potash feldspar, chloritized mafics, and apatite. Calcite and sericite have been identified in altered dikes and may be after plagioclase.

Age and Correlation

Latite is younger than andesite and in most places seems older than rhyolite. The minimum thickness, as measured in a section near Black Copper Canyon, is 519 feet. The apparent thickness of discordant bodies is 2,000 feet.

The quartz latite porphyry, described in the Eagle Nest area, is correlated directly with the Latir Peak latite (McKinlay, 1956, p. 14).

Rhyolite Group

Rhyolite forms the third member of the volcanic series. In general, the rhyolites are light colored, porphyritic, and fine grained and occur as dikes, plugs, flows and tuffs. In contrast to the latite, texture varies more with the mode of emplacement. This group has been subdivided according to mode of emplacement and variations in texture; composition for the most part remains constant.

Dikes and Plugs

A swarm of rhyolite porphyry dikes first noted by Lindgren, Graton, and Gordon (1910, p. 80) strike northwestward in the Rio Hondo, near Amizette. The swarm continues along South Fork, but a flattening of dips to the west causes an arcuate pattern in the cirques around Vallecito Mountain. Another north-south group intrudes the Pennsylvanian rocks in the area between Comanche Creek and Taos Peak. A third group is subparallel with dikes of latite and monzonite porphyry in the area of North Moreno Creek, where the trend is northwest. Thickness is commonly 15 to 25 feet, although the dikes in Rio Hondo usually attain as much as 80 feet. The lengths are variable and in part discontinuous, but the dikes can be traced for 1 to 2 miles in all the areas mentioned.

In general, rhyolite porphyry dikes may be recognized by their bold outcrop, light color, and the feldspar and quartz phenocrysts as large as 7 millimeters. Differential weathering leaves the dikes as near-vertical walls in the sides of the Rio Hondo valley. Poorly developed chilled zones can be seen along the contacts.

In thin section, potash feldspar, mostly orthoclase, exhibits subhedral outlines; some intergrowth with vermicular quartz is possible. Other grains with 2V = 25 to 30° may be soda sanidine (anorthoclase). Moderate alteration to sericite is usual. Quartz grains are distinctive by virtue of their embayed outlines and rounded, resorbed margins (fig. 10E). Infrequently, quartz preserves idiomorphic hexagonal outlines. Plagioclase in subhedral grains up to 2 millimeters long occurs mostly as albite, An_2-An_{11}, with some alteration to sericite. Biotite, 0.5 to 1.5 millimeters long is pleochroic and dark green to light brown, becoming altered and associated with magnetite grains. The mafic mineral is not always present. The groundmass consists of fine (0.05 millimeter) anhedral grains of quartz and feldspar, with lesser amounts of biotite and sericite. No flow structures were observed.

A large body of rhyolite immediately northwest of Wheeler Peak Village is here called the Relica Peak rhyolite plug. It has been dissected by erosion along a structural line of weakness (pl. 1). The plug consists of fine-grained, light-gray or cream rhyolite porphyry. An aphanitic groundmass is studded with small white crystals of feldspar, small dark angular grains of quartz, and a few specks of black biotite. Few fluidal structures were detected either in the field or in thin section in the main part of the plug, and they are only poorly developed at the contact. The Relica Peak rhyolite is regarded as a plug because of its crosscutting relationships with adjacent rock types. A poor exposure in a side gulch one mile north-northwest of Wheeler Peak Village suggests that latite is domed by the underlying rhyolite, which is lirnonitized and brecciated. On the southwest side of the body, Precambrian mafic rocks are sheared and brecciated at the contact. From the floor of the Red River Valley to the top of Relica Peak, 2,000 feet of rhyolite is exposed. McKinlay (1956) noted rhyolite plugs to the north in the Costilla and Latir Peak quadrangles.

This type of rhyolite is also found in the drainage divide between Red River and Cabresto Creek where rhyolite overlies andesite and latite. The rhyolite has been divided into two parts: a fine-grained porphyry with little flow structure and an overlying welded tuff. The fine-grained porphyritic type also occurs along the northern bank of Cabresto Creek and above the Enderman mine in Bitter Creek overlying Precambrian rocks and overlain by the welded tuff.

Under the microscope, the rhyolite porphyry contains 5 to 10 percent potash feldspar, 5 to 15 percent quartz, 2 to 10 percent plagioclase, and 2 percent biotite, all as phenocrysts. The microcrystalline groundmass, which accounts for 60 to 80 percent of the rock, contains potash feldspar, quartz, plagioclase, chloritized biotite, and magnetite, with lesser amounts of ilmenite, sericite, and apatite. Potash feldspar is orthoclase, sanidine having been tentatively identified only once. Grain size ranges from 0.5 to 4.0 millimeters, 2V is large, and Carlsbad and Baveno twins can be seen. Moderately small 2V in other grains suggests anorthoclase. Weak alteration to sericite occurs along cleavages, and little "clay" is at grain boundaries. Quartz is anhedral, 0.2 to 3.0 millimeters in diameter; the grains are rounded and may be partly resorbed in the groundmass. In some sections, pseudohexagonal outlines were observed and probably represent oblique sections cut through the dihexagonal pyramidal crystals observed in the Relica Peak rhyolite plug. Rare graphic intergrowths of quartz and orthoclase were noticed. Plagioclase up to 4 millimeters in length, subordinate to potash feldspar, is a sodic albite to sodic oligoclase, An_1-A_{16}. Some replacement by potash feldspar is suggested. Biotite is subhedral to euhedral, 0.1 to 0.6 millimeter in size, pale brown but green where chloritized. Secondary mica is interstitial in the groundmass, together with specks of magnetite and rare ilmenite.

A similar variety constitutes the upper part and bulk of McElvoy Hill. The eastern part of the hill falls within the Philmont quadrangle, and has been mapped as dacite porphyry (Robinson, and others, 1964). However, the distinctive light color and texture show that rhyolite covers the western slopes over a vertical distance of 1,500 feet and extends eastward 0.5 miles into the adjacent quadrangle. The lower part of the rhyolite is probably intrusive; in the saddle north of the hill, the contact apparently crosscuts the easterly dipping Mesozoic sediments. The eastern part shows layers of rhyolite intruded as sills above and below the Dakota Sandstone. The easterly limit suggests that the lowest of these sills is above and discontinuous with the westerly part of the Palisades dacite porphyry located in lower Cimarron Canyon.

Welded Tuff

Rhyolite welded tuff appears to overlie the fine porphyritic variety in the vicinity of Sawmill Mountain and in Bitter Creek at the northern limit of the map area.

In the field, this rock is easily recognized by characteristic black streaks and lenses of flattened pumice. Otherwise, it is light gray with white felsic material and quartz grains set in an aphanitic matrix. The collapse of pumice fragments perhaps was caused by the weight of overlying rock during cooling. The fragments vary from 12 to 20 millimeters in length and up to 4 millimeters in width.

In thin section, pumice lenses are brown and have devitrified into a microcrystalline to cryptocrystalline mosaic of quartz grains, apparent under crossed nicols and high magnification. Pore space has been eliminated and a eutaxitic structure persists (Ross and Smith, 1961, p. 34) (fig. 10F). The other major constituents are quartz and sericite. Quartz occurs in grains 0.1 to 0.5 millimeter in size and varies in outline from euhedral to rounded, partly resorbed grains, against which pumice lenses are molded. The remaining material is made up of fine quartz and alteration products. Feldspar has been completely replaced by sericite and quartz (Ishihara, 1964, p. 24).

In Sawmill Mountain, total thickness of the rhyolite including the fine-grained porphyritic type as well as the welded tuff, is 1,365 feet, based on leveling and estimates from the geologic map. The upper welded tuff is at least several hundred feet thick, but because of the lack of good exposures, a definite figure cannot be cited. Ishihara (1964, p. 22) gave a thickness of 1,700 feet for the welded tuff alone. East of Latir Lake, McKinlay (1956) suggested a thickness of 1,000 to 1,500 feet for the rhyolite including a lower, partly welded layer 200 feet thick. In many other places, he believed a tuffaceous phase is capped by an aphanitic felsite.

Other than indicated at Sawmill Mountain, a stratigraphic sequence has not been worked out in the map area, although the same relationships observed by McKinlay may well obtain, because the rhyolites between the two areas probably correlate.

Locally dips of these and other units are steep, and may be related to deposition on an irregular topographic surface. Attitudes could be equally attributed to rotation due to faulting, or landslides, observed on several occasions.

Lithic and Crystal Tuff

Rhyolite tuffs, bearing fragments of crystals and some fine rock chips occupy an area from Bitter Creek eastward to Van Diest Peak.

In the field, this rock weathers gray to white. In places, bedding is crude, and the rock tends to crumble badly, masking the structure. Lithic fragments up to 15 millimeters in size are set in a fine-grained matrix of rock and crystal fragments. Breccia of purple felsic material was seen in the tuff on the south side of Van Diest Peak, and in other places fragments of amphibolite (?) were included. In hand specimens, cream and gray-white feldspars, dark grains of quartz, and altered biotite can be recognized.

In thin section, the lithic part consists of angular fragments containing phenocrysts of potash feldspar, plagioclase, quartz, chloritized biotite, and a few laths of white mica, all set in a groundmass composed predominantly of angular quartz grains. The matrix surrounding the fragments consists of plagioclase, quartz, and minute flakes of light and dark mica and sometimes limonite after pyrite.

Those parts that are predominantly crystal tuffs are readily distinguished by angular and broken grains of quartz ranging in size from 0.1 to 2.0 millimeters. Some particles appear to be glass. Other mineral constituents include relatively unaltered potash feldspar, 0.2 to 1.0 millimeter in size. Plagioclase grains 0.1 to 0.5 millimeter long are albitic, An_2 –An_5. Biotite, 0.5 millimeter in size, is chloritized and crushed by adjoining mineral grains. Finer material is brown and consists essentially of the same minerals with the addition of sericite. One or two lithic fragments may be present, and bedding can be detected.

Flows

These flows, found on four topographic highs stretching from Black Mountain on the west to a point half a mile west of the mouth of Foster Park Canyon, are believed to be erosional remnants of flow material previously covering a much wider area. Fluidal structures were observed in all but the remnant on Black Mountain. The remnants overlie the earlier volcanics of intermediate composition, which in turn rest on the Precambrian basement (p1. 1, D - D'). The flows described here differ from the fine porphyritic type previously described, inasmuch as the lack of flow structures in the fine porphyritic type stems from its intrusive character, where cooling was slower and mixing greater after eplacement.

In the field the flows usually have a faint pink or purplish tinge that, on occasion, approaches some of the unaltered andesites. Hand specimens are characterized by small white phenocrysts of feldspar enveloped by hairlike threads of purplish-brown material.

Thin sections show that the feldspar is commonly orthoclase, occurring in prisms 0.2 to 0.8 millimeter in width set in a microfelsic to cryptofelsic groundmass containing quartz, potash feldspar, plagioclase, and magnetite dust. Much of the quartz is spherulitic. Lenses of siliceous cryptocrystalline material 2 to 8 millimeters in length and up to 1 millimeter in width are possibly devitrified glass fragments, usually contorted and partly rolled up. Flow structure is parallel except around the orthoclase phenocrysts. The flow banding is visible because of the variable concentrations of iron ore dust in the rock constituents.

INTRUSIVE SERIES

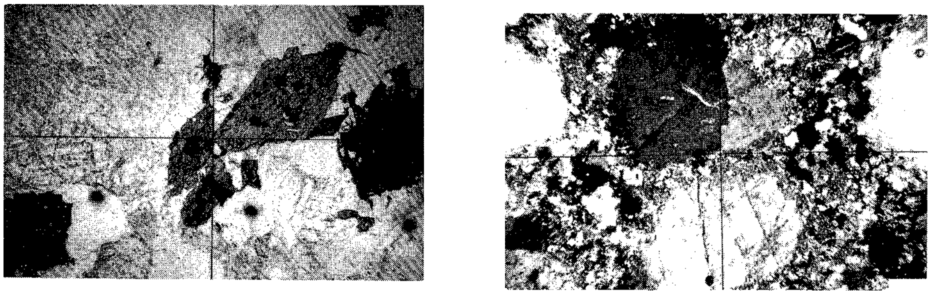
Hornblende Granite

Distribution and Lithology

Hornblende granite occurs at several localities along the western margin of the quadrangle. In Cabresto Creek, it intrudes Precambrian quartzite; in Rio Hondo, it cuts the mafic gneiss group. There, only part of a large body is included in the map area, the remainder occurring in the adjoining Questa quadrangle on the west. The granite is elongated in a northwesterly direction, stretching from Rio Hondo to Columbine Creek in the Questa quadrangle. The length is about five and a half miles, the width approximately 1 mile.

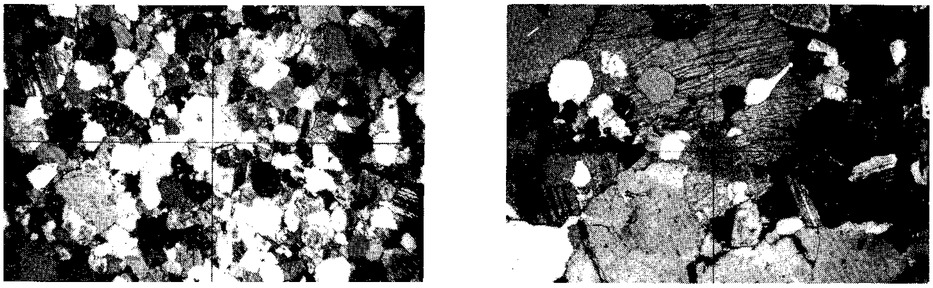
The rock is a medium- to coarse-grained porphyritic biotite-hornblende granite (fig. 9B) consisting of white to faintly pink phenocrysts of orthoclase up to 15 millimeters long, white plagioclase up to 10 millimeters long, and quartz grains about 1 millimeter in diameter. The mafic minerals are dark green laths of hornblende up to 10 millimeters long and black shining plates of biotite with dimensions up to 4 millimeters.

The texture, as seen in thin section, is hypidiomorphic-granular (fig. 12A). Additional minerals identified under the microscope are magnetite, sphene, apatite, and zircon. Orthoclase is anhedral, contains much string and patch perthite, and has been slightly altered to sericite. Growth zones are numerous, with some small intergrown quartz grains. Plagioclase is subhedral; stubby laths bear witness to a little replacement by potash feldspar. Composition is either albite or oligoclase, An_5-An_{28}, and is also zoned. Quartz grains sometimes show undulatory extinction and occur in an inter-locking mosaic reminiscent of Precambrian granite. Hornblende, pleochroic from light to dark green, is recognizable by lathlike form and distinctive cleavage in cross sections. Biotite, pleochroic in brown colors, replaces hornblende to some extent. Magnetite is associated with the chloritized mafic minerals. Sphene is found in characteristic idiomorphic acute-angled rhombic sections, some of which are only partly



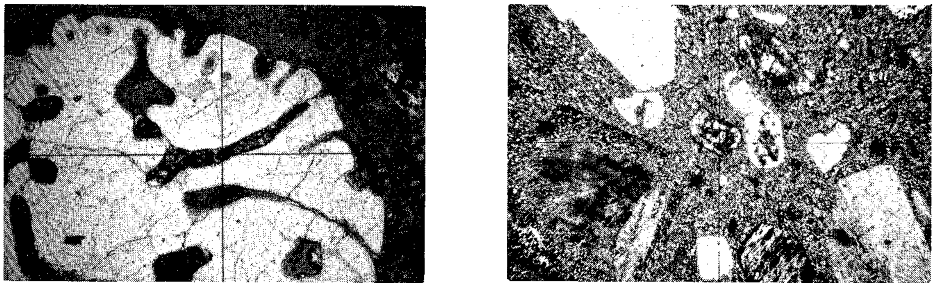
A. *Hornblende granite. Cross* sections of euhedral hornblende, black biotite, potash feldspar in southeast quadrant and light quartz in southwest quadrant. Texture is hypidiomorphic granular. Crossed nicols, X 14.

B. *Aplite porphyry.* Red River stock. Subhedral phenocrysts of perthitic orthoclase are set in a fine-grained groundmass of quartz, feldspar, and biotite. Crossed nicols, X 14.



C. *Aplite.* Red River stock. Equigranular allotriomorphic mosaic of orthoclase, quartz, albite, and biotite. Crossed nicols, X 56.

D. *Biotite granite.* Questa mine stock. Inequigranular texture. Minerals are biotite, under crosshairs; perthitic orthoclase at top; albite and white quartz. Crossed nicols, X14.



E. *Quartz porphyry. Typical* radially disposed lenticular replacement embayments of the groundmass in a quartz grain. Plane polarized light, X 14.

F. *Monzonite porphyry.* Potash feldspar has rectangular outlines. Plagioclase lath is in southeast quadrant, black biotite is euhedral, whereas quartz is rounded and white. Groundmass is fine grained and partly altered. Crossed nicols, X 14.

FIGURE 12—Photomicrographs of Tertiary intrusive rocks.

developed. Minute laths of apatite, with low birefringence and relief, are embedded in other minerals, together with rare prisms of zircon.

Specimens from the granite bodies in Cabresto Creek are similar. Texture is coarsely porphyritic to seriate. The groundmass sometimes has a slight pink color, and the amount of hornblende is usually less because of replacement by biotite. Some graphic intergrowth of quartz with potash feldspar may be present. Plagioclase ranges from An_8 -An_{24}. Inclusions of similar but finer-grained granite material having high percent-age of biotite are fairly common throughout the rock. Feldspars are much altered. Modal analyses of hornblende granite are given in table 5.

TABLE 5 –*Modal Analyses of Tertiary Granites*

Mineral	Hornblende granite, Rio Hondo	Hornblende granite, Cabresto Creek	Aplitic biotite granite, Red River	Inequigranular biotite granite, Questa mine	Inequigranular to porphyritic biotite granite, Bear Canyon	Inequigranular to porphyritic biotite granite, South Fork	Inequigranular biotite granite, Arroyo Seco
Quartz	36.7	36.5	43.7	42.5	40.6	42.2	51.9
Potassic feldspar	32.8	44.8	45.7	38.8	37.6	39.6	35.5
Plagioclase	22.7	11.7	8.5	17.6	20.6	16.7	9.8
Biotite	3.9	5.0	0.8	0.6	1.1	1.8	2.3
Hornblende	2.0	0.8	–	–	–	–	–
Other	2.0	1.5	1.2	0.6	0.2	–	0.6
Total %	100.1	100.3	99.9	100.1	100.1	100.3	100.1

Small bodies of granite porphyry (not shown on map) are exposed in lower Red River Canyon. The largest is a small plug in the upper part of Sulfur Gulch. In this rock, in addition to orthoclase, the plagioclase is near An_{10} although it varies to a more calcic variety. The mafic minerals are biotite and lesser amounts of hornblende, giving the rock characteristics of the hornblende granite, as well as of the biotite granite, although it cannot be correlated with either. This plug is 800 feet in diameter and roughly circular. According to Carpenter (1968) its roots have largely been destroyed by aplitic flooding and replacement at depth. Hydrothermal alteration is pervasive.

Age

In the Rio Hondo, this granite only intrudes Precambrian mafic gneiss because rocks of younger age are absent. The granite is itself intruded by a swarm of rhyolite dikes, previously described, which are probably latest Oligocene age. Parallel to this swarm are a few other dikes of uncertain age and composition. Although exposures are poor, these dark-colored and fine-grained dikes are also believed to cut the Rio Hondo Granite. The texture, as seen in thin section, is inequigranular, tending to be ophitic, reminiscent of the Precambrian diabase dikes. They contain plagioclase, perthitic orthoclase (?), pyroxene, hornblende, biotite, and quartz. Such a composition does not correspond to that of any other rock in the area, although the orthoclase suggests a composition near latite. However, the characteristic plates of biotite and rounded grains of quartz are absent. In contrast, though, the strike is northwesterly and, paralleling the rhyolite dikes, may be interpreted as implying a Tertiary age rather than Precambrian, because the preferred trend of the diabase dikes in this area is east-northeast. The dikes have tentatively been assigned to the post-aplite group of andesite dikes because definite evidence for a Precambrian age could not be found.

In adjacent areas the hornblende granite has been regarded as Tertiary because it appears to intrude the Latir Peak latite (McKinlay, 1956, p. 18). The relationship is obscure as, south of Rito Primero, the granite was found in contact with a latite dike that appeared to have been emplaced along its contact.

Absolute age determinations by two different methods disagree as to the age of this granite. Naesser (1967, p. 1525) obtained two determinations by the fission track method, using apatite and sphene. These were 27 ± 6 and 34 ± 5 m.y., respectively. Rehrig (1969) collected samples of the Rio Hondo granite from Italiano Creek. The potassium-argon method determination of 50.9 ± 2.8 m.y. is compatible with the pre-Oligocene age suggested by the cutting dike relationships, and the age of the hornblende granite is considered as Eocene.

Augite Diorite Porphyry

Several large and extensive dikes are found on the north side of Baldy Mountain. Most of these are in the extreme northwest corner of the Philmont quadrangle, but a few lie in the northeast corner of the Eagle Nest area.

The dikes have two main trends, north-northeast and west-northwest. The first set predominates and extends several miles toward the Colorado-New Mexico line. Widths vary from 30 to more than 100 feet. The dikes are characterized by regular pattern and continuity of strike. Much of the outcrop is exposed as low ridges along drainage divides. In hand specimen, small crystals of light-colored feldspar and ferromagnesian minerals pepper the freshly broken surface. The rock is well jointed and commonly stands above the host Poison Canyon sediments' as a rocky ledge.

Under the microscope, the main mineral components are 25 percent plagioclase, 15 percent augite, 5 percent hornblende, and rare quartz phenocrysts. Plagioclase is andesine near An_{40}, euhedral to subhedral and moderately altered to sericite. Augite is characterized by octagonal sections, some of which have been partly replaced by chlorite. Hornblende occurs in slender laths up to 2.0 millimeters long. A few small angular grains of quartz are present. The groundmass constitutes 40 percent of the rock and is made up of quartz, chlorite, feldspar, sericite, and iron ore. Grain size is near 0.05 millimeter.

In the vicinity of Baldy Mountain augite diorite porphyry dikes cut sediments of Paleocene age and appear to be geometrically and genetically related to quartz diorite porphyry and quartz monzonite porphyry. The age of these intrusions may be Oligocene or later and, in part, is contemporaneous with the igneous activity in the Red River district. Pettit (1946, p. 20) considered these dikes as localized by faulting, evidence for which is given later.

Quartz Diorite Porphyry

The bodies of quartz diorite porphyry in the Moreno Valley are somewhat removed in space from the igneous activity so far described in the Red River area. But in age and composition, they show some similarity. The numerous sills and dikes in the Baldy-Cimarron Range are among the earliest representatives of the intrusive series of the mid-Tertiary igneous complex represented in the Eagle Nest area.

Sills and Dikes

The occurrence of quartz diorite porphyry bodies in the Eagle Nest area, and the adjoining Cimarron Mountains to the east, is mainly confined to sills and dikes. Within the map area, they intrude sedimentary rocks of Cretaceous and early Tertiary age.

Sills of porphyry of various dimensions are found in and around Scully Mountain and Iron Mountain, and because they are sometimes discordant in relation to the bedding of the rocks they intrude, some may be regarded as dikes. The Scully Mountain intrusive is discordant at the surface with various formations of Mesozoic age, while at the same time probably being floored by the Sangre de Cristo Formation of upper Paleozoic age, and therefore, has the characteristics of a laccolith.

In the area of Elizabethtown, sills crop out as hummocky low hills and ridges having a sparse grass cover. The sills dip to the east at moderate to low angles, as do those in Baldy Mountain and Touch-Me-Not Mountain; whereas in the vicinity of Iron Mountain, Grouse Gulch, and at Mills Divide, they are flexed into an anticlinal fold. Most of the outcrops are similar to those at Elizabethtown, although at some localities the bare rock may be exposed in cliffs and ledges.

In hand specimen, this rock type contains phenocrysts of white plagioclase, rounded quartz grains, and dark plates of biotite and laths of hornblende, all set in a fine-grained gray groundmass. The dimensions of the phenocrysts are 1 to 3 millimeters. Ledges are well jointed, and thickness of sills ranges from a few feet to several hundreds of feet. In the Cimarron Mountains, Robinson and others (pl. 5) indicated thicknesses in excess of 1,000 feet.

Under the microscope the proportion of phenocrysts is 30 percent plagioclase, 10 percent hornblende, 10 percent biotite, and 5 percent quartz. The groundmass, which varies from fine grained to aphanitic, contains 45 to 60 percent of the rock. Staining tests with sodium cobalt-nitrate suggest that minute grains of orthoclase are present in the groundmass. Quartz grains, up to 2 millimeters in diameter are rounded, embayed, partly resorbed, and reminiscent of those in latite in the Red River area. They may have been included in the magma at a late state and clearly contrast with other grains that are idiomorphic and regarded as phenocrysts (fig. 10D). Plagioclase, about 1 millimeter long, is subhedral to euhedral, is commonly zoned, and has the composition of oligoclase, An_9-An_{31}. It is moderately altered to fine sericite. Hornblende is characteristically developed in laths 1 to 2 millimeters long, less frequently in rhombic cross sections, some of which display twinning. It has a deep green color and may be partly chloritized. Biotite plates, about 1 millimeter in size, are also chloritized. Rare potash feldspar grains are usually altered.

The phenocrysts are set in a fine-grained groundmass of an aggregate of quartz, plagioclase, orthoclase (?), hornblende, and biotite. Accessory minerals include magnetite and apatite and the alteration minerals chlorite, sericite, and calcite. No flow structures were seen.

Lindgren, Graton, and Gordon (p. 94) used the term "monzonite porphyry" with reference to this rock. Although useful in the field, this term does not take into account the subordinate role of orthoclase to plagioclase or the composition of the plagioclase. The term does, however, imply intrusive and textural characteristics so well displayed. On the other hand, Robinson and others (pl. 1) referred to the same rock as "dacite porphyry," which the texture resembles in places; but the implied plagioclase composition and quantity of orthoclase, plus the extrusive connotations, are undesirable. The rock is believed to be a quartz diorite porphyry, or granodiorite, which captures the textural and chemical implication of the previous classifications.

Bodies of quartz diorite porphyry intrude Cretaceous shales and the coarse clastics of the Raton and Poison Canyon formations. At the contact with the calcareous shales of the Smoky Hill Marl, a suite of contact-pyrometasomatic minerals has been produced. Little alteration occurs at the contacts with the Paleocene sediments, other than local baking.

In the upper part of South Ponil Creek, a quartz monzonite variety is partly exposed. This rock is characterized by porphyries of potash feldspar and a lighter color than the normal facies. In places, it is cut by small quartz veins. In thin section, the porphyritic mineral components are 20 percent quartz, 15 percent orthoclase, 15 percent plagioclase, 10 percent biotite, and 5 percent hornblende. The groundmass, which makes up 35 to 40 percent of the rock, contains a granular mass of quartz, potash feldspar, plagioclase, iron ore, shreds of ferromagnesian minerals, and rare apatite (?). The dimensions of this body are unknown, although its presence may have far-reaching implications with regard to uplift and mineralization in the Baldy Mountain area.

Based on field evidence, the quartz diorite porphyry is at least post Paleocene, and apparently, in part, contemporaneous with the major epoch of thrusting in late Eocene or early Oligocene time. A potassium-argon date made on a sample taken from the correlative Palisades sill in Cimarron Canyon by Armstrong (1969, table 1), gave 33.8 m.y., corresponding to middle Oligocene time. Evidently emplacement of quartz diorite porphyry may be an early phase of the middle Tertiary igneous complex.

Biotite Granite

Distribution

Stocks of biotite granite occur in and around the map area. The Red River stock lies immediately north of the town and is further exposed in Mallette and Bitter creeks. The Questa Mine stock, only partly in the map area, is at the confluence of Sulfur Gulch and Red River. Small dikes and plugs lie east of Sulfur Gulch in the lower part of Red River Valley and to the west opposite .the mouth of Columbine Creek in the Questa quadrangle. To complete the regional picture, mention is made of the Flag Mountain (Bear Canyon) stock some three miles west of Sulfur Gulch. Furthermore, ten miles south of Flag Mountain and in the southeast corner of the Questa quadrangle, McKinlay (1957) mapped another biotite granite. Gruner (pl. 13) had previously indicated this body in the area of Opal Peak and Cuchilla del Medio. We show that this body extends into the Eagle Nest area where it is exposed in Arroyo Seco and in Manzanitas Canyon. Other smaller exposures were also found in South Fork. The distribution of these granites is shown in fig. 16, and the comparison by modal analyses is given in table 5.

Red River Stock

The Red River stock is fairly well exposed in Mallette and Bitter creeks. The exposed shape is irregular. Along its maximum dimension, which runs north-south, it outcrops for more than 3 miles, but the width varies between one and one and a half miles in an east-west direction.

In general, the rock is light colored and varies in texture from aplitic to aplite porphyry and granite porphyry. In the coarser-grained varieties, feldspar 2 to 3 millimeters in size, quartz 1 millimeter in diameter, and biotite up to 3 millimeters in length can be recognized in hand specimens. The aplite phase is a uniformly fine-grained quartzo-feldspathic rock, sparingly peppered with biotite.

A ridge developed on the granite marks the drainage divide between Mallette and Bitter creeks. Steep cliffs of well jointed rock are numerous in the lower part of Mallette Creek. The stock intrudes the rhyolites of Sawmill Mountain on the west side and rocks of intermediate composition on the north and east sides. The southern margin is concealed by alluvium of Red River. This contact is an abrupt linear feature and probably marks the line of the Taos Cone fault because of a well-defined triangular facet on the southern end of the Mallette-Bitter creek drainage divide (fig. 2A). Contacts with adjoining rock types are poorly exposed because of the forest cover and widespread alteration in this area. Remnants of mafic gneiss, rhyolite, and latite on the upper surface of the stock are probably part of the roof at the time of emplacement.

In thin section, the porphyritic variety is studded with subhedral phenocrysts of perthitic orthoclase, moderately altered to sericite and corroded at the rims (fig. 12B). A little vermicular quartz intergrows with orthoclase in the groundmass. Quartz phenocrysts are clear but anhedral and corroded. Subhedral to euhedral laths of plagioclase have a composition of sodic oligoclase, An_{11}-An_{13}. Replacement is by sericite, and some small laths of apatite are included. Subhedral biotite, tending to be ragged, is pleochroic light to dark brown. The groundmass has a grain size of 0.1 to 0.2 millimeter in diameter and consists of feldspar, biotite, magnetite, and rarely apatite and zircon. The proportion of phenocrysts to the groundmass is 46:54, with orthoclase forming more than half the phenocrysts.

The aplitic variety consists of an allotriomorphic granular mosaic of orthoclase, quartz, plagioclase, and biotite (fig. 12C). Seen under the microscope, the grain size varies from 0.2 to 0.5 millimeter. Quartz grains are clear, equant, and subhedral. Anhedral orthoclase is weakly altered to clay. Plagioclase is an albite, composition An_6-An_9, and occurs in stubby subhedral grains. Biotite flakes are pleochroic light to dark brown. Apatite may be included in the feldspars, and magnetite is sparsely scattered throughout the rock.

Questa Mine Stock

The Questa mine (Sulfur Gulch) stock is composed of various phases of biotite granite. As exposed, the stock is roughly elliptical in outline, being about three quarters of a mile wide. It is elongated around the mouth of Sulfur Gulch, with the long axis trending north one and a half miles. Only part of the stock lies within the map area, and because it has already received much attention was not examined again in detail. The granite was first described by Larsen and Ross (1920), who referred to it as an alaskite porphyry. Vanderwilt (p. 617) used the term "albite granite," whereas Schilling (1956, p. 26) referred to it as soda granite. The term "biotite granite" as used herein includes all the granite intrusives of the region other than the hornblende granite already described.

The granite is well exposed in the steep walls of Sulfur Gulch. It intrudes both Precambrian rocks and the volcanic series. Small dikes and plugs east of Sulfur Gulch intrude fine-grained andesite and have sharp contacts. Some evidence of a chilled margin was seen on the east side of the main stock. According to Schilling (1956, p. 25), the Sulfur Gulch stock intrudes all but the uppermost part of the rhyolite group. Figure 9C shows a hand specimen of the common inequigranular type.

In thin section, the rock has a perthitic to inequigranular texture (fig. 12D). Potassium feldspar is orthoclase, commonly with a string-type perthite, and is slightly altered to clay. Quartz is found in subhedral grains. Plagioclase also occurs in subhedral grains, slightly altered to minute shreds of sericite and clay at the center. Zoning is weak and the plagioclase is mostly albite and sodic oligoclase, An_4-An_{13}. Magnetite is associated with ragged biotite, pleochroic light to dark brown. Zircon and sphene (?) were seen on occasion.

The contact metamorphic effect of this intrusion is masked by the widespread alteration effects. Nevertheless, haloes of metamorphism around this and other stocks in contact with the volcanic rocks have been noted by Ishihara (1967). These effects give rise to a spotted andesite that features biotite clots. Associated pyrite, sericite, clay and chlorite were also developed, although most of these changes have been attributed to later alteration effects.

Flag Mountain Stock

The Flag Mountain (Bear Canyon) stock, outside the map area, is similar to the Sulfur Gulch intrusive both in texture and composition. Composition of the plagioclase, as determined in thin section, is albite-oligoclase, An$_9$-An$_{13}$. A modal analysis is also given in table 5.

Arroyo Seco and South Fork Intrusives

Biotite granite occurs in Arroyo Seco, in Manzanitas Canyon, and in small areas in South Fork. In South Fork, poor, isolated exposures are found in the side and at the base of a great amphitheater made up of several cirques. More extensive outcrops are found in a belt across Manzanitas Canyon and northwestward to Arroyo Seco and beyond to the margin of the map area. Farther west, the granite is continuous along the ridge south of Arroyo Seco and is considered a southeastern extension of the granite mapped by McKinlay (1957, pl. 1). The extent of this granite body is seen in aerial photographs. Opal Peak is believed to overlie sheared Precambrian granite, although biotite granite is found on its north and south flanks.

The granite in all these localities is usually medium grained and inequigranular, although some aplite porphyry specimens have been obtained from the localities in South Fork. Cream-colored potash feldspars, up to 6 millimeters long, gray-white plagioclase about 1 millimeter long, equidimensional quartz grains up to 3 millimeters in diameter, and black plates of biotite about 1 millimeter in size are the main constituents. The aplite porphyry variety is quite similar to equivalent phases in the Red River area. Both types have a low color index and tend to crumble when weathered.

As seen in thin section, the quartz is anhedral and may have corroded margins. Orthoclase is subhedral and microperthitic. Plagioclase is also subhedral, with some alteration to sericite and some replacement by orthoclase. The plagioclase is albite-oligoclase, ranging in composition from An$_9$-An$_{13}$. Biotite is in subhedral plates, pleochroic brown, and scattered throughout the rock. Accessory minerals include magnetite, sphene, and zircon. A modal analysis is given for both textural types in table 5.

Quartz Veins

Quartz veins intruding rocks of the igneous complex contain five distinct mineral assemblages. The veins are arranged in fracture systems located in six directions (details given in the discussion of the Red River mining district). The source of these veins is believed to be the biotite granite stocks along the lower Red River Valley. The fractures in which the veins occur are related to the Miocene high-angle fault systems active prior to, contemporaneous with, and subsequent to the period of igneous intrusion.

The molybdenite-bearing quartz veins in the Questa Mine stock were described in detail by Vanderwilt (p. 632-639), and by Schilling (1956, p. 42-59). Elsewhere in the Red River mining district, other quartz veins containing different mineral assemblages are described by Schilling (1960, p. 23-97).

Summary

Two distinctive types of granite have been outlined. Coarseness of grain size, presence of hornblende, and the wider range in composition of plagioclase (Ans -An$_{2\ 8}$) characterize the hornblende granite. The biotite granite, on the other hand, is not so coarse, usually has an aplitic porphyry phase in addition and is hornblende-free, The plagioclase has a narrow sodic range, An$_4$ -An$_{13}$. The association of molybdenum with at least three of these alkali granite bodies is another important factor.

The term "biotite granite" is used herein and not albite or soda granite. Although the composition of the plagioclase is more sodic than that of the hornblende granite, the amount of plagioclase as compared with potash feldspar is actually reduced, as shown in table 5. Chemical analyses of the Questa Mine stock compared to average granite are shown in table 6.1n general, the percentage of K_2O is greater than normal, whereas Na_2O is about the same or less than normal. The term "biotite granite," is therefore preferred to albite or soda granite. Ishihara (1964, p. 55-59; 1966) developed this theme and showed that the Questa Mine stock, and to a lesser extent the Flag Mountain stock, are relatively rich in quartz and potash feldspar-a result of differentiation. The Questa Mine stock has differentiated more than the Flag Mountain stock, and because molybdenum is characterized by a preference for the late products of magmatic fractionation, the main molybdenum deposits are concentrated there.

The age of biotite found in mineralized veins in the Questa Mine stock has been obtained by the potassium-argon method. Ishihara (1967), cites 23 ± 3 m.y., and Damon (1968) obtained 22.3 ± 0.7 m.y., both of which agree with an average of 22.4 ± 0.6 m.y. for the Questa Mine and Log Cabin (Flag Mountain) granites cited by Laughlin and others (1969).

TABLE 6-*Chemical Analyses of Questa Mine Stock*
(Courtesy R. H. Carpenter, Colorado School of Mines)

Constituent	Average granite (Nockolds, 1954)	Aplite (main phase), main tunnel, Questa mine	Aplite (main phase), crosscut south, No. 3, Questa mine	Aplite (chilled margin), No. 1, crosscut north, Questa mine
SiO_2	72.08	73.22	75.04	75.18
Al_2O_3	13.86	11.98	11.66	12.53
FeO	1.67	0.45	0.44	0.58
Fe_2O_3	0.86	1.36	0.27	0.09
TiO_2	0.37	0.28	0.15	0.25
MnO	0.06	0.01	Nil	0.01
CaO	1.33	1.16	1.08	0.12
MgO	0.52	0.52	0.11	0.18
K_2O	5.46	5.51	6.89	8.31
Na_2O	3.08	3.29	2.68	2.18
H_2O (-)		0.18	0.64	0.06
H_2O (+)	0.53	0.67	0.46	0.63
CO_2		0.14	0.32	0.09
P_2O_5	0.18	0.04	0.04	Nil
Total	100.00	98.81	99.78	100.21
K_2O/Na_2O	1.8	1.6	2.6	3.8
K_2O+Na_2O/CaO	7.5	7.6	8.9	87.3

Quartz Porphyry

Small intrusive bodies of quartz porphyry have a distribution similar to that of the aplite granite stocks along the lower part of the Red River Valley. The major areas of outcrop are at the head of Hottentot Canyon and in the bodies that intrude the Red River stock. Similar rocks outside the map area and west of Sulfur Gulch have been referred to as the Goat Hill quartz porphyry plug by Carpenter (1960, p. 81). A similarity between this plug and the Hottentot quartz porphyry is implied by Ishihara (1964, p. 33). In the map area, they tend to be lenticular, ranging from a few hundred feet to more than one mile in length.

Large, rounded phenocrysts of quartz with a radial structure. and light-colored feldspars, set in a light-gray aphanitic groundmass, characterize the (Hottentot) quartz porphyry. Quartz grains are 10 millimeters or more in diameter, whereas feldspars commonly range from 5 to 10 millimeters in size.

Under the microscope, the rounded quartz grains show a characteristic radial structure because of lenticular embayments of the groundmass at the periphery of the grains (fig. 12E). Pits in the quartz grains combine to produce a type of sieve texture. Other grains suggest that they are strongly resorbed into the groundmass. Potash feldspar has been completely altered to a cryptogranular mass of sericite, clay, and silica. The shape of the grains still remains, although they are subhedral with corroded outlines. In the Goat Hill quartz porphyry, Ishihara (1964, p. 35) identified sanidine. Grains of plagioclase, up to 5 millimeters, are also greatly altered. Extinction on ghost polysynthetic twinning suggests albite, although Carpenter (1960, p. 84) recognized oligoclase in the Goat Hill quartz porphyry. Biotite occurs in rare altered flakes, being heavily sericitized and chloritized. The groundmass is cryptofelsic and contains sericite, quartz, chlorite, and specks of magnetite. Pyrite, introduced later, is common in some specimens.

The quartz porphyry is later than the intrusives hitherto described. It cuts members of the, volcanic series and the Red River stock. These bodies (plugs?) are commonly associated with areas of intense alteration, marked by erosion scars in the sides of steep canyons. The Hottentot quartz porphyry probably contains a high percentage of silica and potash (by analogy with the Goat Hill quartz porphyry). This condition, coupled with the soda plagioclase, suggests that the rock is a product of extreme differentiation.

Monzonite Porphyry

Dikes of monzonite porphyry are one of the last expressions of Tertiary intrusive igneous activity. The dikes have a widespread distribution in the northern part of the area. Three trends are distinguishable, subparallel to the fracture systems in the Red River-Cabresto Creek area. East-northeastward-striking dikes predominate between upper Bitter Creek and Sulfur Gulch; whereas, in an area south of the Red River fault dikes strike north, and strike northwest between Red River Pass and Costilla Pass.

Monzonite porphyry dikes make a bold outcrop attaining lengths from one fifth of a mile to one mile. Thickness ranges from about 10 to 50 feet. In hand specimen, the dikes have a medium- or dark-gray groundmass studded with large potash feldspar crystals (some of which attain sizes of 1 to 2 inches), white plagioclase, rounded quartz grains, and black books of biotite (fig. 9D). The mineral proportions are 20 percent plagioclase, 10 percent biotite, 5 percent potash feldspar, and 5 percent quartz; the groundmass contains 40 to 60 percent of the rock.

The phenocrysts appear set in a fine-grained groundmass composed of the same minerals, with the addition of accessory magnetite and sphene together with epidote, sericite, and calcite where the rock is altered. A moderate 2V suggests that some of the potash feldspar is anorthoclase and possibly sanidine. Ishihara (1964, p. 28) identified sanidine by x-ray diffraction methods in a similar dike located in Goat Hill Gulch. Phenocrysts are euhedral, contain quartz inclusions, are little altered, and display Carlsbad twins. Plagioclase in subhedral to euhedral laths is commonly oligoclase, although the composition ranges from An_5 to An_{30}. Biotite is euhedral and generally chloritized. Slender laths of hornblende are present in some specimens. Quartz grains are rounded, embayed, and partly resorbed (fig. 12F). Quartz, plagioclase, potash feldspar, biotite, sphene, and alteration minerals occur in decreasing order of abundance in the groundmass.

In areas of strong alteration, these dikes assume a green color, as at the Memphis mine. Other dikes contain chloritized (?) twinned potash feldspar crystals that tend to weather out. One of these dikes is half a mile up the jeep trail in the east bank of Hanson Gulch.

Monzonite porphyry dikes are directly correlated with those described by McKinlay (1956, p. 18). There they cut the conglomerate of the Amalia Formation, indicating a late Tertiary age.

The youngest intrusives are small, dark-colored (post-aplite) dikes of intermediate composition, described by Ishihara (1966), that cut the Questa Mine stock and late quartz-molybdenite veins. Poor exposures of dikes cutting the Rio Hondo Granite have been described in this report, but as yet correlation has not been established between these hypabyssal rocks. In addition, dikes of aplite breccia occur in the hood zone of the Questa Mine stock. They cut the border phase of the aplite and the intruded andesite volcanics. Carpenter (1968, p. 1338) suggested that they were developed at the close of intrusive activity.

LATE TERTIARY AND QUATERNARY

High-Level Gravel

Coarse, unconsolidated gravel overlies latices and andesites of the volcanic series. It occurs on the flat tops of drainage divides north and south of Placer Creek and above Foster Park Canyon.

The deposits consist predominantly of rounded cobbles and boulders of Precambrian mica quartzite, granite gneiss, and porphyritic lava of intermediate composition. The base of the gravel is about 9,900 to 10,000 feet elevation. The lower limit is not sharply defined because some of the gravel has worked down the mountainsides. Therefore, thicknesses are only approximate. Above Foster Park Canyon, the thickness is estimated at between 20 and 50 feet. A greater thickness, apparent in the vicinity of Placer Creek, may be as much as 300 feet, but as will be shown later, the true thickness may be about half this figure. North of Placer Creek, the gravel lies 1,000 feet above the Red River; near Foster Park Canyon, the gravel is about 850 feet above the river bed.

The gravel is definitely later than the volcanic series and is, therefore, post-Miocene. Ray and Smith (p. 206) believed that by the close of mid-Tertiary time, a featureless plain of deposition had developed in this area and may have been continuous with the broad erosional surface in the San Juan Mountains of Colorado. The gravel is regarded as being deposited on this surface by fluvial processes. It appears then that a late Tertiary (Pliocene?) age, as suggested by Park and McKinlay (1948, p. 10), may be assigned to these deposits.

Tertiary-Quaternary Gravel

Miocene and post-Miocene normal faulting, subsequent to the extrusion of the Miocene volcanic series, disrupted the widespread erosion surface formed on these and older rocks. The southern Rocky Mountains geanticline was uplifted, and a series of structural basins developed. The Rio Grande-San Luis valley was initiated at this time on the western side of the Sangre de Cristo Mountains (Kelley, 1956). Farther east, the "parks" of Colorado and the Moreno Valley in New Mexico were developed. Locally derived syntectonic materials, from the adjoining Sangre de Cristo and Cimarron ranges, accumulated as gravel in the Moreno Valley. Ray and Smith (p. 207) referred to these deposits as the Eagle Nest Formation.

The deposits consist of cobbles, pebbles, sand, and silt. They are made up predominantly of Precambrian metamorphic rocks and, to a lesser extent, rocks of later age, including subangular to subrounded fragments of sandstone, arkose, hornfels, and quartz diorite porphyry. In some places, a thin soil has developed, below which lies a layer of caliche. Though not measured, thicknesses of 40 to 50 feet are common in stream cuts. In places, the gravel may lie as deep as 440 feet as evidenced in under-ground placer mines in Grouse Gulch. In general, the thickness is believed to be only a few hundred feet or less because bedrock is exposed in several places in the floor of the Moreno Valley. In the southern part of the Moreno Valley and beyond the limits of the map area, about two miles east of Agua Fria, the gravel is overlain by basalt flows of late Tertiary or early Quaternary age.

The gravel has been tentatively assigned a Pliocene age by Ray and Smith (p. 207), whereas Wanek and Read considered the age as late Tertiary or early Quaternary. Correlation with deposits in adjoining areas is believed possible because analogous events were taking place. Immediately to the north in the Costilla quadrangle, gravel and sand overlie the mid-Tertiary volcanics and the Amalia Formation. McKinlay (1956, p. 19) suggested that the gravel deposits are equivalent in part to the Santa Fe Formation, the upper part of which was being deposited in Pliocene time (Baldwin, 1956, fig. 2; Lambert, 1966). Later, in the Taos Plateau, the Santa Fe was covered by extrusions of basalt and andesite which Larsen and Cross (1956, p. 196) correlated with the Hinsdale Formation of the San Juan region. The age of these extrusive rocks is probably late Pliocene or early Pleistocene. In the Raton basin, the Ogallala Formation was deposited in Pliocene time (Johnson, Dixon, and Wanek, p. 132) and was covered by late Tertiary and early Quaternary 1âvas. In the area around Guadalupita, Las Feveras Formation, perhaps equivalent to the Santa Fe Formation, is also overlain by basalt flows (Bachman, 1953).

In conclusion, the writers consider that the earliest part of the Moreno Valley fill was deposited in Pliocene time and that the upper part was accumulated in early Pleistocene time.

Glacial Deposits

The Eagle Nest area has 65 glacial cirques. In the cirques and in the ice-sculptured valleys below are well-defined deposits that, although small in area, play an important role in interpreting the Quaternary history of the area.

Stevenson (p. 177) recognized that some of the high summits in the Sangre de Cristo Mountains in New Mexico had been glaciated. Salisbury (1901) and Stone (1901) made further reference to the glacial deposits. The first extensive investigation was made by Ellis (1931), who described glaciation in the Moreno and Red River valleys and the glaciation of all New Mexico (1935). Ray (p. 1891-1892) discredited belief in the existence of glaciation in the lower Red River valley and in the Moreno Valley, although Lindgren, Graton, and Gordon (p. 83) had earlier noted a terminal moraine near the mouth of Rio Hondo (at an elevation of 7,750 feet). The present writers did not find any glacial deposits in the Moreno Valley or in the lower parts of the Red River and Rio Hondo valleys. However, some evidence, possibly attributable to pre-Wisconsin glaciation, may be seen at the entrance to the Rio Hondo where a glacial U-shaped valley has been later trenched by a V-shaped gorge (Clark, 1966a, pl. 21A).

The glacial deposits in the map area have not been investigated in detail. However, Ray (his fig. 10) described the deposits in Lake Fork and the East Fork of Red River. In these valleys he recognized five substages of Wisconsin glaciation that can be correlated with other areas in the southern Rocky Mountains. Richmond (1962) also examined the deposits in Lake Fork and, while recognizing the five Wisconsin substages, was able to detail more than one moraine in each substage. The correlation between Richmond's work and Ray's is shown in table 7.

TABLE 7—*Correlation of Glacial Deposits in Lake Fork, Eagle Nest Area*

		Richmond (1962)	Ray (1940)	Form of terminal moraine
Recent	Neoglaciation	Gannet Peak (G) 12,000 ft.		Very small rock accumulations, little vegetation
		Temple Lake (T) 11,850 ft.	W_5	Small moraines or rock glaciers, protalus, little vegetation
Late Pleistocene	Pinedale	Late Pinedale (Pl) 11,000 ft.	W_4 W_3	Hummocky moraines upstream from Bull Lake moraines; W_4 dams cirque lakes; W_2, W_3 dissected by streams
		Middle Pinedale (Pm) 10,850 ft.		
		Early Pinedale (Pe) 10,200 ft.	W_2	
	Bull Lake	Late Bull Lake (Bl) 9,700 ft.	W_1	Broad, smooth, and mature moraines, dissected by streams; forest-covered
		Early Bull Lake (Be) 9,400 ft.		

Both men correlated glacial deposits regionally by examining (1) the character and topographic position of the moraines, (2) the relationship between successive valley trains and terminal moraines, (3) differences in weathering of the materials composing the moraines, and (4) recognizing an old soil zone between tills assigned to the first and second substages. We tentatively identify some of the moraines in other valleys that hitherto have not received attention. The first two criteria cited above served as the basis for identification which seems reasonable, considering the proximity of the valleys in the map area. Distinguishing features of the moraines are given in table 7.

In general, the first Wisconsin substage is represented at an elevation of 9,400 feet by a broad, smooth, mature terminal moraine supporting heavy stands of timber. At Wheeler Peak Village, a beautiful arcuate moraine was deposited by a valley glacier that must have been about 6 miles long (pl. 1). Soled boulders and cobbles are common, a few with striations. The matrix is clay and mud, and the height of the moraine is about 70 feet above the valley alluvium.

Wisconsin 2 and Wisconsin 3 substages appear least well developed, partly because of the extensive forest cover and the difficulty in distinguishing these somewhat irregularly shaped masses from lateral moraines distributed along the sides of the valleys. Elevation of the second substage terminal moraine is 10,000 feet. Richmond recognized 11 small cirques in Lake Fork distributed around the periphery of a great amphitheater more than one mile wide. Below the high cirques at an elevation of 11,000 feet is a large hummocky moraine (Wisconsin 3 substage) that dams Williams Lake.

The Wisconsin 4 substage, a somewhat bouldery moraine perched on the lips of the individual cirques, is smaller than those in the valleys' below. The elevation of these moraines, in Lake Fork and in the other valleys, is between 11,000 and 11,500 feet. Good examples were found at Lost Lake, Bear Lake, and Horseshoe Lake. Only one moraine has been definitely recognized on Baldy Mountain: a small but well-developed accumulation on the northwest flank. The central part of this mountain has been eroded by glaciation, but this is largely masked by Recent erosion in the upper part of the South Ponil Creek, above Copper Park. Similar conditions are found at the head of Big Negro Gulch above the west part of the Deep Tunnel, and some remains of glacial materials appear to be in both canyons. Apparently, the small extent of glacial action is because of the limited summit area (Smith and Ray, p. 914).

The highest moraines, assigned to the Wisconsin 5 substage, are found at an elevation near 12,000 feet. They are small, bouldery, rock accumulations at the heads of cirques and in some instances are regarded as protalus rampart materials (Ray, p. 1895-1896). Examples are found in the high cirques adjacent to Wheeler Peak and Old Mike, in the southern part of the quadrangle, and in a few cirques flanking Gold Hill in the area to the north. The materials of this substage tend to form rock glaciers with distinctive flow ridges. These glaciers are somewhat different from the talus streams formed by material derived from glacially oversteepened cliffs, although all gradations between the two types may be present. The talus streams are probably similar to the talus glaciers described by Siebanthal (1910, p. 19) in the Sangre de Cristo Range in Colorado and by Howe (1909, p. 31) in the San Juan Mountains. Talus is being added to these rock streams today, so that with continued movement, vegetation is unable to develop (fig. 2B).

Mudflows and Cemented Gravel

Along Red River, below the town, the floor of the valley is choked with consolidated mudflow material derived from the adjoining side canyons and individual flows have coalesced; but elsewhere, as in Mallette Creek, Bitter Creek, and Cabresto Creek, mudflows are less prevalent and individual fans are still preserved.

Mudflows are initiated by torrential rains over the red and yellow areas produced by hydrothermal alteration. The loose material is washed into a myriad of gullies and from there into the canyon, picking up more water and solids. By then the mudflow is competent to move boulders and fallen trees. The debris is swept out into the Red River valley, and many of the finer materials are carried into Red River, imparting the color for which it was named. Much of the coarse material is left at the mouths of the side canyons and is mixed with talus derived from steep interfluve slopes. At times, the culverts on New Mexico 38, at Sulfur Gulch, Hottentot Canyon, and other side canyons, cannot handle the volume of material, and the highway becomes blocked. Damage to the Questa mine plant to date has been relatively small, and the effects of open-pit mining in the Sulfur Gulch altered area have prevented further mudflows from developing.

Each year, hundreds of people, unaware of the potential hazard, use the vacation campsites provided by the Forest Service in this part of the Red River valley. Although no fatalities from mudflows are known to the writers, personal property damage was observed during the summer of 1964 at the time of prolonged cloud-bursts.

Upon drying mudflow materials become hard and assume a brown to buff color.

They consist of angular fragments derived from local sources, set in a matrix of sand, silt, and clay. The color is due to the secondary iron oxides. Bedding is not particularly noticeable. Thickness varies, although Schilling (1956a, p. 32) recorded 35 feet.

The broad flat floor on which the village of Red River stands consists of alluvium developed on a scale not seen in other places along the course of the river (fig. 2A). Powell (1950) recognized that the river had been blocked in earlier times by an alluvial fan, with the subsequent formation of a small lake at the site of the present settlement. The presence of this body of water explains the flat surface of today. We believe the alluvial fan was mudflow material that today is exposed one mile downstream from the town (pl. 1).

Cemented gravel deposits are similar in appearance to mudflows. Gravel commonly occurs in side canyons associated with alteration areas. This gravel is angular and cemented by limonitic material ranging in color from orange brown to dark brown. The gravel is believed to be talus that has worked down the steep canyon sides. Cementation is by iron salts dissolved in water coming from the altered areas.

There has been no transport analogous to the mudflows. Bedding varies but, where developed, dips into the canyon and downstream. Outcrops are in the form of discontinuous ledges perched on the sides of the canyon walls, as later erosion deepened the bottom of the canyon. Schilling (1956a, p. 31) recorded ledges from 5 to 20 feet above the bed of the canyon in the vicinity of Sulfur Gulch, but the estimates in Straight Creek are nearer 60 to 70 feet.

Landslides

Landslides on an appreciable scale have been detected in only a few places. Probably a considerable number occur on the sides of the valleys and at the base of rocky cliffs, but they are hidden by the extensive forest cover in all but obvious occurrences.

Constriction of the Red River near the mouth of Foster Park Canyon is ascribed to slumping of andesite breccia along the line of the Taos Cone fault from the adjacent valley sides. The attitudes of some volcanic rocks between Red River and Cabresto Creek could have been similarly caused.

An occurrence of hummocky material half a mile east of Ditch Cabin is believed to be a landslide of Pennsylvanian strata. At first sight, the slide resembles a glacial moraine, but there is no obvious cirque above. The steep cliffs from which the materials were derived consist of eastward-dipping sediments.

A similar topographic feature, although larger, occurs half a mile north of Larkspur Point. It lies below and west of a fault block of Pennsylvanian sediments. The slide partly blocks Rio Lucero Canyon.

Alluvium

In the high valleys, much of the Pleistocene and Recent unconsolidated deposits cannot be readily differentiated. The deposits consist of talus, moraine, landslide, stream terrace gravel, and alluvium mapped together as one unit (pl. 1).

Elsewhere, in particular in the grassy parks and in the Moreno valley, active alluvium is associated with streams and is best developed in the flood plains of Moreno, Comanche, and Six Mile creeks. Gradients of the major fluves are gentle where they enter Eagle Nest Lake, but the drowned shore line of this artificial body of water shows some evidence of delta formation at low water level.

Structure

The Eagle Nest area contains only a small part of a much larger structural feature extending from southern Colorado into north-central New Mexico. The Sangre de Cristo Range is part of an eastern belt of the southern Rocky Mountains of Colorado and New Mexico .

A regional map (fig. 13) shows that the Sangre de Cristo uplift is characterized by its arclike form, some 200 miles in length being convex toward the east, and by its small width, which ranges from 10 to 20 miles. The uplift is bordered on the west by the Rio Grande depression and on the east by the syncline of the Raton basin. The eastern margin of the Sangre de Cristo uplift is marked by thrust and high-angle reverse faults, whereas the western margin resulted from high-angle normal displacements.

Tertiary and Quaternary volcanic rocks of the region can be assigned to the Mount Taylor, Jemez, and San Juan fields. Intrusive igneous rocks of Tertiary age follow the arc of the uplift and extend southward from southern Colorado into northern New Mexico.

In late Eocene or Oligocene time, thrusting and uplift of the Sangre de Cristo region was accompanied by downwarp of the Raton basin. The western part of the Sangre de Cristo uplift was defined in Miocene and Pliocene times by the formation of the Rio Grande depression.

In the vicinity of the map area, the range is bounded on the west by the Rio Grande depression and to the east in part by the Moreno Valley, Cimarron Range, and the Raton basin.

The structures found in this region, in particular the Eagle Nest area, range in age from Precambrian to Cenozoic and vary in character because of the type of deformation they represent. Cenozoic structures dominate the picture.

PRECAMBRIAN

Foliation

Precambrian rocks are mostly foliated, although the gray and pink biotite granites are in part massive. The older series of foliated Precambrian rocks includes the mafic gneiss group, of sedimentary and igneous origin, and the metaquartzite group, of sedimentary origin. Recrystallization and foliation of these rocks bear witness to great deformation, in part, prior to, and, in part, accompanying the emplacement of the later granites.

The dominant foliation trend is northeasterly, with a moderate to steep dip to the northwest. Reversals of dip are uncommon. Isoclinal folding has been observed in the mafic biotite schists on rare occasions.

Foliation is best developed in the micaceous schists and the banded gneisses. But in these rocks, little can be said of the structures on which the foliation has been impressed because of the poor exposures and the lack of continuity of outcrop. Further-more, the relation of foliation to bedding in the metasediments of the mafic gneiss group is largely obscure.

In the metaquartzite group at some places, foliation appears, in part, to parallel bedding, but at other localities, strong jointing masked the relationship. Elsewhere, lack of correspondence of foliation with original bedding suggests that the regional foliation is probably parallel to the axial planes of folds.

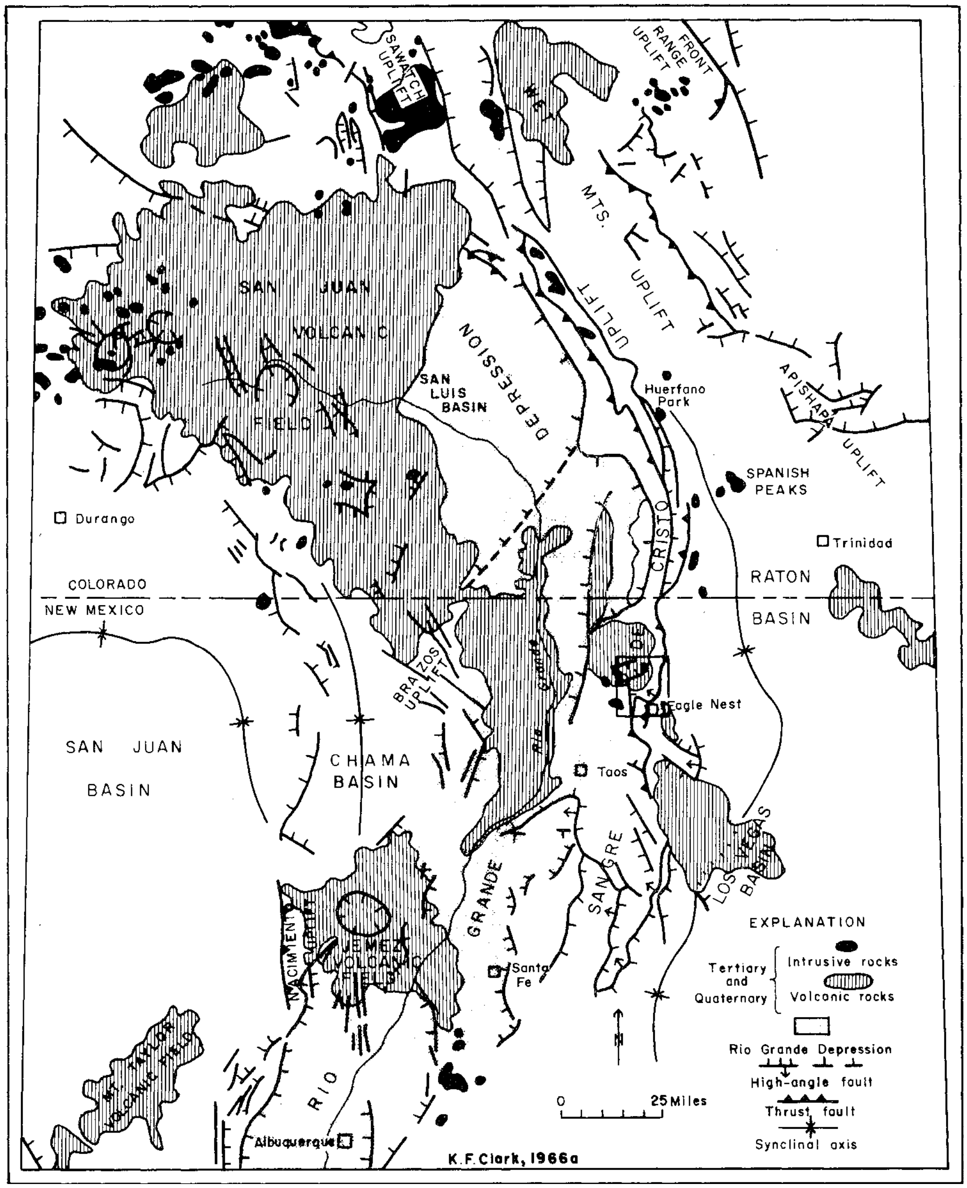


FIGURE 13—Tectonic map of the Sangre de Cristo uplift and adjacent areas. *(adapted from Cohee, and others, 1961; Kelley, 1955, 1956; and Boltz, 1965)*

Lineation

Linear structures, other than the parallelism of elongate minerals, are scant. At the Frazer mine and at one or two other localities in Lake Fork, corrugations were seen in the mafic schists.

Parallelism of elongate minerals is poorly developed in hornblende gneiss but is well developed in tourmaline schist one and a half miles south of Amizette at the contact with Precambrian granitic gneiss. In this rock, subparallel black rods of tourmaline, distinctly visible in a silvery groundmass of white mica lie in the plane of schistosity.

Folds

A large asymmetrical, open syncline in granitic biotite gneiss plunges to the north-east at Costilla Pass (pl. 1). The well-exposed limb is flanked by units of the metaquartzite group that can be traced around the nose of the fold. Andesite conceals the northern limb, but a sufficient amount is exposed to make a reasonable projection to depth. The nose of the fold has become flattened by numerous smaller en echelon folds, although only one has been delineated with any certainty.

Dips of the metaquartzite in Cabresto Creek suggest folding, but lava cover and faulting obscure the structure.

Faults

Direct evidence for Precambrian faulting is difficult to recognize because of the strong dislocations that occurred in Cenozoic time. However, the trend of quartz veins, pegmatites, and diabase dikes suggests that fracture systems with east-northeast, northwest and northeast trends formed during Late Precambrian. Evidence for rejuvenation along these lines in Cenozoic times will be presented. The strongest of these trends appears to be northeast and roughly parallels the regional foliation. Numerous shear zones, marked by quartz veins or pegmatites, are found in mafic Precambrian rocks along Lake Fork and Long Canyon.

Intrusive Rocks

Large areas of intrusive granite and granitic gneiss are found within the map area. Structure sections show that granitic rocks underlie much of the mafic gneiss, schist, and migmatite and reach batholithic dimensions. The present level of erosion reveals only part of this large body.

The forceful aspects of intrusion, previously described, with accompanying migmatization, potash metasomatism, and granitization of old sediments, bear further witness to the extensive nature of this Late Precambrian crustal deformation.

Belts of migmatite tend to have an east-northeast trend, suggesting that granitic intrusion was controlled to some extent by folding and foliation of the host rocks.

The last phase of Precambrian igneous activity was marked by the emplacement of veins, pegmatites, and diabase dikes. As these minor intrusive bodies are but little foliated, the compressive forces of regional metamorphism apparently relaxed. The culmination of orogenic earth movements, however, must have resulted in the formation of large mountain uplifts, subsequently deeply eroded and now partly re-exposed below the upper Paleozoic sediments.

LOWER PALEOZOIC DEFORMATION

Lower Paleozoic time is not recorded in north-central New Mexico; the first record of deposition following Precambrian time is found in rocks of Mississippian age. However, rocks of lower Paleozoic age are found in southern New Mexico and in the northern Sangre de Cristo Mountains in Colorado (Litsey, 1956). Consequently, this region may have been part of the broad, ill-defined, southwest-trending "continental backbone" (King, 1951, p. 30) on which sedimentary rocks older than Mississippian were not deposited, although Haun and Kent (1965, p. 1783) subsequently indicated that northern New Mexico was covered by Ordovician seas.

Earth movements during early Paleozoic time in this region were restricted to epeirogenic warping on an otherwise stable area in northern New Mexico. The Espiritu Santo Formation indicates deposition in a shallow transgressive sea. Later uplift is suggested by the development of a karst surface on the limestones. Repeated warping in Mississippian time led to renewed shallow marine transgressions. Deposition of the members of the Tererro Formation is marked by minor unconformities (fig. 6).

The first indications of a major orogeny are suggested by the presence of clastic sediments in basal Mississippian beds. This was interpreted by Haun and Kent as an incipient uplift of the northern part of the Ancestral Front Range.

UPPER PALEOZOIC DEFORMATION

Uplift in a region comprising Colorado and northern New Mexico in late Paleozoic time formed the ancestral Rocky Mountains. Major positive elements affecting the map area were the Uncompahgre-San Luis geanticline on the west, the ancient Front Range-Apishapa uplift to the north, and the old Sierre Grande uplift to the east (fig. 8). The development of positive areas with intervening troughs and basins of deposition was first indicated by Lee (1923). The Eagle Nest area is near the eastern margin of the old San Luis highland.

Further development of these ideas was prompted by additional surface and subsurface data available in more recent years. Among the many papers written on the subject, Ver Wiebe (1930) believed that the ancestral Rockies began to develop in Proterozoic time and were rejuvenated at the close of Ordovician and Mississippian times. Melton (1925a) thought that maximum development was in Permian time, as reflected in the great thickness of Sangre de Cristo conglomerate at La Veta Pass in Colorado. Heaton (1933) drew attention to a narrow trough that must have existed between the "Front Range" and the "San Luis Highlands." Read and Wood (1947) referred to this trough in New Mexico as the Rowe-Mora basin. They believed sedimentation in such basins was continuous during the periods of mountain building in adjacent areas passing from marine to continental facies in time and space. Brill (1952) referred to this trough as the Permo-Pennsylvanian zeugogeosyncline of Colorado and northern New Mexico. He emphasized that sediment was contributed from landmasses on both sides and that subsidence was relatively rapid.

MESOZOIC DEFORMATION

The hiatus between Permian and Triassic rocks indicates the sea withdrew during Late Permian and Early Triassic times. Continuation of continental deposition in Late Triassic time, followed by shallow-water deposition in Middle and Late Jurassic time, indicates that the area was again relatively stable but subject to minor warping. These conditions persisted into Cretaceous time. Appreciable thicknesses of Upper Cretaceous marine strata which accumulated in the Eagle Nest region bear witness to a gradual deepening of the basin of deposition. But by late Upper Cretaceous time, the seas withdrew—a prelude to the orogenic disturbances that were to follow.

CENOZOIC DEFORMATION

The structures in the Eagle Nest area are part of a broad belt of Cenozoic deformation that sweeps across New Mexico from north to south (Kelley and Silver, 1952, fig. 20).

The form of Laramide faults and folds is not everywhere apparent inasmuch as their topographic expression, in some instances, is not marked. But later Miocene movements were relatively simple vertical displacements, and contribute more conspicuously to differences in relief.

Orogenic disturbance in Late Cretaceous and early Tertiary times is again marked by coarse continental deposits. The Raton and Poison Canyon formations were derived from newly-uplifted mountains formed during the Laramide orogeny, and the gravel forming the Moreno Valley fill was derived from the adjacent mountain slopes subsequent to Miocene faulting.

Laramide Thrusts and Folds

Regional compression directed from the west resulted in a series of imbricate thrusts associated with overturned folds. This style of tectonic deformation has modified the Moreno Valley on its western limb, resulting in a shallow synclinorium. Thrusts are stretch types and result from faulting which follows folding. Thrust sheets and high-angle reverse faults are found in the west slope of the valley, from near the floor to the crest of the range. Numerous faults are aligned in a north-south belt about seven miles wide. The lowermost faults are better preserved, as only the erosional remnants of the others are found at the crest of the range. Folded and overturned strata are associated with thrust faults.

The age of the faults is latest Cretaceous to post Paleocene, inasmuch as older rocks have been brought in fault contact with the Poison Canyon Formation. Thrusting in the Eagle Nest area was recognized previously by Wanek and Read (p. 82).

In the floor of the Moreno Valley, intrusion by igneous rocks locally modified the attitude of the sedimentary strata. Sills of quartz diorite porphyry were probably intruded slightly before or simultaneously with the Laramide disturbances.

Moreno Valley Synclinorium

The earliest Laramide deformation resulted in the production of coarse sediments of Paleocene age, but later folding and thrusting also affected these sediments and probably resulted from the main disturbances in Eocene and Oligocene times, as envisaged by Johnson (1959, p. 114). Still later, modification occurred by normal faulting along the sides of the valley in Miocene and later times, and largely resulted in the present topographic expression of the valley.

The synclinal nature of the valley was first deduced by Ray and Smith (their pl. 1). In general, a broad, shallow synclinorium developed along a north-south axis. It varies in width from three to four miles and is covered mostly by loose Cenozoic deposits (pl. 1, A-A', B-B'). Only the northern part is discussed in this report, but the total length of the valley is about 16 miles. Variations of dip along its flanks have been brought about by events simultaneous with and later than the formation of the valley.

Iron Mountain Anticline

Folding along the eastern side of the Moreno Valley produced an anticline with an axis paralleling the Moreno Valley synclinorium. In the map area, this anticline is best developed in Iron Mountain (pl. 1, B-B'), but its northward extension was found in the Grouse Gulch and Mills Divide areas. It appears to be upright with the west flank, dipping at a maximum angle of 35 °W into the Moreno Valley.

Iron Mountain, has also been intruded by a number of sills of quartz diorite porphyry. These sills appear to coalesce in the area between Anniseta Gulch and Grouse Gulch and suggest that the anticlinal structure in this locality may be caused in part by igneous doming of the sedimentary rocks. Such effects, however, are regarded subordinate to compressional Laramide forces because the sills are relatively thin.

Scully Mountain Dome

The Scully Mountain dome is about two miles wide and about three miles long, with the long axis aligned north-south. Mesozoic sediments appear arched up by a thick body of quartz diorite porphyry that is well exposed on the south side. The form and origin of this body are open to speculation. On the south side, it apparently is uniform but weathers into arcuate ridges that suggest that its emplacement was controlled by bedding of sedimentary rocks. Overall, it has been interpreted as a thick sill, as shown by Ray and Smith (their pl. 1). However, the body has a discordant contact with the country rocks, being found below the Dakota Sandstone on the southwest flank of the dome but below the Dockum Group and the Entrada Sandstone on the northeast flank. The sill is floored by the Sangre de Cristo Formation, which dips under the dome on the west side but does not reappear at the surface to the east (pl. 1, B-B').

Other small sills appear on the north and east sides of the dome but at higher stratigraphic horizons, being found above the Dakota Sandstone and Greenhorn Limestone and intruding the Carlile Shale and the Niobrara Formation. In this respect, they are stratigraphically similar to, and, in part, continuous with, those in Iron Mountain.

Six Mile Creek Thrust

This low-angle to flat-lying thrust sheet runs from the southern limit of the quadrangle northward to Six Mile Creek and beyond to Scully Mountain, a distance of seven miles. The trace of the leading edge of the upper plate is sinuous because of dissection by east-flowing streams, principally Six Mile Creek. Beds of the Magdalena Group and the Sangre de Cristo Formation have been thrust over Mesozoic strata.

The southern part of the thrust plate is characterized by gray arkosic sandstones of Pennsylvanian age thrust over red beds of the Sangre de Cristo Formation (pl. 1, A-A'). However, in the vicinity of Graney Creek, a salient of the upper plate has broken forward, bringing Pennsylvanian and Permian rocks over the Dakota hogback. Here, the thrust surface has been stepped up into the Sangre de Cristo Formation (pl. 1, B-B'). The salient is bounded along its northern side by a small tear fault, and is faulted along its southern side; but, in between, subsequent erosion has created a fenster in the bowed-up overriding rocks to re-expose the Dakota hogback. The for-ward part of the salient, still preserved in a small syncline on the south side of Graney Creek, will be referred to herein as the Graney Creek syncline. The overlying red beds and the Dakota dip west on the eastern limb of this structure. Further evidence of forward movement of the thrust sheet is found in a klippe of Pennsylvanian rocks resting on the contact between the Sangre de Cristo Formation and the Dockum Group at Idlewild. Another smaller klippe occupies the same position southwest of Lakeview.

Northwest of the Graney Creek syncline the overriding plate has been thrown into an overturned anticline, while the leading edge of the plate is in thrust contact with Mesozoic sediments immediately west of Scully Mountain (pl. 1, B-B'). The lower limb of the fold dips about 85^0W, whereas the upper limb dips about 25^0W. The axial trace of this fold trends to the northwest where it is terminated by a high-angle tear fault.

West of the overturned anticline, the axial trace of an open syncline also strikes northwest. The western limb of this fold, formed by the forested slope of the Moreno Valley, is underlain by Pennsylvanian rocks. The only departure from this inclination is in the shallow folds farther south in the Pennsylvanian strata between Lakeview and Rio Pueblo de Taos.

The northward extension of the thrust is lost under alluvium in Comanche Creek, but is believed to die out in the steeply dipping beds of the Sangre de Cristo Formation on the west side of Scully Mountain. Its northward extension may be marked by a rhyolite dike that can be traced for two miles.

The forward movement of the thrust plate appears to have deformed the underlying strata, particularly in the vicinity of Scully Mountain. Disturbance of the Mesozoic rocks may have been accentuated by emplacement of the Scully Mountain intrusive. The chief mechanism is believed to be buckling of formations into an overturned syncline by movement of the thrust plate against the Scully Mountain sill. Evidence in North Moreno Creek suggests that sills of quartz diorite porphyry were intruded before the thrusting began, as they are broken by a thrust fault. Presumably, the Scully Mountain intrusive has a similar age.

This overturned syncline is the northern end of the Graney Creek syncline. The limbs are indicated by the repetition of the Dakota; and the core is made up of dark-gray Graneros Shale. Other formations, stratigraphically higher, are probably present but are concealed by alluvium (pl. 1, B-B'). The west limb dips about 70°W; the east limb is inclined 80°W, becoming vertical. The northern limit of this fold is pinched in the side of the Scully Mountain dome, whereas the southern end is lost from view at the surface by a small tear fault. In plan, the fold bulges to the east, due, in part, to pressure directed from the west by thrusting, and, in part, to offset along the line of the tear fault.

The leading edge of the thrust as now exposed, is quite flat and even dips to the east at about 10°; at one place, a dip of 34°E was measured, indicating that the thrust may be a gravity slide from the crest of the range into the Moreno Valley. But this interpretation is not preferred because a normal contact with Precambrian rocks has been exposed at several places along the east fork of Red River and along Rio Pueblo de Taos. Easterly dips may be due to later tilting caused by differential vertical uplifts during a later period of Cenozoic deformation. Such effects were noted in the Huerfano Park area by Burbank and Goddard (1937, p. 956). A normal contact is preserved along the east fork of Red River because the thrust surface is stratigraphically lower, inasmuch as Precambrian is thrust over Pennsylvanian in the subsurface. Thus, the form of the thrust changes from east to west from a folded, near-beddingplane attitude to that of a scission. Perhaps at depth this thrust plate is a splinter of the thrust at Blue Lake. Other evidence not compatible with a gravity-sliding approach is found in the deep-seated nature of the other thrust faults within this belt of deformation, and the absence of Pennsylvanian sediments in the floor of the Moreno Valley. The possibility that the Six Mile Creek thrust is a downthrown part of the Blue Lake thrust has been considered and rejected because the throw on the Taos Cone fault is probably insufficient. Furthermore, the Blue Lake thrust cannot be recognized north of Wheeler Peak village as would be expected if it were to account for the Six Mile Creek thrust at Comanche Creek and farther north. Finally, the apparent slip on this thrust in the plane of section B- B' (pl. 1), is about 9,000 feet, whereas maximum stratigraphic throw is about 6,600 feet.

Blue Lake Thrust

The effects of the Laramide orogeny are perhaps best expressed by a complex fault traced in a northeasterly direction from the vicinity of Larkspur Point to Mills Divide and beyond. The fault is well exposed in the glacial cirques at the crest of the range, the most impressive of which is at Blue Lake. The attitude is such that the Precambrian has been brought against sediments ranging in age from Pennsylvanian through Paleocene. Overall, this fracture has been traced more than 17 miles across the map area.

Near Blue Lake, crystalline rocks consisting of chlorite schist, dark gneiss, and granite have been thrust over Pennsylvanian sediments. The form of the thrust contact is misleading. For example, at Lew Wallace Peak, the trend is straight because the contact occurs along the summit of a high ridge and does not suggest a low-angle fault. But at Blue Lake, the fault plane passes through the walls of a cirque and its trace is correspondingly curved. The north wall of this cirque is in Taos Cone, and the crystalline rocks can be seen in thrust contact over the Pennsylvanian (fig. 14). Below the contact the sedimentary rocks have been folded by drag from above and pressure from the west. The thrust plane dips 10°W. The drag folds are locally overturned, with axial planes dipping westward. The upright limbs dip 20° to 40°, but the overturned limb dips 74°W.

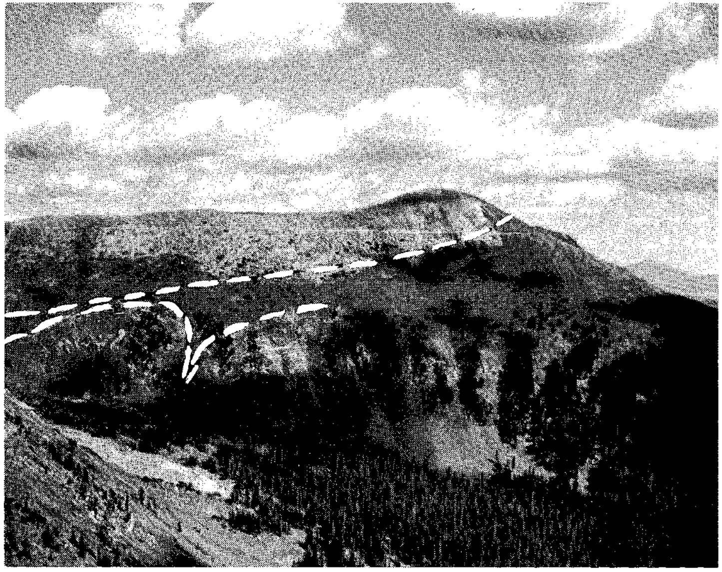


FIGURE 14—Northward view across the Blue Lake cirque, which exposes the thrust contact on the south side of Red Dome. Precambrian mafic and granitic gneiss have been thrust over folded Pennsylvanian strata.

In Lew Wallace Peak, near-vertical dips were recorded on the limbs of a small syncline and anticline. The axes of these folds may have once been continuous with the folds in Taos Cone. Farther south, the folds associated with the thrust are more shallow in the area between Waterbird Lake and Larkspur Point.

One thousand feet west of Taos Cone, the contact between mafic gneiss and Pennsylvanian arkose, in the divide between the east fork of Red River and Rio Pueblo de Taos, is vertical. The thrust must have assumed a near-vertical attitude at this point, although a later normal vertical fault has brought the sediments down to the east and largely obscured the thrust plane. The thrust is concealed by alluvium and glacial deposits along Red River; but in the valley wall south and east of Wheeler Peak village, where cliffs in the Precambrian rock are near the line of the fault and mark its steep inclination, the thrust is detectable and passes into an associated tear fault.

However, erosional development of the east fork of the Red River Valley also reveals, in places, a sedimentary contact with underlying Precambrian rocks east of the

Blue Lake thrust fault (pl. 1). The contact here was mentioned in connection with the attitude of the Six Mile Creek thrust in the subsurface.

A little farther north, evidence of the thrust is found in an old prospect pit, where Pennsylvanian sediments are still preserved in contact with the Blue Lake fault because erosion has been prevented by overlying latite. At the contact, silicified Precambrian rocks abut metamorphosed Pennsylvanian sediments. The contact surface dips 74°E; some semblance of drag is apparent; the limestones and arkosic sandstones have dips from 49°E to 76°E.

North of the offset caused by the tear fault, the high-angle thrust is further contained in the area of Comanche Creek having an arcuate contact with the Sangre de Cristo Formation. A block of biotite granitic gneiss has been thrust along a high-angle and near-vertical fault with the red beds. This salient is bounded on the south side by the tear fault that formed at the same time and is regarded as part of the thrust system. But later vertical movements occurred along the tear fault bringing latite against the gneiss.

At the entrance to Comanche Creek the red beds are overturned in an anticlinal fold, the axial plane of which dips westward. Locally, the upright limb dips 25°W, and the overturned limb dips 85°W. The trace of the axial plane is due north, being difficult to reconcile with the arcuate trace of the thrust plane. East of this fold, the red beds are concealed under a small, grassy valley but reappear in the base of the west side of Scully Mountain where their dip is to the east at a high angle.

The canyon of Comanche Creek is believed to follow the line of a fault that cuts out the late Paleozoic and Mesozoic sediments in the north flank of Scully Mountain (pl. 1). The Dakota hogback and the underlying formations are abruptly terminated and a pediment has formed on the north side in the vicinity of Hollenback Creek. In Comanche Creek, the high angle thrust is little offset because of the high-angle nature of the fault planes.

The tear fault on the south side of the Precambrian salient appears to be nearly vertical. Evidence of drag suggests right-lateral movement in an east-southeasterly direction. The amount of movement cannot be ascertained, but if the eastward bulge in the Graney Creek syncline is a measure of the strike-slip, the displacement is between 2,000 and 3,000 feet.

The arcuate segment of the Blue Lake thrust plane passes under the alluvium of the Moreno valley to the north. The thrust probably swings northeast and reappears in the west bank of North Moreno Creek, becoming part of another eastward thrust salient of Precambrian rocks. About one mile north of the LeSage ranch, a small outcrop of Dakota Sandstone is found on the west side of the creek. Dip is to the west. A small outcrop of biotite granitic gneiss nearby suggests that these two lithologies are in fault contact. Furthermore, if this fault is part of the thrust system, folding of the sedimentary rocks to the east would be expected by analogy with the localities previously described. The immediate vicinity is covered with alluvium and basin-fill gravel, but near Mills Divide, the Carlile Shale, the overlying Poison Canyon Formation, and the intruded sills are folded into an anticlinal structure. This fold is a continuation north-ward of the fold seen in Iron Mountain and Grouse Gulch. Disposition of the over-turned syncline bordering this anticline on the west is based mainly on the appearance of the Dakota Sandstone at the surface in North Moreno Creek and its subsurface position at Mills Divide.

The most northerly part of the Blue Lake thrust, east of North Moreno Creek, strikes north-northeastward. There, gneiss, schist, and metaquartzite are in thrust contact with the gray and red coarse clastics of the Poison Canyon Formation. Exposures are poor because the mountainsides are covered with loose pebbles and cobbles of the

Paleocene sediments which mask the fault contact. However, evidence of the fault was found 2 miles N21°E of the LeSage ranch where at the contact, the Precambrian is limonitized and brecciated. At second locality, 2.8 miles S45°E from Costilla Pass at the Big Ditch level, muscovite-hematite granulite has become schistose because of shearing.

North of the Eagle Nest area the thrust marks the structural and topographic break between the Sangre de Cristo Mountains on the west and the Great Plains to the east. The continuation of similar thrusts to the south of the map area in Coyote Creek and beyond to Las Vegas marks a similar boundary.

However, immediately east of Eagle Nest, the Cimarron Range occupies a position that has few parallels along the east front of the Sangre de Cristo Range. The problem of assigning the Cimarron Range to a structural and topographical province was out-lined by Ray and Smith (p. 199), although the anomaly had been previously noticed by Lee (1922).

The hogback formed by the Mesozoic sediments along the western side of the Moreno Valley was recognized by Ray and Smith, but the bordering thrusts here described appear to have escaped their attention. On the east side of the Cimarron Range, the structure is repeated. Thus, the western limit of the Great Plains Province can be drawn at two possible places. Structurally, but not topographically, the western side of the Moreno Valley seems to be the boundary. The Moreno Valley could then be regarded as a border depression along the east side of the Sangre de Cristo Range; the Cimarron Range being an anomalous extension or salient of the Sangre de Cristo Range, consisting in part of a Precambrian core flanked by faulted sedimentary rocks.

Contacts

Within a radius of 5 or 6 miles of Eagle Nest, the Precambrian has been found in contact with rocks ranging in age from Pennsylvanian to Cretaceous, and the question arises whether these. contacts are sedimentary or faulted (or both), to account for the missing part of the section.

A fault contact was adopted by Wanek and Read (1956, p. 82-83) to account for the small features found in the Moreno Valley and the much larger structural features embodied in the Cimarron Mountains. They considered the crystalline rocks to have moved upward and eastward in diapiric fashion in the form of plungers of various sizes and with differing inclinations to the horizontal. The overlying sedimentary rocks were pierced to different horizons at various places, but in the Cimarron Mountains, the crystalline core has been completely exposed by a combination of uplift and erosion. According to this view, the range is bounded by a high-angle normal fault on the west side, which cuts and displaces an earlier flat fault. The flat fault continues around the north plunge of the anticline-like mountain mass in the vicinity of Cimarron Canyon and connects with the high-angle Fowler Pass fault on the eastern side of the range. Evidence of the flat fault was found in exposures near Eagle Nest Lake dam and elsewhere in the Moreno Valley.

The first evidence for this fault was mentioned by Smith and Ray (p. 906), who indicated that the Precambrian core of the Cimarron Range plunges northward beneath the sedimentary cover. They mapped the contact in Cimarron Canyon as normal, although they felt that a fault might be present. Earlier, Graton (in Lindgren, Graton, and Gordon) concluded that a small, positive area in Triassic and Jurassic times, which had occupied a larger area in Paleozoic time, could explain the contacts observed.

As a consequence Wanek and Read (p. 83, 92) interpreted the Cimarron uplift as a giant plunger of Precambrian rocks that has a flat underthrust contact with sediments west of the range and a high-angle overthrust contact at the surface with sediments east of the range. Baltz, Read and Wanek (1959) constructed a section through the Cimarron Range embodying these ideas.

Robinson, and others (p. 116) largely avoided the issue. They did, however, provide a section through the Cimarron Mountains based on the plunger hypothesis. At the same time, they indicated that an explanation involving high-angle reverse faults alone is just as likely. Furthermore, Simms (p. 58) found no evidence for flattening of the Fowler Pass fault at depth in Rayado Canyon.

Graham (in Prucha, Graham, and Nickelsen, 1965, p. 973) described high-angle reverse faults in analogous structural positions on the east side of the Sangre de Cristo Mountains near Mora. There, Precambrian blocks have been uplifted and tilted, resulting in upthrust on the east side of the basement block. No movement was recorded on the west side of the block between the sedimentary cover and the crystalline substratum, but should movement occur, then underthrusting and diapiric movement, as interpreted by Wanek and Read in the Eagle Nest region, could be logical. The possible relationship of this diapiric structure to the Taos and Cimarron ranges has been indicated by Clark (1966b, fig. 3).

The possible absence of the Magdalena Group should also be considered in this context. Robinson, and others (pls. 3, 5) show the Sangre de Cristo Formation directly overlying the Precambrian on the flanks of the proposed plunger. But Simms (his fig. 3) considered Devonian (?), Mississippian, and Pennsylvanian strata present in the subsurface. An oil test on the Philmont anticline, in the Rayado Canyon area, penetrated only to the Morrison Formation, but a test on the Ocate anticline, some 20 miles south of Eagle Nest, revealed about 5,000 feet of the Magdalena Group (Baltz, Read and Wanek, 1959).

A few wells have penetrated to the crystalline basement in the area north and east of Cimarron. This and similar information has been used by Foster and Stipp (1961, map) to construct a relief map of the Precambrian in New Mexico. Comparison with data obtained from an airborne magnetometer survey (Dempsey and Page, 1963) shows that the Las Vegas basin is separated from the Raton basin by an east west saddle. This saddle is now partly exposed in the Cimarron Mountains, although a logical continuation of the feature would be in the Sangre de Cristo Mountains.

The presence of nearly 3,000 feet of Pennsylvanian strata in the west flank of the Moreno Valley suggests that this low saddle caused only a shoaling of the ancient seaway, particularly east of Eagle Nest: no positive area is envisaged. Referring to this feature as the Cimarron arch, Baltz (p. 2045) suggested that it may have formed in Middle to Late Pennsylvanian time. This suggestion is partly substantiated by the presence of only 647 feet of Pennsylvanian in the Conoco No. 2 Rocky Mountain well (Foster, p. 83), suggesting the greater effect of the arch as the Sierra Grande positive is approached. But north and south of this saddle, several thousand feet of Pennsylvanian have been recorded in the subsurface. Thus, apparent thinning up to and including the Dockum Group, together with the faulted contact at Eagle Nest, is given by Baltz (his figs. 3, 5), who suggested further that Laramide deformation postulated by Wanek and Read occurred on this arch.

In the north bank of Comanche Creek a small area of Precambrian is in contact with the Sangre de Cristo Formation. The crystalline rocks have a roughly semicircular outcrop area, truncated on the south by the alluvium-covered transverse fault in Comanche Creek. A coarse ledge of conglomerate overlies the biotite gneiss and dips about 20°E. Tracing the conglomerate around the contact the dip swings to the north and then to the northwest. On the west side, beds of arkose and shale are locally contorted. The contact is marked by gray material composed of small angular fragments of rock, principally pink biotite gneiss and pink feldspar grains, together with arkose of the Sangre de Cristo Formation. These pieces are set in a light-colored arkosic matrix subsequently veined by calcite. Thickness varies inasmuch as relief on the Precambrian surface is more than one foot. A thin section of this rock showed the mineral grains are cracked and veined by calcite and quartz and enclosed in fine-grained calcite. Trains of smaller particles lie in the "shadow" of the larger fragments, and these rock components have subparallelism.

Our interpretation is that movement and accompanying grinding of rock materials occurred along the contact. Wanek and Read (p. 83, 93) regarded the Precambrian gneiss as a plunger. Read considered it a possible detachment from the main (Blue Lake) thrust located 1,300 feet farther west; it moved upward and eastward, doming the rocks above.

Whether or not the Pennsylvanian is present in the subsurface is analogous to the situation in the Cimarron Mountains. The nearest Pennsylvanian rocks are one mile southeast along the line of a tear fault. Attributing this loss of section to sedimentary wedge-out alone on a Pennsylvanian positive area is not tenable. Furthermore, the Pennsylvanian clastics at this locality are not conglomeratic, as would be expected near an old shoreline, nor is angularity evident. We conclude, therefore, that at least some thickness of Pennsylvanian rocks is present below the Sangre de Cristo Formation in Comanche Creek. Consequently, the Precambrian body of rock has domed the red beds by underthrusting the east-dipping Pennsylvanian-Sangre de Cristo contact.

The problem is repeated near Lakeview. Small areas of Precambrian are in contact with rocks of the Pennsylvanian, Permian, Triassic, and Jurassic systems, while a little farther to the south, the Dakota Sandstone (Cretaceous) has a similar relationship.

One mile farther west the Pennsylvanian Precambrian contact (on the Six Mile Creek thrust plate) is believed normal, but a similar interpretation will not satisfactorily explain the remaining contacts; too many unrecorded coincidental events of local deposition, warping, and erosion through late Paleozoic and Mesozoic times would be required. The alternative explanation is by mechanical means.

The form and origin of these fensters are similar to that in Comanche Creek. Burbank and Goddard (p. 957) noticed similar features adjacent to thrust plates in the Huerfano Park area in the northern Sangre de Cristo Range. Possibly underthrusting by Precambrian rocks in the Lakeview area could be ascribed to the flat fault marking the western flank of the postulated Cimarron Mountains plunger.

On the drainage divide between Eagle Nest Lake and Tolby Creek, several patches of Triassic rocks rest directly on the crystalline basement. Attitude of the sediments varies, and in places appears to dip into the Precambrian. Contact specimens show fine-grained, hard, light-colored rock material containing light brown and purple lenses and streaks. A section of this material shows the major constituents are quartz grains 0.1 to 1.5 millimeters in size, extensively cracked, and with subangular outlines. Chips broken off the grains occur in clusters or isolated fragments embedded in the matrix. The matrix consists of brown limonitic material and minute shreds of mica masses swirling around quartz grains. The appearance is one of mortar structure produced by deformation and alignment of the softer materials in response to shear.

Elsewhere, particularly along Cimarron Canyon, field examination of the Permian and Triassic contacts with the Precambrian show a few feet of fine shaly (?) material containing scattered grains of quartz and feldspar. At no place have the authors seen an indisputable normal relationship.

In summary, a low arch in the vicinity of Cimarron extended into the Eagle Nest area in Middle to Late Pennsylvanian time. Some strata may have thinned over this arch. Angularity or other features in the sediments, ranging in age from Pennsylvanian to Cretaceous, indicating a positive area are little evident. In Comanche Creek, at the head of Eagle Nest Lake, and along Tolby and Cimarron canyons, contacts with the basement are disturbed or show comminuted rock materials, suggesting faulting. Evidence from Blue Lake, Lost Lake (and Bear Lake), shows that the basement has been involved in thrusting. The Blue Lake thrust becomes a high-angle reverse fault in places and is offset by tears that form prominent salients. The Six Mile Creek thrust possibly could be considered a giant landslide because of its easterly dip at some localities, but absence of slump features in the floor of the Moreno Valley, the normal contact observed above the East Fork of Red River, and its association with tears precludes this interpretation.

Lost Lake Thrust

Further evidence of Laramide thrusting is found in a series of erosional remnants of upper Paleozoic strata located at the crest of the range. The most common associated structural features are the synclinal and overturned folds exhibited by the Espiritu Santo and Tererro formations. The cores of these synclines are occupied by Pennsylvanian beds. The folds are interpreted as drag below from a thrust plate that moved from west to east but has since largely been removed by erosion. The largest and most revealing exposures are found high on the cirque wall at Lost Lake (pl. 1, B-B').

On Old Mike, an overturned syncline in the Mississippian contains a core of Pennsylvanian rocks. The upright limb dips 41 °w, whereas the overturned limb dips as much as 35°W. Contact with the underlying Precambrian is largely obscured by debris on the west side of the remnant, but appears normal on the east side. There, the basal correlative of Del Padre Sandstone is stained by secondary copper minerals derived from a diabase dike in the subjacent crystalline rocks. The Mississippian Pennsylvanian contact is possibly normal, but exposures are inadequate.

On the northeast flank of wheeler Peak, the Pennsylvanian again overlies Mississippian in an arcuate north-dipping remnant. The sediments are turned up on the west side and dip 48°E. The upper contact between the Mississippian and Pennsylvanian is normal, as is the relationship between the Mississippian and Precambrian.

To the north of Horseshoe Lake, Paleozoic sediments have been thrown into open folds, with the youngest beds preserved in a syncline. Similar features appear north of Lost Lake, although folding was restricted to upturning on the west side. Both these localities are detached from the main remnant.

However, on the south side of Lost Lake cirque, outcrops are apparently continuous across the divide between Red River and Lake Fork drainages. Strata are folded with axial planes on strike with the axial planes of folds at the locality north of Horseshoe Lake. The underlying Mississippian is turned up under the Pennsylvanian. At the contact is much breccia, part of which is the sedimentary breccia of the Macho Member of the Tererro Formation. At the true contact with the overriding Pennsylvanian strata, a feldspathic sandstone is brecciated and limonitized extensively. Small veinlets containing drusy quartz penetrate the sandstone and the underlying Mississippian lime-stone. The Pennsylvanian appears to have moved over the Mississippian (Clark, 1966a, pl. 15C). The underlying rocks have been crumpled and may have become locally detached from the Precambrian beneath. Elsewhere, particularly on the west side of the drainage divide, the Mississippian-Precambrian contact looks normal.

The root of the Lost Lake thrust lies farther west, but the exact locality is uncertain. At Bear Lake, Paleozoic rocks are again overturned, reflecting drag of a thrust moving eastward. At this locality the Precambrian has moved east (pl. 1, A-A').

The folds observed result from upthrust of the Precambrian in the immediate vicinity of Lost Lake. Evidence for this interpretation may be seen at the north side of the lake, where the sediments are vertical to overturned, and by the attitude of the Mississippian on Old Mike and Bear Lake. However, on the south side of Lost Lake, differential movement between Pennsylvanian and Mississippian appears to have taken place.

Miocene Faulting

The last earth movements in the Eagle Nest area accentuate the topographic features seen today because vertical displacements are characteristic. The age of this deformation is Miocene, possibly as late as late Pliocene, because the Moreno Valley fill has been faulted (Ray and Smith, 1941, p. 208). In the Moreno Valley, the earlier Laramide thrust plates and folds have been faulted. In the igneous complex of Red River, volcanic rocks are cut by a series of faults of various trends; and intrusives are localized along the same lines. The structures are dominated by high-angle normal faults that sharply contrast with the Laramide thrusts and folds described above. The principal trends are east-northeast and north-northeast and, to a lesser extent, north-_ west. A subordinate group includes east-west, north-south, and east-southeast. The most complicated area is along lower Red River, where all the trends are present. Several structural elements are recognized; the Taos horst, Red River ring structure, Red River graben, Moreno Valley, and the Cimarron Range.

Taos Horst

The structure of the Sangre de Cristo Mountains in this area is dominated by the Taos horst which exposes Precambrian rocks at its crest (Clark, 1966b, fig. 3). This horst is a dissected uplift expressed today as the Taos Range.

The Taos horst is some 17 miles long in a north-south direction and about 10 miles wide in an east-west direction. However, the width is variable at the north end because of the divergence between the Taos cone fault and the Blue Lake thrust. The Taos horst, as defined here, is considered a local structural element, developed by Miocene faulting impressed on the Sangre de Cristo uplift, that was developed by both Laramide and Miocene faults.

The western side of the uplift, although outside the map area, is marked by a sharp topographic break between the Rio Grande depression and the flank of the Sangre de Cristo Mountains (fig. 15). The Taos Range has been elevated along a zone approximately paralleling the present position of the mountain front on the west, according to McKinlay (1957, p. 14).

The eastern margin of the Taos Range is bordered by the Moreno Valley. The common slope of these two features is a complex zone of normal, reverse and thrust faults. Thrusts are complex in that they consist of low-angle segments which pass into tears and high angle portions. Dip-slip and forward movement ranges from 2,000 to 9,000 feet. The thrusts (Laramide) are broken by high-angle normal faults (Miocene) in both sides of the Moreno Valley.

The northern part of the horst is truncated by the Red River graben, but the southern limit is less well defined, although it extends as far south as the upper part of Rio Pueblo de Taos.

The vertical displacement is as much as 7,000 feet on the west side of the horst (McKinlay, 1957) and up to 3,000 feet along the Taos Cone fault on the east side. To the north in the Red River graben, vertical displacement is 2,800 feet, but to the south, the magnitude of displacement is unknown.

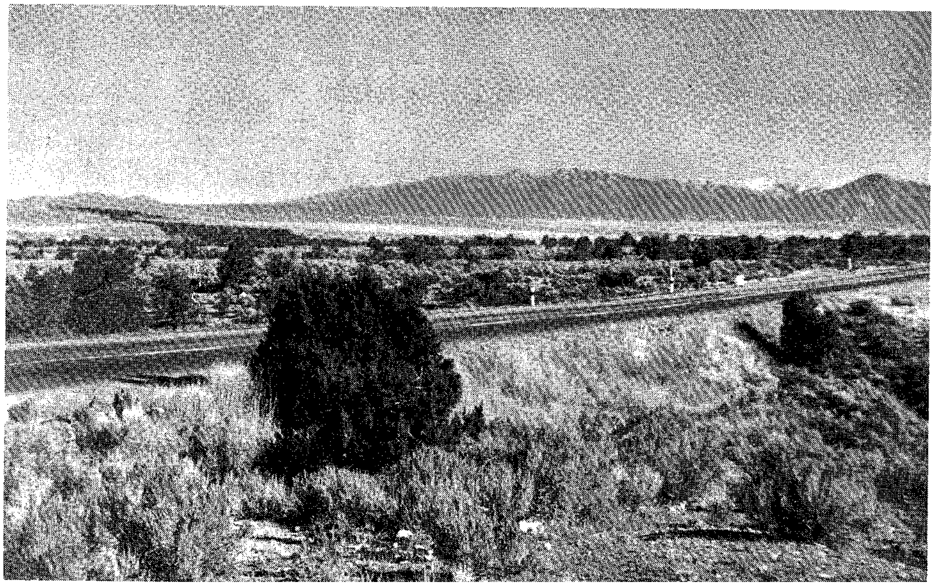


FIGURE 15—Northward view of west side of Taos Range. The Rio Grande depression, referred to locally as the Taos Plateau, is covered with late Pliocene gravel and basalt that have been deeply incised by the Rio Grande. The bottom of the gorge, seen at the left side of the picture, is 7,000 feet below Wheeler Peak, 16 miles to the east. Some low volcanic cones are on the horizon.

Red River Ring Structure

On the geologic map (pl. 1) a circular pattern is etched by the Red River. This ring is completed by the drainage patterns of Rio Hondo, the unnamed stream northwest of Amizette, and Columbine Creek in Questa quadrangle. The ring, averaging about eight miles in diameter, has a core of Precambrian rocks with a thin cover of volcanics in the northeast. At the periphery are the biotite granite stocks at Flag Mountain, Sulfur Gulch, and Red River; the Relica Peak rhyolite; and the Rio Hondo hornblende granite (fig. 16). Clark (1966a, p. 246) noted that the emplacement of these Tertiary igneous intrusives in such a geometrical arrangement was more than fortuitous.

The east-northeast fractures along the north and south sides of the ring are marked by the Red River fault and a series of shears near the Frazer mine in Rio Hondo, respectively. This direction is nearly parallel to the foliation in the Precambrian rocks and the fractures filled with pegmatites and quartz veins. Rejuvenation along this old direction of weakness is apparent. Schilling (1960, p. 35) noted that the Red River downfaulted area lies along a northeast trend of volcanic activity extending from Springerville, Arizona, to Spanish Peaks in Colorado. Included along this line are Mount Taylor, Jemez caldera, volcanoes of Taos Plateau, and the volcanic rocks of the Taos Range. He further suggested that this belt reflects a deep-seated zone of weakness explaining the unusual trend found along the Red River.

Completing the structural segments of the Red River ring are the northwest-trending faults bordering the Rio Hondo granite on its east side, and the fault bordering the Red River stock along its south side. The remaining part of the ring is comprised of a fault along upper Red River Canyon referred to as the Taos Cone fault, being colinear along a high-angle segment of the Blue Lake thrust.

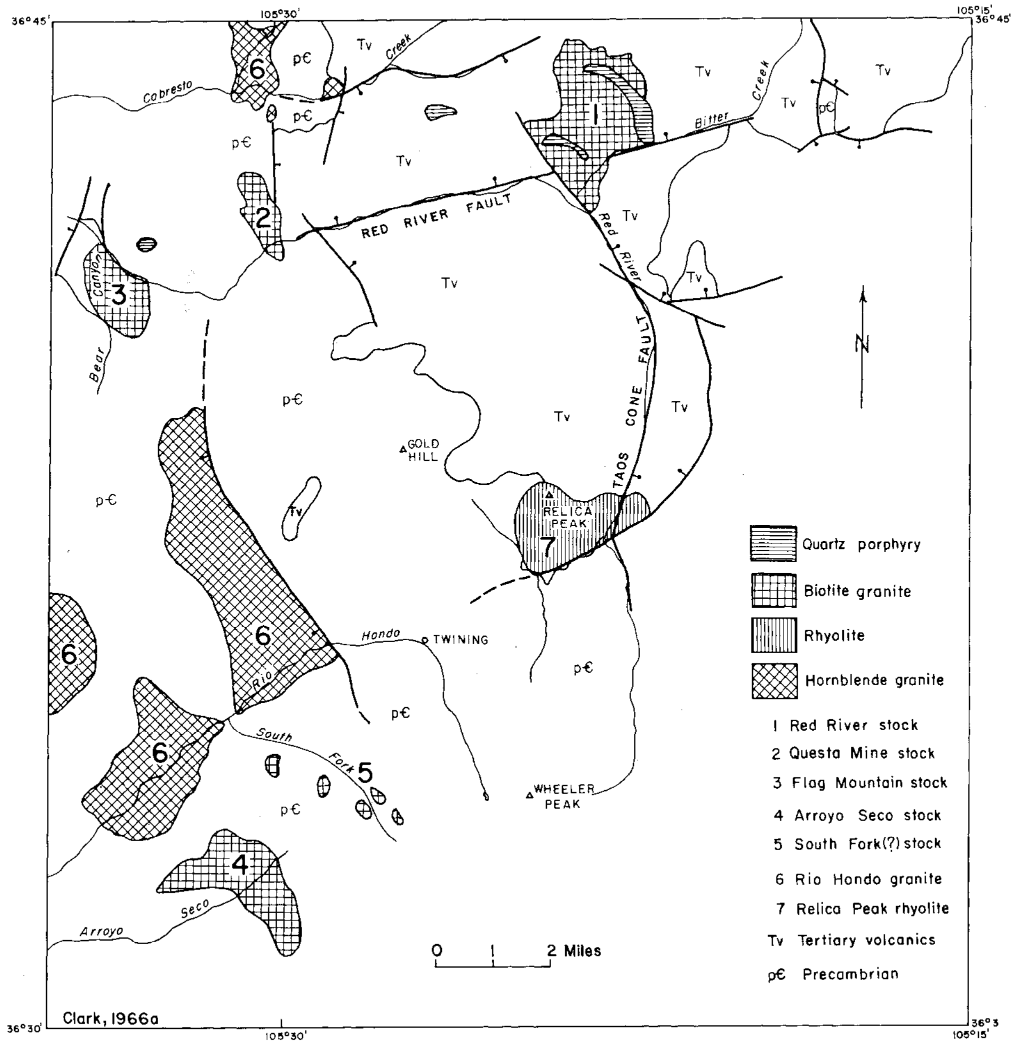


FIGURE 16—Red River ring structure, showing relationship to the Precambrian basement and Tertiary volcanic and intrusive series.
(geology after McKinley, 1957 and Clark, 1966)

In summary, the vertical displacements characteristic of Miocene and post-Miocene faulting appear to have been active around a competently welded block of Precambrian rocks, in such a way that its core has been relatively undisturbed by Cenozoic deformation. At the periphery, siliceous igneous stocks have been intruded, and major thicknesses of volcanic rocks have been preserved in fault angles on the north and east sides. Within the ring, the volcanic rocks have been largely stripped away by erosion. Similar drainage patterns developed in the area include a partial ring defined by Rio Hondo, Lake Fork, and Rio Lucero in the Eagle Nest area, and around the Costilla massif in Costilla quadrangle.

Although the individual intrusives occur along lines of weakness, evidence does not show that the ring results from a single integrated structural break. The interpretation offered here is that the east-northeast, north-south, and northeast Miocene fracture systems have been etched by the drainage to form the ring structure. Doubtless the ring structure is near the center of Cenozoic igneous activity in this region. Not only is it associated with intrusives, but it is flanked and cut by dike swarms, and circumscribed by Tertiary and Quaternary volcanics of north-central New Mexico.

Red River Graben

This element is a negative structural feature consisting of jumbled and tilted fault blocks aligned in an east-northeast direction, referred to by Clark (1966a) as the Red River Graben. Previously, Schilling employed the terms "down-faulted zone" and "graben-like area" (1956a, p. 33-35), "down-faulted area" (1960, p. 20), and "down-faulted trench" (1965, p. 26).

The structure is only partly contained within the map area; its full extent occupies parts of the Questa, Costilla, and Latir Peak quadrangles. The relation of molybdenum mineralization in the Red River district to this feature and to other lineaments in the western United States has been pointed out by Clark (1966c, 1968, p. 560). However, it cannot be overemphasized that this structure is complex and that numerous cross faults have greatly modified the picture of a simple linear depression.

This structure is aligned in an east-northeast direction, stretching from near the western margin of the Sangre de Cristo Range in the Questa quadrangle to the Midnight-Anchor area in Costilla quadrangle. Overall the length is about 14 miles and the width ranges from two to four miles. As shown in section D-D', plate 1, a considerable thickness of the volcanic series is structurally preserved. The thickness of this wedge is greater than that immediately to the north and south of the structure. To the south, the base of the volcanics lies on a high platform of Precambrian rocks; it thins and then disappears entirely south of Gold Hill on the west and Wheeler Peak village on the east. A small area of Tertiary volcanics appears as far south as Tienditas Creek-La Junta Canyon south of the map area. North of Cabresto Creek and Bonito Canyon, Precambrian mica quartzite is extensively exposed, but the thickness of the volcanics increases thereafter towards Latir Peak before the limit is reached some 10 miles farther north on the Costilla massif. The eastern and western limits are more difficult to ascertain. To the east, the graben is lost in upper Bitter Creek, although the volcanic rocks appear as far east as Costilla Pass and as far north as the area of Ortiz Peak in the Costilla quadrangle (McKinlay, 1956, pl. 1). To the west, the limit is again ill defined in that both Precambrian and Tertiary rocks are found at the mouth of Red River Canyon, where north-trending faults predominate along the mountain front.

The major fault along the graben follows the line of Red River and Bitter Creek. Although almost completely concealed by alluvium and mudflow, its presence can be inferred by the attitudes of the Precambrian-Tertiary unconformity, and to a lesser extent, the elevation of the base of the rhyolite group. This high-angle normal fault has been referred to as the Red River fault. To the south, it is bordered by a parallel fault that probably forms the southern limit of the graben. This fault is possibly continuous with an east-southeast fault that brings latite against andesite in the vicinity of Red River Pass.

North of the Red River fault a line of hydrothermal alteration areas marks a parallel fault. The northern limit of the graben, in the line of the structure section (pl. 1, D-D') is in Bonito Canyon, where at one locality the base of the andesite is 100 feet higher than the base of the downfaulted rhyolite. The elevation of the base of the andesite is 9,800 feet, the same as that in upper Pioneer Creek on the south side of the graben. The base of the andesite in the intervening depressed area is almost 7,000 feet, which indicates a structural relief of 2,800 feet in the line of section.

The segmentation of the Red River graben by northerly striking faults is illustrated in an east-west structure section (pl. 1, C-C'). In Spring Gulch, the Questa Mine stock appears locally exposed along the line of a north-trending fault that brings up Precambrian mica quartzite against andesite. Nearby, the base of the andesite, resting on mica quartzite, is at an elevation of 10,300 feet, which suggests a throw on this fault of about 2,000 feet. Farther east, the base of the volcanic series is repeatedly dropped to the east, with one exception, by high-angle cross faults.

The andesite thins and is locally absent in the line of section east of the Red River stock. Meanwhile, the increasing thickness of latite attains its maximum in Bitter Creek. Above the Enderman mine, rhyolite rests directly on the Precambrian suggesting that this area was a topographic high on an erosion surface bevelled on Precambrian rocks.

West of Van Diest Peak, rhyolite and andesite are faulted down against mica quartzite; this fault may mark the structural eastern limit of the Red River graben.

The base of the andesite is not exposed on the east side of this fault, but judging from thickness considerations is believed to be near 10,600 feet. Comparison with the elevation of 10,300 feet near Spring Gulch and the structural low of 6,800 feet elevation east of Hottentot Canyon indicate a structural relief of 3,500 to 3,800 feet.

Finally, Tertiary granite intrusives are found along the axis of the graben. These include the Flag Mountain, Questa Mine, and Red River stocks, in addition to several smaller bodies of quartz porphyry.

Moreno Valley

On the west side of Moreno Valley a fault along Red River and Rio Pueblo de Taos, though variable, may have a throw of as much as 3,000 feet near Taos Cone. The Taos Cone fault displaces the volcanic rocks in the upper Red River Canyon (pl. 1), and at the entrance to Foster Park Canyon, the andesite tuffs and breccias have slumped into, and partly block, Red River Canyon. Farther south, the fault coincides with a segment of the Blue Lake thrust.

At Wheeler Peak village, the Taos Cone fault offsets another high-angle fault that marks the eastern limit of the volcanic rocks and the western limit of a large salient of Precambrian granitic biotite gneiss (pl. 1). The latter fault is interesting because it connects an earlier tear fault along the south side of the Precambrian salient with a tear along the north side of the salient. The fault extends southeast and may die out in the shears near the Frazer mine at Twining.

The tear on the north side of the salient strikes in an east west direction from Hematite Creek eastward to North Moreno Creek where it passes into the northern part of the Blue Lake thrust. Although this tear is poorly exposed, it has sheared the muscovite-hematite granulite, producing a lustrous schist. An apparent offset of the granulite on the north side of the tear suggests a forward movement of about 2,500 feet. In other words, the tear marks the south side of another salient of Precambrian rocks in the area of North Moreno Creek.

Another high-angle normal fault on the west flank of Moreno Valley cuts and displaces the flat trace of the Six Mile Creek thrust. Sections A-A' and B-B' (pl. 1), show it parallels the Taos Cone fault and strikes along Sawmill Creek southward to the margin of the map area. There, Precambrian granitic rocks are in fault contact with the Magdalena Group along a small scarp. The throw on this fault is only 200 to 300 feet. Topographic expression of this fault is imperceptible compared with that on the east side of the valley; the west flank of the valley is largely a dip slope of Pennsylvanian rocks.

Finally, the synclinorium produced by Laramide thrusting, folding, and doming in the Moreno Valley has been modified by high-angle Miocene faulting, inasmuch as the synclinal structure occupies a topographic depression (fig. 17).

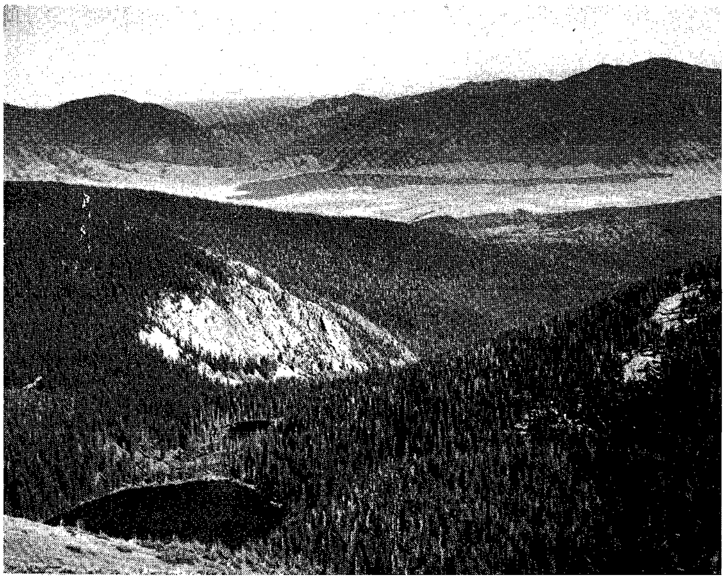


FIGURE 17—Eastward view of Blue Lake cirque and Moreno Valley. Upper part of a gorge is cut in mica quartzite. Lower tree-covered slopes are underlain by the Magdalena Group, whereas Mesozoic sediments underlie the grass-covered valley floor. The Precambrian core of the Cimarron Range is exposed east of Eagle Nest Lake.

Cimarron Range

Along the east side of the valley, the Eagle Nest fault can be traced from Eagle Nest Lake northward through Baldy Mountain and beyond, the northernmost part marked by a large diorite porphyry dike intruding Poison Canyon sediments. The line of this fault, traced intermittently for 12 miles, becomes flexed and branched in the vicinity of the McElvoy Hill rhyolite. Apparently the intersection with the southeasterly trending Fowler Pass fault localized this intrusive body. Referring to a segment of this fault system, Wanek and Read (p. 83) indicated that it "cuts and displaces an earlier flat fault." The flat fault referred to is the underthrust fault of the postulated plunger core of the Cimarron Mountains, described earlier.

Much of the differential uplift of the Baldy-Cimarron Range due to normal faulting takes place along the Eagle Nest fault. The present physiography of the range (fig. 18) is the result of mid-Tertiary high-angle faulting along its western flank; although, like the Taos Range, the full extent of the structural and topographic relief can best be interpreted by additional consideration of Laramide deformation and doming by igneous intrusion. Graton (in Lindgren, Graton, and Gordon, p. 294) drew attention to the eastward dip of the Mesozoic strata in the Baldy area: these strata are tilted up to the fault and consequently dip away from it. The implications of the uplifted Precambrian core in the range south of Cimarron Canyon have been dealt with under Laramide deformation.

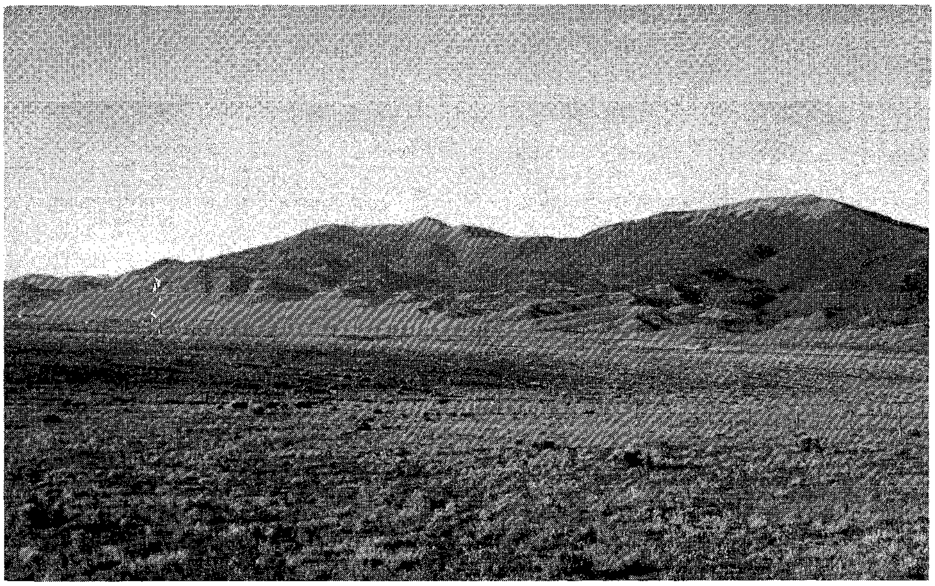


FIGURE 18—Northern part of Cimarron Range seen across Moreno Valley. Foothills are part of the downthrown side of the Eagle Nest fault. Baldy Mountain at center and Touch-Me-Not Mountain at the right are underlain by eastward-dipping Mesozoic rocks intruded by sills of quartz diorite porphyry.

Summary

Ideas concerning the structural origin of the southern Rocky Mountains may be summarized as follows: some investigations favor the theory of lateral compression, while others consider vertical movements dominant. Burbank and Goddard (1937, p. 933) recognized both thrust faults as well as vertical uplifts in Huerfano Park. Differential vertical movements apparently became dominant during the latter stages of deformation, with upthrust of the Precambrian core and the downfaulting of adjacent valleys. We subscribe to these views, based on our study of the Eagle Nest area. We further believe that an account of the mountain building must also include effects due to the emplacement of the Tertiary granites and volcanic-tectonic depression within the area (Clark, 1966a, p. 253).

More recently Petersen (1969, p. 66) and Petersen and Woodward (1969) have used models simulating uplift in the adjacent Tienditas Creek-La Junta area. They were able to reproduce upthrusting similar to that described by Prucha, Graham and Nickelsen (1965). The stress responsible for these simulated movements was ascribed to doming by magma from below. This event was followed sequentially by upthrusting, collapse, and grabening.

In Cenozoic time a sequential and possibly related series of closely spaced tectonic epochs contributed to the complex structures in this region. Lateral compression, folding, thrusting, and movement of the basement have preceded igneous intrusion, doming and collapse along vertical faults. Different structural elements have emerged as a result of one or more of these processes. The overall result is one of complexity to the point of being anomalous when compared to other segments of the Sangre de Cristo Mountains.

Geomorphology

The Eagle Nest area, as part of the Sangre de Cristo Range, falls within the southern Rocky Mountains Province. However, some structural evidence indicates that the west side of Moreno Valley could locally be considered as the western limit of the Great Plains Province.

Erosional features, accentuated by rock type and structural control, dominate over depositional features. Erosional features possess the striking relief of the area. The western and eastern parts of the map area are rugged in contrast to the middle part, which is characterized by the more gentle surface bounding the Moreno Valley. In particular, the western part is made up entirely of crystalline rocks, which, in the Taos uplift have been sculptured by glaciation. In contrast, depositional features consisting of glacial moraine, talus, landslide, mudflow, and alluvium, are confined to valley floors.

Within the Eagle Nest area and adjoining country are several elements whose lithology, geomorphic history, and structure differ widely. They include the Taos uplift, Red River graben, Moreno Valley, and the Cimarron Range (fig. 19). Briefly, the Taos uplift consists mainly of Precambrian rocks bounded by high-angle normal faults and is a glacially sculptured horst. It is bounded on the west by the Rio Grande rift and on the east by the Moreno Valley. The Moreno Valley is floored by sedimentary rocks largely covered by alluvium, bounded on the west by high-angle normal and thrust faults. The negative physiographic expression of the Moreno Valley strongly contrasts with the positive Taos uplift on the west and the Cimarron Mountains on the east. The Red River graben is composed primarily of volcanic rocks and associated intrusives of mid-Tertiary age. Structurally, this graben is complex. Its boundaries are

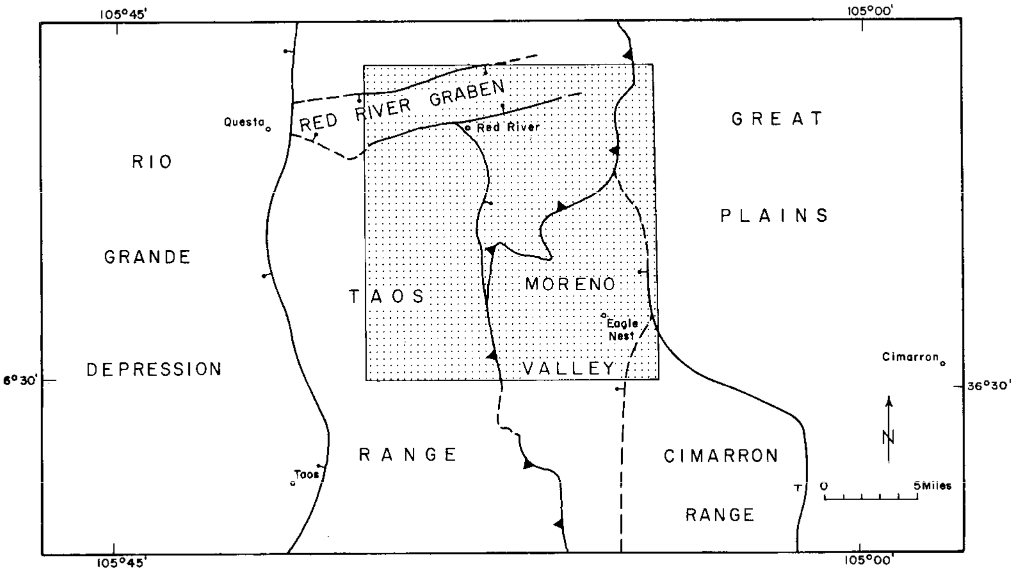


FIGURE 19—Relation of local structural and geomorphic elements of Eagle Nest area to regional provinces.

indicated by the structurally higher Precambrian rocks. Its physiographic expression is intermediate because it does not exhibit the glacial features of the Taos uplift but does show major dissection by fluvial processes.

MOUNTAINOUS AREAS

The high country is localized in three areas in the western and eastern parts of the region. The largest of these areas of rugged mountainous terrain is around Wheeler Peak, elevation 13,173 feet, the highest point in New Mexico. Flanking this peak and on the same ridge, subsidiary peaks, also in excess of 13,000 feet, include Mount Walter to the north and Old Mike to the south. Many other summits nearby reach an elevation near, 12,500 feet, the most prominent of which are Vallecito Mountain, Fairview Mountain, Lake Fork Peak, Lucero Peak, Lew Wallace Peak, Red Dome, and Taos Cone. Radiating from these peaks are the drainage systems of South Fork, Lake Fork, Red River, Rio Pueblo de Taos, and Rio Lucero (pl. 1). A similar situation occurs in the second, smaller area in and around Gold Hill. This mildly rounded peak is some 7 miles north-northwest of Wheeler Peak and is separated from it by a broad, partly dissected ridge that forms the backbone of the Sangre de Cristo Range in this area (fig. 20). The summits above this level appear to be monadnocks (pl. 1, D-D'). Gold Hill, elevation 12,711 feet, stands alone insofar as no other peaks of comparable elevation are nearby. Drainage is radially disposed around this mass of old crystalline rocks and comprises Placer Fork, Deer Creek, Pioneer Creek, Goose Creek, west fork of the Red River, and Long Canyon.

The divides separating these drainage systems are narrow and in places are aretes, as between Lucero Peak and Simpson Peak and east of Vallecito Mountain. They have been created by headwall recession of the cirques below. These ridges have undulose crests punctuated by small cols. Both areas lie above timberline and provide the best exposures of Precambrian rocks.

Individual cirques range from 1,000 to 2,000 feet in width but coalesce to form large amphitheaters more than a mile in diameter (frontispiece). Cirques are charac-

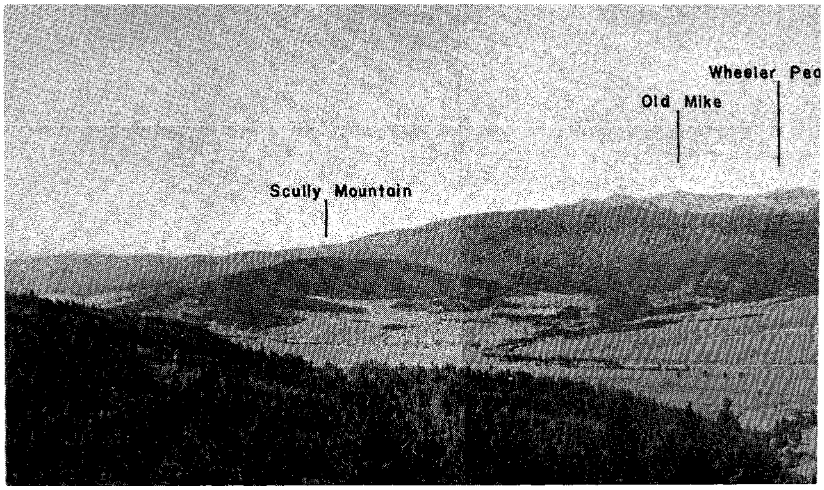
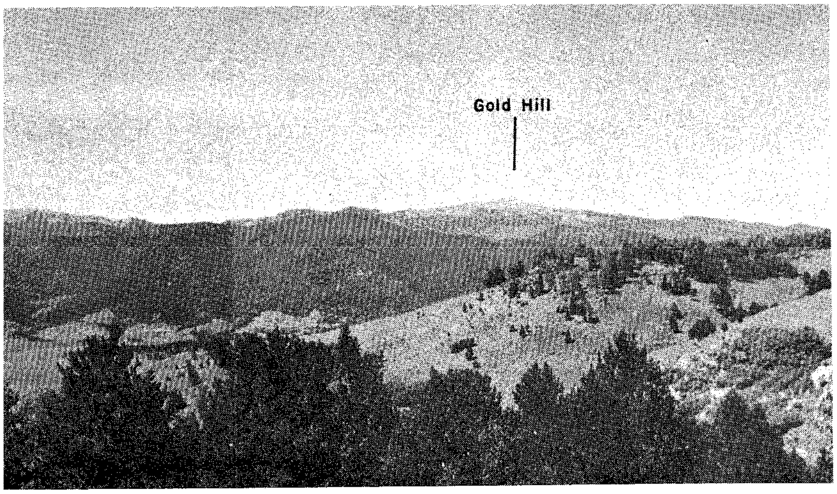


FIGURE 20—View toward the southwest of Moreno Valley and Taos Range from Mills Divide. Peaks on the skyline, including (left to right) Old Mike, Wheeler Peak, and Gold Hill, form the crest of the Taos horst, which has a crystalline Precambrian core. The forest-covered slopes in the middle background, underlain in part by eastward-

terized by precipitous walls, and, in many, lakes impounded by moraines perched on the cirque lips. Among numerous examples are Goose Lake, Williams Lake, and Blue Lake (fig. 17). Recent rock falls tend to form rock glaciers usually found below the lip. The cirque with its distinctive form and contained products of degradation, is one of the most striking land forms of the area (fig. 2B).

Below the cirques, deposits of early Wisconsin substages are found in the glaciated valleys. Terminal moraines are recognized by their form and elevation as summarized in Table 7. Valleys are U-shaped, especially in the more resistant bedrock, such as the deep gorge cut in metaquartzite below Blue Lake. Cross sections of these glaciated valleys have been modified by subsequent erosion. Valley sides and intervening ridges have been worn away and much of the loose material clings to the lower valley wall, thereby softening the profile. The lowest limit of Wisconsin Glaciation is 9,400 feet, but the general form of the valleys is carried lower and is probably due to earlier mountain glaciation. Finally, hanging valleys, although present, are poorly preserved. Some of the better examples are in the east fork of Red River. Postglacial fluvial erosion has partially destroyed these glacial features.

The map area contains the western parts of Baldy Mountain, elevation 12,441 feet, Touch-Me-Not Mountain, elevation 12,045 feet, and other smaller peaks north and south included in the Cimarron-Baldy Range (fig. 18). Highest elevations are above timberline, but, in general, the outline of these peaks, despite their diverse structure and lithology, is not so rugged as the glaciated peaks composed of Precambrian rock in the Taos horst primarily because of the presence of eastward-dipping sediments that make up the bulk of the northern part of the range. Locally, gradients are very steep, particularly where sills are present or where erosion has steepened the west flank of Touch-Me-Not Mountain along the line of the Eagle Nest fault. This fracture probably accounts for the distinct shoulder-and-peak outline of Baldy Mountain where the section has been downthrown on the west. Farther north, the line of the fault is marked by a small but definite ridge, indicating a large diorite porphyry dike. North of Mills Divide, elevation 9,752 feet, a prominent ridge parallels the faulted Precambrian-



dipping Pennsylvanian strata, are on the downthrown side of the Taos Cone fault. The Scully Mountain dome is to the left in the valley; the remainder of the valley is underlain by Mesozoic formations intruded by Tertiary sills.

Poison Canyon contact to beyond Valle Vidal. The eastern side of this ridge is a dip slope of early Tertiary sediments dissected by streams flowing into the middle fork of Ponil Creek.

South of Touch-Me-Not Mountain and separated from it by a high saddle, McElvoy Hill is underlain predominantly by intrusive rhyolite forming the steep northern wall of upper Cimarron Canyon. Rhyolite scree covers the hillside, except where Cimarron Creek has cut through and deposited alluvium over the Precambrian along the canyon floor.

The south side of Cimarron Canyon in this area, with the exception of Triassic erosional remnants, is underlain by basement crystalline rocks. The east side of Eagle Nest Lake is marked by a distinct escarpment separating the lake from Tolby Creek. This creek is structurally controlled by a splinter of the Eagle Nest fault running beyond the limits of the map area and probably passing into the Lost Cabin fault. The escarpment may be formed by a concealed branch of the fault system, which is covered by valley fill and the lake itself. East of Tolby Creek, a ridge lies beyond the north-south Eagle Nest fault and the southeasterly striking Fowler Pass fault.

Ray and Smith (p. 199) considered the Cimarron Mountains an eastward-tilted fault block of the southern Rocky Mountains geanticline and treated the Moreno Valley as a border depression along the western side. But the Cimarron-Baldy Range is complex lithologically and, in addition, structurally and, to a lesser extent topographically, divisible along Cimarron Creek.

DRAINAGE SYSTEMS

The drainage systems are greatly influenced by the characteristics of the morphotectonic elements. The principal drainage is the Red River, which eventually empties into the Rio Grande some 10 miles west of the map area. Other major streams draining to the west are Rio Hondo, Rio Lucero, and Rio Pueblo de Taos. With the Red River, they rise in the high, mountainous, Taos uplift. These drainages are controlled by former radial dispersion of mountain glaciation from the Wheeler Peak and Gold Hill areas, as well as by the fault patterns created during Miocene deformation. These effects are vividly displayed by the counter-clockwise course of the Red River.

The profiles of side streams tend to be short and to have steep gradients. However, a vast network is gradually superimposing a dendritic pattern on the earlier controls. The dissection is believed to be in a stage of early maturity.

The Red River graben element is drained by the lower part of the Red River, and its tributary, Cabresto Creek, both of which are structurally controlled. Drainage patterns are similar to those in the Taos uplift, although the orientation is different, and locally a trellis pattern predominates. The hydrothermally altered areas are so easily eroded that heavy precipitation produces mudflows.

The drainage of the Moreno Valley is completely different. The west slope of the valley has a dendritic drainage pattern developed on the eastward-dipping strata of the Magdalena Group. The profiles across these consequent stream valleys are more gentle than in the western part of the area. This situation persists to the northern end of the valley, where profiles become quite gentle in the grassy parks developed between Red River Pass and Costilla Pass, despite the fact that this area is underlain by crystalline rocks. The surface, in general, is one of little relief and is broken only by the rises of Tetilla and Van Diest peaks. Otherwise, the surface elevation is near 10,000 feet, the significance of which will be discussed later.

The northeast side of the Moreno Valley is formed by a hogback of mica quartzite, resulting from thrusting and folding. Northeast of Mills Divide, consequent drainage developed on the eastward-dipping strata have dissected the Poison Canyon Formation and flow into the middle fork of Ponil Creek. Farther south in the eastern wall of the Moreno Valley, stream profiles are quite steep but become gentle in the valley floor, and little water is carried off the slopes of Baldy Mountain. South of Elizabethtown, the Moreno Valley is constricted by the anticlinal mass of Iron Mountain and the intrusive dome of Scully Mountain. Flowing between this constriction is the sluggish Moreno Creek.

Formation of the Moreno Valley was complete following late Miocene faulting, and became filled with gravel of Pliocene to early Pleistocene age. According to Ray and Smith (p. 200), the drainage of this basin resulted in a through-flowing stream that continued southward along a physiographic feature traced to the vicinity of Mora. North of the Moreno Valley, a similar feature can be traced into Colorado. In Pleistocene time the whole length of this valley was the course of a large river that drained the east slope of the Sangre de Cristo Range. The stream was named the ancestral Coyote River (Baltz and Read, 1956, p. 71). Furthermore, this ancestral river was disrupted by headward erosion, stream capture by east-flowing streams tributary to the Canadian River, and by the extrusion of basalt flows in the southern end of the Moreno Valley. Today, the northern part of the Moreno Valley is terminated by the low divide at Costilla Pass, and without a drainage connection with the valley to the north.

According to Ray and Smith (p. 200-203), during the through-flow of the ancestral Coyote River, a series of surfaces was cut on bedrock and valley fill as the valley gradually widened. These surfaces were graded to successive levels of the river. The capture of drainage by headward erosion of the Cimarron River was thought to have occurred during the first phase of erosion. The drainage of the southern part of the Moreno Valley was reversed, and today is represented by Cieneguilla Creek. North of Eagle Nest, and within the map area, the drainage has continued along the line of the present Moreno Creek. The first surface, named the Broad Valley stage, developed on a surface 600 to 800 feet above the present stream level.

Three later surfaces were cut on valley fill in Pleistocene time. Surface 1 was graded to the stream when it was about 140 to 150 feet above its present elevation. Surface 2 was at a level approximately 60 feet above the present gradient, whereas surface 3 was only 20 to 30 feet above the present stream (pl. 1). Ray and Smith (p. 202) referred to these surfaces as pediments. However, Clark (1966a, p. 264) suggested that locally they may be indistinguishable from stream terraces.

The surfaces form striking erosional features in the Moreno Valley. They have been remapped with the aid of aerial photographs and are plotted on plate 1. Surface 2, on the south side of Six Mile Creek, is shown in fig. 21. The valley fill around Scully Mountain and Iron Mountain was gradually removed as the base level of Moreno Creek was lowered and bedrock was gradually uncovered. At some unknown time, connection with the valley north of Costilla Pass was severed. Today, Moreno Creek is a small segment of a former large river. Its size and erosive capacity bear no relation to the valley through which it flows. Moreno Creek is an underfit stream.

MIDDLE TERTIARY EROSION SURFACES

A high undulating surface characterizes much of the surrounding country. From the vantage points of the high peaks, a surface can be seen between wheeler Peak and Gold Hill. The elevation ranges from 11,000 to more than 12,000 feet, as seen in profile (pl. 1, D-D'). Above this surface are the monadnocks of Gold Hill and Wheeler Peak, which are 500 to 600 feet higher. Part of this surface is broken by the valley of Rio Hondo. In contrast, between lower Red River and Cabresto Creek, the surface is at an eleva-

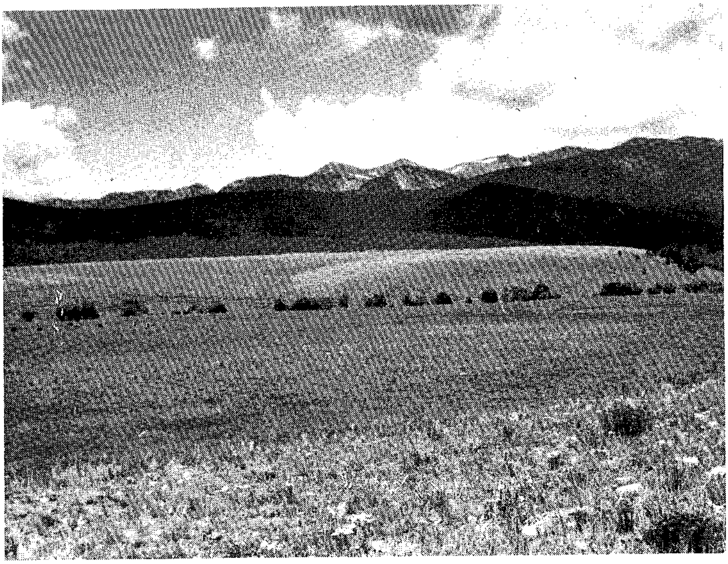


FIGURE 21—Erosion surface at Sixmile Creek. Notice the geomorphic expression of the regular surface cut on basin-fill gravel, compared to the slope of the Moreno valley underlain by Pennsylvanian strata, and the uplifted and dissected Precambrian terrane of the Taos uplift on the skyline.

tion of 10,000 to 10,500 along the length of the Red River graben. This general elevation extends farther eastward to the vicinity of Costilla Pass. Red River Pass is a structural and physiographic sag between the Moreno Valley and Red River. The high surface appears on the east side of the Moreno valley, flanking the Baldy Mountain monadnock (fig. 18). Here, an accordancy of summits between 11,200 feet and 12,000 feet north of Cimarron Canyon differs from the main interior highland surface cut on the Precambrian core south of the canyon, which Ray and Smith (p. 913) indicate is nearly at 10,000 feet. Consequently, more than one stage of erosion may be represented. However, for the purpose of this discussion, only one surface will be considered; Ray and Smith (p. 206), correlated it with the San Juan peneplain.

Atwood and Mather (p. 25) determined the age of the San Juan peneplain as Pliocene because it cut across Miocene volcanics in the San Juan Mountains. Later, Atwood (1940, p. 305) classified the San Juan peneplain as mid-Tertiary. Whatever the age, the Hinsdale Formation of late Pliocene to Pleistocene age rests on the peneplain surface. In describing this surface, they pointed out that the peneplain is neither smooth nor horizontal, varying from 9,000 to 13,000 feet in elevation. The summits of the San Juan Mountains are only a few hundred feet above this upland surface, and were regarded as residual hills at the time of peneplanation. They furnished gravel that was deposited along the courses of numerous streams. Later deformation arched this surface into a low dome, the remnants of which are seen today.

Many similarities are in the Eagle Nest area. The monadnocks of wheeler Peak, Gold Hill, and Baldy Mountain have already been mentioned. High-level gravel, resting on the upland surface, is found near Red River, and, by analogy, may have a fluvial origin. It contains many cobbles of metaquartzite, the nearest outcrops of which are two miles northeast. These deposits were thought to have a glacial origin, possibly correlating with the Cerro till of early Pleistocene age, not related to glaciation that formed the local cirques (Ellis, 1935, p. 29). Ellis considered the gravel deposited by the Red River lobe of the Moreno Glacier. The direction of transport could have eroded the quartzite on Red River Pass, although other source terranes within the area may have contributed by other processes.

Miocene and post-Miocene faulting in the map area may, in part, be simultaneous with early doming of the San Juan Mountains in late Tertiary time. Materials derived from these two uplifted areas were deposited in the San Luis basin. On the east side of the Taos uplift, similar materials were deposited in the Moreno Valley.

The high-level gravel of the Red River area and the San Juan Mountains are thought to be somewhat older than that found in the adjoining depressions. It became perched and stranded, whereas the new products of erosion were swept into adjacent depressed areas by rejuvenation of the streams. Thus, the base of the gravel above Red River is 10,000 feet, whereas the elevation of the Broad Valley stage of erosion in the Moreno Valley is 9,200 feet.

The base of the high-level gravel east and west of the Taos Cone fault is approximately the same, although difficult to delineate on the west side. Thus, the apparent throw on the fault, based on this evidence alone, is only 50 to 100 feet. More likely, however, the gravel is not nearly so thick as the 300 feet cited, being probably nearer 135 feet as found in the shaft of the Hilltop prospect. The throw of the fault would then be a few hundred feet, comparable with the displacement of the base of the andesite series in the Red River graben.

Geologic History

Although the earliest geologic events are partly shrouded by the many events of succeeding periods, a glimpse of earliest history is afforded by re-exposure of the Precambrian terrane.

The area was initially occupied by shallow to moderately deep seas, in which great thicknesses of' quartzo-feldspathic and quartz sands were deposited. Minor fluctuations and deepening of this basin of deposition are reflected in the accumulation of fine elastic materials and carbonaceous shales interbedded with thick sand layers. Later, the character of deposition changed so that vast quantities of argillaceous and lesser amounts of calcareous materials accumulated in a deepened basin. Nor was igneous activity lacking; layers of basic and ultrabasic rocks, indicating the first phases of crustal unrest, became interbedded with the muddy and calcareous sediment. The character of the source area from which these sediments formed is purely speculative, other than its major mineral composition which is probably reflected in the basin of accumulation.

Later in Precambrian time, compressional forces of regional metamorphism acted upon the sedimentary prism and produced a northeasterly grain sufficiently strong to survive all later events. The quartzo-feldspathic and quartz sands were changed to granulite and mica quartzite, respectively; whereas the interbedded shales and carbonaceous shales were converted to sillimanite mica gneiss and graphite mica gneiss, respectively. Newly produced minerals were oriented in planes perpendicular to regional compression, thereby producing a northeast foliation that largely obliterated the sedimentary structures. The overlying argillaceous and calcareous sediments were metamorphosed to a lower grade. The transformations resulted in chlorite, biotite, and hornblende-rich schists and gneisses produced from the argillaceous sediments and tremolite-actinolite schist from the calcareous facies. The interlayered mafic igneous rocks were converted to amphibolites and hornblendite.

During the latter stages of regional metamorphism, the emplacement of granite in batholithic proportions characterized the first phase of orogenesis. The surrounding metamorphic rocks were profoundly affected, and, along the margins of the granite, mixed rock was produced. Accompanying the production of migmatites were the metasomatic effects that introduced silica, potash, and, to a lesser extent, boron. The final phases of consolidation resulted in the transfer of late-stage fluids into fractures in the granite and surrounding rocks, becoming embodied in granitic stringers, pegmatites, and quartz veins. This period of plutonic activity is correlatable with the younger (Elsonian) granites of the Southern Rocky Mountains. The ebbing regional compressive forces were still strong enough to impart a foliation to the granite; this was followed by the intrusion of diabase dikes, possibly synchronous with regional uplift.

The positive area created in late Precambrian time appears to have been preserved throughout the lower Paleozoic, with the possible exception of Ordovician time, as part of a broad, southwest-trending continental arch. Earth movements must have been confined to crustal warpings, but by Early Mississippian time, the positive area had been sufficiently leveled to allow the transgression of a shallow sea. At the close of this short period of deposition, the area was uplifted and a karst topography developed on the newly formed limestone. Marine deposition was renewed, but repeated crustal warping produced unconformable relationships among the various lithologic units.

Pennsylvanian time was marked by orogenic uplift in northern New Mexico and Colorado, so that positive areas were produced but separated from one another by troughs in which vast quantities of materials accumulated. These uplifts have been called the ancestral Rocky Mountains. The Eagle Nest area was situated on the western side of the Colorado-Northern New Mexico zeugogeosyncline. Immediately to the west, this trough was marked by the Uncompahgre-San Luis positive axis, from which materials were locally derived. Sediments were mainly shallow-water marine in character, although the basin must have been rapidly subsiding to permit deposition to continue. A prolific fauna indicates an early to middle Desmoinesian age for the containing rocks. Deposition continued into Early Permian time, but the sediments changed in character with the advent of a continental environment. At this time, several thousand feet of red beds of the Sangre de Cristo Formation were deposited. The extent to which deposition continued in Permian time is unknown because the overlying formations are missing, probably because the positive (or source) areas had already been reduced to base level.

Then followed a long period of nondeposition and erosion, producing a distinct hiatus between rocks of Permian and Triassic ages. The first Mesozoic record consists of continental deposits of Upper Triassic age derived mainly from a source area to the north. The rocks of the Dockum Group are believed to have been deposited on a flood plain.

During Mesozoic time, the area was subject to epeirogenic warping, and the lower formations of the Triassic and Jurassic systems are absent. Renewed shallow-water transgression over a wide area in northern New Mexico and elsewhere marked the beginning of Late Jurassic time, as indicated by the basal Entrada Sandstone and the overlying interval of variegated silts and shales. Source of the sediments was probably a low area to the north. The period closed, as withdrawal of the shallow waters was followed by some erosion of Upper Jurassic rocks. Renewed downwarping in Cretaceous time allowed widespread regional marine transgression, marked at the base by the Dakota Sandstone. Later, deepening was accomplished and dark marine shales and limestones were deposited in appreciable thicknesses in the Raton basin and adjacent areas. The withdrawal of seas at the end of Cretaceous time heralded the third major orogeny in the region.

Laramide folding and upwarping of the Southern Rocky Mountain province as a broad geanticlinal structure ended Late Cretaceous marine deposition. Orogenic uplift was reflected by the accumulation of coarse clastics at Eagle Nest and adjoining regions in latest Cretaceous and Paleocene time. On the eastern flank of the geanticline, the present Sangre de Cristo Mountains were being formed by a series of closely spaced orogenic eposides culminating in a period of folding and eastward thrusting in late Eocene or early Oligocene time. Along the west margin of this geanticline, analogous thrusting was in a westerly direction in the Nacimiento Mountains.

Ensuing erosion removed the sedimentary cover and partly re-exposed the Precambrian. In the uplifted area, conglomerate and finer-grained clastics accumulated in depressions on this surface of slight relief. In late Oligocene and early Miocene time, a volcanic series was extruded in north-central New Mexico and adjacent areas in Colorado. The earliest volcanic materials in the vicinity of Red River consisted of pyroclastics and breccia interbedded with andesite flows. These volcanic products accumulated on a moderately undulating surface cut on Precambrian terrane and surficial deposits. Succeeding the andesite are dikes, sills, and thick flows of latite. The last phase of volcanism was marked by the production of rhyolite tuffs and flows, and the intrusion of various rhyolite bodies. Granite stocks, smaller quartz porphyry intrusives, and monzonite porphyry, intruding the volcanic series along lines of structural weakness, propylitized the extrusives over a large area. Hydrothermal alteration related to the granitic stocks produced pyrite, quartz, sericite, kaolinite, and carbonate.

Minerals of economic importance introduced at this time include molybdenite in veins and disseminations, and gold, silver and base metals in fissure deposits. Igneous activity had also been taking place in the Moreno Valley and the Cimarron Mountains. Here, the sediments have been preserved; dikes of augite diorite porphyry and sills of quartz porphyry diorite intrude rocks that range in age from Permian to Paleocene. An intrusive body of rhyolite has been localized along a line of structural weakness. At certain horizons, deposits of gold formed in veins, in contrast to iron minerals produced along quartz diorite porphyry contacts.

Widespread erosion reduced the San Juan Mountains, the Sangre de Cristo Mountains, and surrounding areas to a near peneplanation. In the Eagle Nest area, this low relief surface was broken only by residual hills that furnished gravel to nearby meandering streams. In Miocene and early Pliocene time, this surface was abruptly broken by high-angle normal faults, resulting in dislocation of the southern Rocky Mountain geanticline into several elements. The major negative feature is the Rio Grande depression, which was downfaulted along part of the old San Luis highland, while farther east a similar parallel, but smaller feature constitutes the Moreno Valley. Uplift in the intervening area resulted in formation of the Taos horst. The Red River graben developed at this time and is considered a negative and topographic element separating the Taos uplift from the Costilla massif. The gravels of the old San Juan peneplain were stranded on the volcanic rocks on which they were deposited. But the initiation of a new erosion cycle by rejuvenation of streams caused the accumulation of more gravel in the Rio Grande and Moreno valleys in late Pliocene and early Pleistocene time. In the mountains, the residual hills of the San Juan peneplain are preserved as monadnocks above an upland surface.

In early Pleistocene time, integration of drainage in the Moreno Valley and its extensions north and south resulted in a through-flowing river that drained the eastern flank of the Sangre de Cristo Range. An erosion surface cut on the bedrock and fill of the Moreno Valley was controlled by laterally eroding streams graded to the surface of the valley fill. Capture of drainage by headward erosion of the Cimarron River disrupted the Broad Valley surface, and drainage of the southern Moreno Valley was reversed and flowed through Cimarron Canyon. Three later surfaces were cut on the Moreno Valley fill during periods of stabilization of the successively lowered local base level of Moreno and Cieneguilla creeks. Development of these surfaces has been related to the physiographic history of the Great Plains, but successive cold climates were also an influence.

Wisconsin Glaciation of late Pleistocene age greatly modified the surface. This process was active until some 10,000 to 12,000 years ago. Thereafter, the present drainage system was developed and largely controlled by radial dispersion of glacial valleys and Miocene structures in the western part of the area.

Economic Geology

Three mining districts are within the map area. The earliest mining was probably done by local Indians, and later continued by Spaniards. In more recent times, strikes were made at Elizabethtown in 1866 and at Red River in 1867. Since then, activity associated with production of gold, silver, iron and base metals has been intermittent to the present day, except for more continuous development and extraction of molybdenum since 1919.

The first descriptions of mineral deposits in this region were made shortly after 1900 by members of the U.S. Geological Survey, whereas later developments have been published mainly through the reports of the New Mexico State Bureau of Mines and Mineral Resources.

The scope of this discussion is limited, insofar as it leans heavily on previous investigations, already describing the major deposits. These descriptions are not reiterated. Attention is drawn to mineral distribution in relation to the areal geology. Used with the geologic map, the present contribution may further the understanding of the geologic framework in which the deposits are located. In addition to locating numerous small unnamed workings, the major prospects and mines have been plotted and listed on the geologic map. Table 8 summarizes the ore deposits according to age, district, class, and principal elements, whereas map 2 (in pocket) gives their spatial distribution.

TABLE 8. *Summary of Ore Deposits in the Eagle Nest Area*

Age	**District**	**Form of Deposit**	**Ore Elements**	**Activity**
Tertiary-Quaternary	Elizabethtown	Placer	Gold	Idle
Tertiary	Elizabethtown	Fissure	Gold	Idle
Tertiary	Elizabethtown	Contact-pyrometasomatic	Gold, iron	Idle
Tertiary-Quaternary	Red River	Placer	Gold	Idle
Tertiary	Red River	"Disseminated"	Molybdenum	Active
Tertiary	Red River	Fissure	Molybdenum, gold, silver, copper, lead, zinc	Idle
Precambrian	Red River	Shear-fissure, metamorphic	(?) Gold, iron, graphite	Idle
Tertiary	Rio Hondo	Fissure	Gold, copper, lead, zinc	Idle
Precambrian	Rio Hondo	Shear-fissure	Copper	Idle

RIO HONDO DISTRICT

The Rio Hondo (Twining) district, some 15 miles northeast of Taos, can easily be reached by road. The district includes a few small prospects in the west fork of the Red River, about eight miles by road south of Red River. The district was active between 1890 and 1905. In 1942, some of the workings of the Frazer mine were cleaned out, and in 1956, some further work was done by the Taos Uranium and Exploration Company. This company also made an investigation of the Highline (Bull-of-the-Woods) and the Silver Star prospects in the west fork of Red River.

Geology, Mineralization, and Production

Precambrian granite has invaded amphibolite, hornblende gneiss, and biotite schist. A swarm of rhyolite dikes cuts the early Tertiary Rio Hondo granite west of Amizette (pl. 1).

Mineralization appears to be of two ages, represented by two suites of minerals. Production from this district has been relatively small.

Prominent northeast shears are found in the Precambrian mafic gneiss, as at the Commodore prospect. Farther south, the Iron Dike, Silver Star, Comstock, Highline, and Frazer workings are on a series of similar shears that probably extend to the South Fork mine (just west of the map area). The shears are commonly in a green chlorite schist, locally intruded by quartz. Although a high-angle northeasterly fault of Tertiary age may be responsible for part of the shearing at the Highline prospect, the deposits are thought to be Precambrian in age and belong to the quartz-copper association (Schilling, 1960, p. 22). Copper appears to be the main ore element and occurs in the form of chalcopyrite, malachite, and azurite, accompanied in most instances by pyrite. Some gold and silver have also been reported at the Frazer mine (Lindgren, Graton, and Gordon, p. 84). The Black Copper mine is also located along the northeasterly striking fault, although the mineralized shears have an east-southeast trend in Precambrian granite. Mineralization includes auriferous pyrite, galena, chalcopyrite, sphalerite, and chalcocite, a common assemblage in the Tertiary veins elsewhere.

Although the Silver Star prospect lies in the shear zone, the presence of galena containing appreciable quantities of silver, suggests that the mineralization may be Tertiary, especially since the veins have a northwest strike.

The Jackpot prospect is situated in a northwest fault that brings the Rio Hondo hornblende granite against mafic gneiss. A thin quartz vein along the line of the fault contains chalcopyrite, malachite, and specular hematite. Free gold is said to have been treated in arrastres. Other ore minerals reported include galena and sphalerite. Claims showing galena and stibnite were also reported from a small prospect in the upper part of South Fork (Lindgren, Graton, and Gordon, p. 84). These deposits lie along the line of the Tertiary rhyolite dike swarm and may be Tertiary in age.

The extensive outcrop of Tertiary biotite granite in the vicinity of Arroyo Seco and Manzanitas Canyon, as stated, is continuous with outcrops of similar material in lower Arroyo Seco. Small patches of this granite are distributed in South Fork and may be part of a larger body at depth. On the basis of texture and mineral composition it correlates with the granite stocks in Red River (table 5). The only mineralization observed in this area was on the north side of South Fork Peak in a small cirque at an elevation of 11,100 feet. At this locality, rhyolite dikes, quartz veins, and a dike of biotite granite have a general south-easterly strike. Pyrite was the only mineral observed. Recently, Missaghi (1968b, p. 2) has reported anomalous geochemical soil samples in this and adjacent areas, particularly with respect to copper and zinc.

RED RIVER DISTRICT

The town of Red River can easily be approached by paved road from Questa and from Eagle Nest. Within this rather large area, access to most of the individual mines is along unimproved dirt roads that follow canyon floors.

Prospecting probably started in 1869; the Copper King was the first prospect to be worked. A smelter, built in 1879, at the site of the present town, operated for only a short time. In 1894, the town was founded and by 1897, some 2,000 people were living in the area (Reed, 1922, p. 3). Presently, most of the district is idle, though assessment work is kept up on some claims. A great resurgence of activity, however, has occurred at the Questa mine.

As Schilling (1960, p. 13) pointed out, much confusion exists with regard to the names and extent of the districts in the vicinity of Red River. The Red River and Anchor-Midnight subdistricts are commonly included in the much larger Red River district.

General Geology

The general geology, alteration and structural controls that accompanied mineralization have been detailed by Clark (1968). The essential lithologic elements of the district comprise a Precambrian basement overlain by Tertiary volcanics, all of which have been intruded by granitic stocks. Important mineralization, accompanied by alteration, is associated with these intrusives. Still later, but also accompanied by alteration, smaller bodies of quartz porphyry and monzonite porphyry were intruded. Miocene faulting resulted in a jumble of downfaulted blocks distributed in the east-northeast-trending Red River graben (pl. 1, C-C', D-D'). This structure has served as a focus for plutonic activity associated with hydrothermal phenomena.

Although most of the mineral deposits are Tertiary, a few prospects have been located on "shows" of obvious Precambrian age. Prospects located in older rocks are generally on fault blocks underlain by schist and gneiss or in windows along the bottoms of some of the major streams, as for example, at the Golden Goose, Cabresto Lake, and Iron King prospects. The minerals sought were gold(?), graphite, and magnetite, respectively.

Alteration

Alteration is widespread along the controlling structural zone parallel to the lower Red River Valley and Bitter Creek. It consists of two types, as outlined by Schilling (1956a, p. 37), shown on the geologic map (pl. 1). Widespread propylitic alteration is represented by light stipling, whereas the more localized and intense alteration is shown by heavy stipling. The whole alteration area is approximately three miles wide and nine miles long, aligned N70°E. West of Sulfur Gulch, the alteration extends for another four miles to the western margin of the Taos Range. Within the two types referred to, several mineral assemblages are recognizable, including, in order of decreasing hydrogen metasomatism, the sericitic, intermediate argillic, propylitic, and potassium silicate assemblages of Meyer and Hemley (1967).

In the field, green propylite is easily recognized in lavas of intermediate composition. Latites and andesites so altered are distinct from those examined in the unaltered areas, although they are all gradations in between. This type of alteration is characterized by a secondary mineral assemblage consisting principally of chlorite and epidote with lesser amounts of carbonate, quartz, and sericite. Abundance of chlorite and epidote is responsible for the green color. Texture is largely preserved, as pointed out by Ishihara (1964, p. 61).

Biotite is strongly altered to chlorite and magnetite, less commonly to sericite. The platy habit is retained. Hornblende is also strongly chloritized but can be distinguished from biotite by morphological criteria. Plagioclase becomes completely or partly altered to sericite, epidote, clay, and carbonate, in order of decreasing abundance. Potash feldspar generally appears to suffer less alteration, although commonly sericitized.

Propylitic alteration is not confined to lavas of intermediate composition as pointed out by Vanderwilt (p. 624). Precambrian schist, sedimentary rocks, and the Questa Mine stock are also affected. For example, the matrix of the conglomerate beds in the vicinity of the Questa mine, becomes dark gray to green and is accompanied by the production of coarse flakes of secondary white mica. In addition, other investigators have identified chlorite and epidote in the altered sediments. The rhyolite group must also have been affected to some extent, although the original mineral composition does not permit the striking effects seen in the other rocks.

According to Schilling (1956a, p. 39), the intensity of propylitic alteration decreased rapidly away from the Questa Mine stock, although he recognized that some effects could still be found at an appreciable distance from the granite. Ishihara (1964, p. 61), noted widespread propylitic alteration, but its full extent was recorded by Clark (1968, fig. 2) and is shown on pl. 1. Beyond these limits only the automorphic effects are distinguishable in the volcanic units, where chloritization of mafic minerals is weak accompanied by partial sericitization and kaolinization of feldspar in an otherwise fresh appearing rock. A similar interpretation was made by Ratcliff (1962) during a detailed study of one locality.

The second type of hydrothermal alteration effects is displayed by small areas of "badland topography" or alteration scars. Both Schilling (1956a, p. 38) and Ishihara (1964, p. 62) refer to these localities as brecciated areas or hydrothermal pipes, formed in the volcanic series. While no detailed study of these features was under-taken, the writers prefer not to use the term pipe, because of genetic implications, although in many instances the most intense effects have been localized along one or more of the fracture systems, at fracture intersections, or around contacts of intrusives. In all instances brecciation prepared the rock for invasion by hydrothermal fluids. Fig. 22 shows a typical alteration scar developed on a northwest fracture near the Hottentot quartz porphyry. The resulting mineral assemblage includes sericite, kaolinite, quartz, carbonate, pyrite and lesser amounts of molybdenum. Textures of primary minerals become wholly or partly destroyed producing a fine-grained, light-colored residium.

The sericitic assemblage is represented principally by sericite, quartz, and pyrite. Potash feldspars alter to sericite, quartz and clay, whereas plagioclase alters to clay, epidote and carbonate. Rhyolites are sericitized and accompanied by mild to moderate silicification and pyritization. Silicification occurs along veinlets in the Questa mine stock. Substantial argillic alteration of plagioclase by clay, quartz and carbonate suggests the intermediate argillic facies. In addition, Ishihara (1964, p. 29, 39) has recorded plagioclase replacement by potash feldspar, which, with formation of a biotite halo around the Questa mine stock, characterizes the potassium silicate assemblage.

In the Questa mine Carpenter (1968, p. 1,344) describes halo-type alteration out-ward from veins and mineralized shear zones. Silica, sericite, and kaolinite replacements of feldspars occur in aplitic rocks; and biotization of andesitic volcanics is strong. Chlorite is found outward from the biotite and, although developing in part as a halo, grades into pervasive propylitization. Post-mineral carbonate, and silica veinlets occupy fractures which cut across molybdenite-bearing veinlets.

FIGURE 22—Alteration area in Straight Creek. Hydrothermal alteration is intense in localized areas; the resulting material is rapidly eroded into the canyon below. Actual color is red and yellow.

The characteristic colors of the alteration scars stem from light-colored alteration products and the formation of secondary minerals. Pyrite weathers to limonite; and jarosite, malachite, and selenite have also been reported. Secondary molybdenum is mostly in the form of ferrimolybdite. It is also found in jarosite, and in minor amounts on clay and as ilsemanite and powellite. Oxidation occurs from a few tens of feet below drainage channels, to several hundreds of feet on adjacent ridges. Over a period of time much of the hydrothermally altered surface rock is washed into side canyons as mudflow, leaving the bare mountain slopes vulnerable to further oxidation. Carpenter (1968, p. 1346) has described the chemistry of molybdenum oxidation and, although vertical and lateral zonation of these products does occur, most ferrimolybdite is formed at the outcrop. The present writers point out that supergene enrichment has not taken place at depth in this deposit.

Mineralization and Production

Deposits related to Tertiary mineralization are numerous; a multitude of adits were driven into the hillsides in search of gold, but notable exceptions occur where other minerals have been exploited. At the Copper King mine, assays of copper ran between 1 to 2 percent (Holmquist, 1947). Assays as high as 60 percent lead, with 1 percent copper and eight ounces of silver were reported from the Victor No. 2 claim in Tenderfoot Gulch (Lindgren, Graton, and Gordon, p. 87).

Tertiary mineral deposits are believed to be associated with the intrusive phase of igneous activity, and deposits are commonly associated with biotite granites, monzonite porphyry, latite, rhyolite dikes, and quartz veins. These bodies are found in various Precambrian and Tertiary crystalline terranes. For example, at the Beverly, Moberg, and Midway prospects, mineralization occurs where monzonite porphyry dikes cut mafic gneiss. Quartz veins, in an east-west shear, subparallel to the trend of the Red River graben, intrude volcanic andesite between the Caribel and Jay Hawk mines. In Bitter Creek, considerable development took place where a series of strong shears containing quartz veins and monzonite porphyry intruded rhyolite tuff in an east-northeast direction. Elsewhere, mining has been carried out along, or within, the biotite granite bodies at a host of small workings in Mallette and Bitter creeks. The important fissure and disseminated molybdenum deposits developed in the Questa mine stock are described separately.

The coarse conglomerate and other sedimentary rocks at the base of the volcanics series were also thought to contain gold. At the Stella and Anderson prospects, these sediments have been intruded by Tertiary monzonite porphyry and latite dikes. At the Purkapile prospect, the conglomerate is extensively pyritized along a shear containing some quartz stringers.

In addition, some gold has been found in the high-level unconsolidated gravel distributed on the planated surface of the volcanic rocks in post-Miocene time. The deposits are of variable thickness, but are definitely later than the Tertiary igneous and hydrothermal activity. The Hilltop property was developed by a shaft 135 feet deep in search of alluvial gold.

Other gold mining was carried out in Placer Creek by rocking, sluicing, and hydraulic methods. The age of the gravel prospected is either late Tertiary or Quaternary, but its source was in the underlying mineralized terrane.

The use of water for mining and milling operations led to the construction of aqueducts in the Red River district. Part of the old flume serving the first operations at the Questa mine can still be seen near the present mill. In Placer Creek, two ditches were dug. The larger brought water from Goose Creek to an arrastre powered by a water wheel on the east fork of Placer Creek. The length of this ditch is two miles, puny compared to the Big Ditch described later. Another water wheel still stands in Placer Creek at the Nashville prospect. Water power was also used at the Frazer mine in the Twining district.

Areal distribution of mineralization is controlled by the Red River graben, along which the intrusives and their hydrothermal effects are aligned. Tertiary mineralization can be classified as stockwork (disseminated) or fissure-vein, both mesothermal.

The stockwork deposits contain many small fractures in numerous orientations in which molybdenum was deposited throughout the mineralizing epoch. This time interval is represented by a period of injection of mineralizing fluids, perhaps related to repeated dislocation in the district as various intrusives were emplaced. Evidence for these events is found in reopened veins containing small amounts of chalcopyrite, sphalerite, galena, fluorite and carbonate.

Throughout the rest of the district fractures are more regularly oriented. Schilling (1960, p. 23) outlined these ore mineral assemblages. A modified paragenetic version is given below together with predominant fracture directions, and order of decreasing temperature of formation.

Ore Mineral Assemblage	Strike of Vein (major trends boldface)					
Molybdenite			**NNE-NE**	**ENE**	E	ESE
Pyrite-gold		N	NE	ENE	E	ESE
Chalcopyrite				ENE		
Galena-sphalerite-chalcopyrite	**NW**		NE		E	
Galena-sphalerite silver	NW				E	

Schilling also detected a zonal arrangement of the ore minerals in vein types outward from the source. Although we have no positive knowledge of zoning in individual veins, a crude zonal distribution of Tertiary hypogene deposits occurs throughout the whole Taos Range. The highest temperature indicator is molybdenum, largely confined to the aplite granite stocks and their immediate vicinity along the Red River graben. Throughout the structure and as far northeast as the Anchor-Midnight subdistrict the pyrite-gold association is common. The chalcopyrite occurrence at the Copper King mine is also in this temperature range. To the north, lower temperature indicators are the galena-sphalerite assemblages at the Hornet and Jenkins prospects. Southward an intermediate range is indicated by galena-silver-chalcopyrite at the Victor No. 2 prospect, and by chalcopyrite-sphalerite-galena at the Jackpot prospect. Lowest probable temperatures of deposition are indicated by galena-silver at the Silver Star prospect in the Rio Hondo district.

Distribution of these assemblages was controlled by fractures that were open at a given stage. Tabulation of the deposits in this manner is consistent with field evidence that, in general, indicates east-northeast fractures are cut by northerly striking sets. The result of mineralization controlled in time and space is a zonation of mineral assemblages as shown in map 2 (in pocket).

The aplitic texture of the granites and their fractured appearance suggests that they were rapidly intruded to relatively shallow depths within the volcanic pile; Ishihara (1967) believes within a few thousand feet of the old surface. Vertical distribution effects of the minerals have been minimized to such an extent that telescoped assemblages have been reported in reopened veins of the Questa mine stock. This resulted in late sulfides and gangue spatially overlapping with earlier molybdenite, quartz and biotite. In a lateral sense, late sulfides were deposited by cooling fluids only after they had been transported through channelways to appreciable distances from the source. Consequently, small deposits of gold and pyrite are aligned in a northeast-trending zone, cutting the axis of the graben in the vicinity of the Red River stock. In contrast, galena, sphalerite, and silver are contained in a northwest trending zone.

Production of gold, silver, copper, and lead in Taos County prior to 1923 had a value of less than $100,000 (Anderson, 1957, p. 145). The Rio Hondo and Red River districts accounted for most of this ore. Individually, the major producers have been the Caribel, Independence, and Memphis mines; production at the Buffalo, Jay Hawk, Nashville, and other properties is also recorded.

The ore was either treated locally, in particular at the June Bug mill, or shipped as concentrates to smelters in El Paso, Texas, and in Colorado.

Questa Mine

The offices and mill are just east of the mouth of Sulfur Gulch about 6 miles by paved road from Questa. Mining activity is presently being conducted about half a mile up Sulfur Gulch.

When the presence of molybdenum was first detected in 1916 Jimmy Fay sent a sample from this area to be assayed, then located some claims. The Western Molybdenum Company was formed but little was done. In 1918, the R and S (Rapp and Savery) Molybdenum Company was formed and acquired claims from the previous company. Additional claims were located and developed, and production began in 1919. Ore was treated at the converted June Bug mill. In 1920, the Molybdenum Corporation of America acquired the property, but work was discontinued in 1921. A mill was built at the present site in 1923 and further development and production continued until the mid-1950's. Toward the end of that phase of activity, the tailings dumps were remilled to supplement the decreasing production of the mine. Mining finished in 1958, but by that time, search for new ore had been initiated.

Mining of the molybdenum bearing quartz veins had been accomplished by over-hand, horizontal slicing in stull-supported or open stopes. The grade of the ore varied from 1 to 40 percent MoS_2. Molybdenum concentrates were produced by flotation (Carman, 1931, 1932). The mill at that time had a capacity of 50 tons of ore a day. The concentrates, averaging 85 percent MoS_2, were shipped to Washington, Pennsylvania, where they were made into ferromolybdenum or calcium molybdate for use in alloys.

Geology, Mineralization, and Production

The following description of the deposit has been drawn from information in the literature and field observations of our own. The first description was by Larsen and Ross (1920), followed by Vanderwilt (1938) and by Schilling (1956a). Later Schilling (1960, p. 38-42), Carpenter (1960), Ishihara (1964), Silman (1964), and Schilling (1965, p. 28-34) described the deposit further. The latest reports are by Gustafson, Bryant, and Evans (1966), Carpenter (1968) and Rehrig (1969).

The ore occurs in the Questa mine stock, a biotite granite that intrudes the andesite unit of the volcanic series. The older operation was concerned with mining quartz veins along a local south-dipping contact with propylitized andesite on the west side of the granite (Schilling, 195 6a, pl. 2). Most of the veins were on the contact or in the granite within 50 feet of, and roughly parallel to, its margin. The ore zone was more than 1,500 feet long at the surface but decreased in length with depth. The molybdenite usually formed irregular aggregates in the vein. Quartz, pyrite, chalcopyrite, biotite, fluorite, calcite, and rhodochrosite were common associated minerals. Lenticular masses of quartz in the vein usually were covered with molybdenite "paint" and as such appeared to be pure masses of the ore mineral. Molybdenite also coated fractures thinly or occurred as finely crystalline material disseminated through fault gouge. Lenticular ore shoots ranged in size from a few feet to a few hundred feet along strike and dip. Altered wall rock and silicification were widespread.

Total production in the period of underground mining up to 1958 was about 18.5 million pounds of molybdenite.

Open-Pit Mining

As the molybdenum production from vein deposits began to dwindle, exploration for new ore was started. From 1957 to 1960, exploration was conducted with the financial assistance of the Defense Minerals Exploration Administration. A geochemical survey was made, together with underground development and diamond drilling, to explore the deeper extension of the southwest zone of the stock, the upper part of which had supplied the bulk of the mine production. More than 260 million tons of ore, averaging 0.25 percent MoS_2 were found. A second mineralized zone was located, and by 1963, exploration results indicated that a northeast zone could be developed by open-pit methods. By 1964, sufficient ore reserves were outlined to initiate a program involving some $18,000,000 to $20,000,000 to bring the mine back into production on an open-pit basis (Schilling, 1965, p. 31).

Building started on a new flotation mill with a capacity of about 10,000 tons of ore a day. In the meantime, stripping of the cover had begun in the northeast zone, near the upper part of Sulfur Gulch. This locality is the northeast zone of the southwest ore body, but it lies northwest of the vein deposits previously mined. The pit, as planned, has a rough circular shape with an average diameter of about 1,600 feet, and an average depth of 500 feet, with a bottom elevation of 8,400 feet (fig. 23).

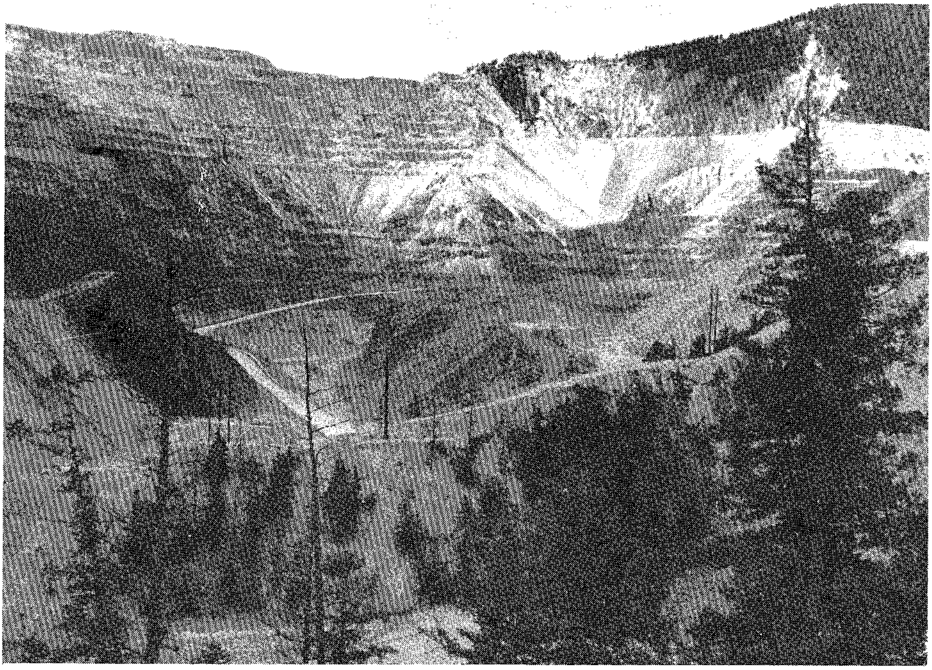


FIGURE 23—Questa open-pit mine, July 1970. View is toward the west. Benches have been developed in andesite and overlying rhyolite to the top of the topographic ridge west of Sulfur Gulch. As a consequence, the alteration area at the head of the gulch has been partly obliterated. The lowest parts of the pit expose aplitic granite that has intruded the volcanic rocks. The mineralized contact zone in aplite and andesite dips southwest.

Open-pit reserves were estimated at 20,509,000 tons of ore, averaging 0.297 percent MoS_2 , assuming a cutoff grade of 0.13 percent MoS_2 . Some 71,000,000 tons of waste material will be removed; lower parts of the ore body, possibly the southwest zone, will be mined later using underground methods. About 23,000,000 tons of ore, averaging 0.35 percent MoS_2, assuming a cutoff grade of 0.21 percent MoS_2 , have been developed for underground mining in the northeast zone *(Metal Mining and Processing,* December 1964). Low-grade material is stockpiled during mining and may be leached later. In late 1965, mining in the open pit was started and the first shipments of concentrates subsequently sent to the smelter in Pennsylvania.

The "disseminated" (stockwork) molybdenum mineralization now being mined overlaps the molybdenite veins; both are part of the same huge deposit. The present ore lies in a network of fissures relatively tight, short, and irregular, yet numerous and fairly closely spaced. This mineralization occurs in the Questa mine stock and to some extent in the nearby volcanics.

The disseminated molybdenum deposits (Clark, 1970) contain only minor amounts of other base metal sulfides. Locally, the form of these deposits is best developed at the Questa mine, although similarities are in the Flag Mountain and Red River stocks.

The shape of the Questa mineralized zone, as seen in section, is a linear feature forming a peripheral shell on the west side of the intrusive. The ore is located in, and along, the granite-andesite contact. In plan, the ore occupies two lobes, established by assay boundaries: the southwest zone and northeast zone. Farther west, the ore zone as a whole has been located 1,500 feet below the surface of a topographic ridge located between Sulfur and Goat Hill gulches.

In detail, the stockwork ore bodies consist of molybdenum distributed in several ways:

a) veinlets in which molybdenite is associated with quartz and lesser amounts of chalcopyrite, sphalerite, and galena

b) fissure-vein deposits controlled by the granite andesite contact. These are best displayed on the west side of the Questa Mine stock where it trends roughly east-west. The veins were first described by Schilling, who attributed their origin to the force of intrusion that sheeted the granite along the contact. Similar sheeting has been noticed in parts of the Flag Mountain stock. These veins supplied the bulk of the ore for the underground mine production

c) fine fractures in which molybdenum occurs as "paint" associated with clay on fracture surfaces. The fractures form a stockwork in the brecciated rock near the contact. The mineralization in (a) and (c) is distributed in a myriad of variously oriented planes (Gustafson, Bryant, and Evans, p. 54), in addition to those parallel to the major fracture systems in the district as a whole

d) disseminated molybdenite occurring as minute flakes and grains within the granite host

e) in or adjacent faults and joints containing minor amounts of oxide minerals. According to Bhappu and Roman (1964, p. 16) some 60 percent of the molybdenum in the oxide minerals is contained in ferrimolybdite. Overall, supergene modification of the molybdenite deposit is restricted to a rather thin zone

Rehrig (1969) notes that the common stockwork structure does not mask systematically oriented fractures. Mineralization was controlled by access along primary, steeply dipping and probably deep-penetrating east-northeast to east fissures. A secondary control, largely responsible for dispersing mineralizing fluids laterally through a large volume of rock, was the pervasive, low-angle, westerly dipping structures. These largely served as the localizing control for mineral deposition and are largely contact conformable. They form an envelope of irregularly layered breakage extending some distance into the intrusive and upward into the country rock.

Composition of the igneous rocks in the Red River district follows a distinct trend that reflects the differentiation history of the source magmas. Ishihara (1964, p. 56-59; 1966) showed that the biotite granites have become the most highly fractionated parts of the original magmas and of these, the Questa mine aplite shows most differentiation and enrichment in potassium. Elsewhere, positive correlation of molybdenum with high potash fractions has been pointed out by other investigators. Since the most valuable molybdenum deposits occur in association with this intrusive, the molybdenum may be assumed to have been concentrated in the residual fluids because of its inability to form in the major rock-forming minerals.

Mining proceeds along benches initiated on the west slope of the upper part of Sulfur Gulch. The bench height is 40 feet, and ore is obtained from the face by blasting from a series of holes drilled from the top of the bench and back of the face. The broken ore is scooped up by shovels having a bucket capacity of ten cubic yards, and is dumped into trucks capable of handling 85 tons of rock at a time. The ore is then hauled to the mill near the mouth of Sulfur Gulch and dumped into the primary crusher.

The primary crusher is a 48-inch Allis-Chalmers gyratory type that feeds into two coarse-ore bins, each having an 8,000-ton capacity. The ore is screened and passed into the secondary and tertiary crushers, which are Symons cones with minus 2-inch and minus ¾-inch discharge. From fine-ore storage bins, having a 5,200-ton capacity, the feed passes into Marcy ball mills, and the discharge is pumped into 20-inch cyclones. The undersize is minus 48-mesh thickness and is fed into the rougher flotation and cleaner flotation units. The tails are piped in ten-inch lines to a sump some 12 miles west, near Questa. After settling, the water is analyzed before release into the lower reaches of Red River. From the cleaner flotation banks, the remaining circuits contain thickening, regrinding, and recleaning units. Regrind is done in Hardinge ceramic-lined tube mills, the recleaner flotation units are Galigher Agitairs. The final product is spray-dried and transported in tote bins by road to Alamosa, then shipped by rail to the smelter in Pennsylvania. Power is generated at the mill by gas turbines.

The activity at the mine is accompanied by further exploration in the surrounding country along the controlling Red River structure. Apparently in the subsurface the Questa mine aplite may connect with the Flag Mountain stock. Exploration for additional ore bodies entails mapping, geochemical sampling of stream sediments and rocks in situ, and drilling. Molybdenum Corporation of America holds, by claim, a wide tract of territory in the western part of the graben extending northeastward to the Midnight-Anchor subdistrict. Over a period of several years the Red River stock and adjacent country have been investigated, using similar methods, by American Metals Climax, Inc.

Recently ore reserves at the Questa main ore body have been revised. Total reserves, proved and probable ore, are 152,183,000 tons at an average grade of 0.173 percent MoS_2. Probable reserves in the Flag Mountain (Log Cabin) ore body are 60,168,000 tons at an average grade of 0.162 percent MoS_2 . These reserves are calculated at a 0.10 percent MoS_2 cutoff (John O. Landreth, personal communication, February, 1971).

ELIZABETHTOWN-BALDY DISTRICT

The Elizabethtown district lies in the extreme west part of Colfax County and was included in the old Maxwell Land Grant. This estate was originally granted in 1841 to Carlos Beaubien and Guadalupe Miranda by the Mexican government, represented by Manuel Armijo, governor of colonial New Mexico. The petition listed the natural resources of the area but indicated that they were useless until they were possessed and worked, suggesting that the occupation of this tract of country by the Ute and Jicarilla Apaches was unsatisfactory to the current regime (Pearson, 1961, p. 3). As finally confirmed by the United States in 1887, following the Treaty of Guadalupe Hidalgo in 1847, the grant contained 1,714,765 acres, of which 1,456,342 acres lay within Colfax County; the remainder were in Las Animas County, Colorado. Beaubien and Miranda made only minor attempts at settlement, but Lucien B. Maxwell, son-in-law of Beaubien, established a ranch at the Rayado River in 1844. In 1869 Maxwell bought Miranda's interest in the grant (Keleher, 1942, p. 41), to become sole owner and the largest individual landowner in the history of the United States. Shortly thereafter, the Maxwell Land Grant and Railway Company was formed, an English and Dutch concern. The company soon ran into financial difficulty, but was reorganized in 1880, and, by royal decree, the Maxwell Land Grant Company was incorporated under the laws of the United Netherlands (Pearson, p. 79).

During the period of Maxwell's ownership, mineralization was discovered on the grant. In the 18 60's, possibly 1866, a Ute Indian brought copper float to Fort Union. The significance of the rock was realized, and the float was traced to near the top of Baldy Mountain at the north end of the Cimarron Range. In 1866, gold was discovered in Willow Creek and by early 1867 a gold rush had started. Gold was discovered in most of the creek bottoms on the west side of Baldy.

Elizabethtown was founded in 1867, and by the following year, several thousand people had settled there, making it the largest town in the state. It served as the county seat of Colfax County from 1870 to 1872. The first newspaper in the county was published in Elizabethtown in 1869, the *Moreno Lantern.* The name of the town honored the daughter of one of the men at the founding.

Following the uncertainties of early mining developments, the population rapidly declined in the middle 1870's; in 1880, less than 400 people were in the town. Today, Elizabethtown is noted as one of New Mexico's ghost towns, although a small community is now situated at Eagle Nest, some 6 miles to the south on U.S. 64, between Cimarron and Taos.

Hematite Creek District

Several smaller mining camps grew up in the Elizabethtown district, an area covering 70 to 80 square miles of country in and around the Moreno Valley. The Elizabethtown district is referred to by several names, some of which do not include the name of the town. It is believed, however, that the name used by Graton (in Lindgren, Graton, and Gordon, p. 92), in describing the mining activities in the area, takes precedence, although "Elizabethtown-Baldy" is more accurate geographically (Bergendahl, 1965, p. 135). The Elizabethtown district has been subdivided further into smaller areas that, unfortunately, have also received the designation "district." The Hematite Creek district is one of these smaller divisions.

Apparently a mining camp grew up in Hematite Creek in a small grassy area about one mile west of present New Mexico 38. The whole district is now part of the LeSage ranch. Hematite Creek is some five miles southeast of Red River and five miles north-west of Elizabethtown. The district, to date, has received little description.

Geology, Mineralization, and Production

The country rocks consist of granitic biotite gneiss, muscovite-hematite granulite, and mica quartzite. These Precambrian rocks have been intruded by north-trending latite and monzonite porphyry dikes (p1. 1).

Most of the prospects were located higher up the creek from the campsite; of these, the Hidden Treasure group was the largest. Farther along the creek and above on the forested hillsides, numerous other claims were developed by shafts, adits, and pits (map 3). Most of the workings were driven on or near latite porphyry dikes, suggesting that some deposits may have resulted from Tertiary mineralization. The district took its name from the hematite grains that spot the Precambrian rocks. Jones (1904, p. 151) mentioned that the most favorable properties were the Black wizard group, Iron Bird, Challenge, Last Chance, and Gold Bell.

According to Pettit (1946, p. 45), cassiterite was reported from a zone in a quartzite in this area. If true, this occurrence may have been due to one of the numerous pegmatites found in the lower part of the creek. Petit also mentioned finding a vein of almost pure schistose mica carrying a high percentage of lepidolite. Although this mineral has not been recognized by the writer, much green mica is associated with a shear along the creek. Developed by an east-west tear in Laramide time, this shear cuts the muscovite-hematite granulite, reducing it to muscovite-hematite schist. No production has been recorded from the district.

West Moreno District

Prospects contained in this district occur along the lower western slope of the Moreno Valley between Idlewild and Hollenback Creek. The history of this ill-defined area is little known, except that it must necessarily be bound to that of Elizabethtown.

Geology, Mineralization, and Production

The area between Comanche Creek and Hollenback Creek is composed of biotite gneiss in a large thrust salient abutting rocks of the Sangre de Cristo Formation. In the vicinity of Idlewild, rocks of Pennsylvanian and Permian ages have been thrust over sediments of Mesozoic age. Later, the rocks were invaded by rhyolite and latite dikes with north and northwest trends.

As the district has not been described, a few remarks regarding individual prospects will be given. Map 4 shows the claims in part of the west Moreno district.

The Gold Leaf prospect is at the end of a poor road, about three and a half miles west of Elizabethtown. Development was by two adits driven in a northwesterly direction and by a shaft. A little drusy quartz was found on the dumps, but other signs of mineralization were sparse.

About one fifth of a mile to the north, several pits and adits on the south bank of Hollenback Creek constitute the Harmon prospect. The workings uncovered small veinlets in granitic gneiss. A chute from these levels connected with an ore bin at creek level. Milling was accomplished by an arrastre housed in a cabin.

About one third of a mile east of the Gold Leaf, and along the road, a shaft and several adits comprise the Prichard prospect. The workings occur along a brecciated zone, two to three feet wide, and contained a little vein quartz.

The Lucia prospect consists of several pits dug on quartz veins that strike northeast and intrude biotite gneiss.

In Comanche Creek, the Denver-Climax prospect was developed by two adits one mile west of the G. Mutz ranch. They are accessible by vehicle from Elizabethtown or by road along Graney Creek. Development was accomplished by drifting on a quartz vein; some gold was reported. A few hundred feet to the west, a rhyolite dike had also been explored. The stream shown in map 4 is referred to today as Little Comanche Creek.

The Pay Ore mine is in the upper part of Graney Creek about five miles northwest of Eagle Nest, at an elevation of 10,000 feet. Four adits, driven at creek level in a northwesterly direction, and a shaft developed the mine. The largest drift, partly flooded, followed a fracture in Pennsylvanian arkose and shale. The dumps indicated several hundred feet of underground workings and contained pyrite, bornite (?), and malachite.

The Klondike mine is one mile west of Idlewild and can be easily reached by road. A mill still stands but is in a poor state of repair. The mill was probably set up to treat gold ore and contained a gravity feed from the ore bin to a ball mill in circuit with flotation cells and tables. The workings were developed by a shaft, and an adit driven due west. The country rock is sandstone of Triassic age. The dumps indicated many hundred feet of workings. Mineralization was scant and, as observed, confined to quartz veinlets containing a little pyrite stained with malachite. Local reports suggest that the "mine" was a promotional affair.

Elizabethtown-Baldy Districts

The mining area of the Elizabethtown district stretches east as far as the eastern slope of Baldy Mountain. The area was subdivided by the Maxwell Land Grant Cornpany (Pettit, 1966) into four "districts" which included Ute Creek, Ponil, Willow Creek, and Moreno (map 5). Only part of the "districts" fall within the map area.

These four areas are geologically similar, therefore, are treated as one, the only subdivisions being the class of deposit. Because all the properties have long been closed, the reader is referred to pages 92405 in Lindgren, Graton, and Gordon, and to pages 28-45 in Pettit (1946).

The Moreno district was the largest subdivision and lies along the east flank of the Moreno Valley in and between Anniseta Gulch on the south and Mud Gulch on the north. Included here are the contact-pyrometasomatic deposits of iron and gold, the fissure deposits containing gold, and the placer gold deposits.

Contact-Pyrometasomatic Deposits

The contact-pyrometasomatic deposits were located in and around Iron Mountain. Several workings occurred at this locality, the principal one being the Iron Mountain prospect (Jones, p.138-151; Lindgren, Graton, and Gordon, p.93-95; and Kelley, 1949, p. 76-78). The principal contact minerals produced in the limy shale were epidote and specularite; the hornfels retains the characteristic color of lime silicate. Graton (in Lindgren, Graton, and Gordon, p. 95) also recognized diopside, hornblende, garnet and scapolite.

Ore mineralization consisted of magnetite as well as hematite, accompanied by a little pyrite and gold. This formed in layers parallel to the bedding of the limy shale in contact with quartz diorite porphyry sills. The ore was oxidized, so that some of it became rather soft. According to Pettit (p. 42), the soft ore averaged $27 a ton in gold and occasionally assayed as high as $140. The hard ore yielded only $5 a ton. Other reports suggest a value for the ore from $2 to $4 a ton. The grade has been estimated at 50 to 55 percent iron (Kelley, 1949, p.78), although some assayed as high as 70 percent iron (Lindgren, Graton and Gordon, p.102). The ore was hauled to the Red Bandanna mill, and, apparently some 500 tons were produced. The deposits were last worked in 1942 by M. Lowrey. The prospect had originally been opened by his father, Joseph H. Lowrey, and Matthew Lynch. Later, it passed to the Maxwell Land Grant Company and was leased. More recently, the Maxwell Land Grant Company sold much of its property. A large part on the east side of Baldy Mountain went to the Philmont Scout Ranch. The Iron Mountain prospect and the land surrounding it to the crest of the Cimarron Mountains is currently held by the Mutz ranch, although the Maxwell Land Grant apparently retained the mineral rights until 1970 when they reverted to the holders of the surface rights.

Fissure Deposits

The second type of primary gold deposit in the Elizabethtown area occurs in the form of quartz-pyrite-gold veins filling fissures in sills of igneous rock and in shale. These deposits are widespread and occur in all four subdistricts on the slopes of Baldy Mountain. The veins unquestionably have some relationship to the (quartz diorite) porphyry sills (Lindgren, Graton, and Gordon, p. 96), and they occur in both the porphyry and the sedimentary host rocks.

The veins are composed essentially of quartz with some calcite in one or two places. Pyrite is by far the most important sulfide mineral. Chalcopyrite and galena are sporadically present in small amounts, and in the shale, pyrite is locally intergrown with a little pyrrhotite. In the Denver mine, magnetite accompanied pyrite. Molybdenite was reported in the Deep Tunnel mine, and small shows are in pits on the Paymaster claims near the summit of Baldy.

According to earlier reports, the gold was originally contained wholly in pyrite and has been liberated in its present free state by oxidation that extends several hundred feet in properties that have been developed. Since the veins are related to the porphyry, they probably represent ore-bearing solutions believed to be the final product of magmatic differentiation of the source magma, whose most abundant and characteristic products were quartz diorite porphyry and rhyolite porphyry.

Alteration of the fissure walls was mainly by quartz and pyrite, particularly noticeable in the porphyry. Veins are narrow, ranging from tiny threads to quartz sheets a few inches wide. Most are not traceable for any great distance, but on the east side of Baldy, they have been followed for more than half a mile.

Since Baldy Mountain is only partly covered in this report, and also because the geologic map was constructed on a scale insufficient to provide enough detail, observations regarding favorable vein trends are tentative.

However, two main fracture systems that run north-south and east-southeast, as displayed by the augite diorite dikes on the north side of Baldy, are readily apparent. Elsewhere, these fracture trends are probably occupied by veins .to a considerable extent, although the distribution of deposits along the contacts of subhorizontal sills or at the contact of dipping sedimentary horizons may be at variance with these directions. In addition, late movements along mineralized faults and along postmineral faults have offset ore bodies and complicated the finding of ore (Pettit, p. 29). Further-more, ore bodies are irregular in size and distribution of values.

The Denver mine is in upper Anniseta Gulch some two miles east-southeast of Elizabethtown. Apparently a little stoping was done on a narrow vein near the contact of a porphyry sill that intruded shale.

The Moreno Centennial shaft is in Grouse Gulch. A 200-foot shaft gives access to a porphyry contact with shale along which a 12-inch streak constitutes the vein. Other claims in the Red Bandanna group included the Red Bandanna, Empire, Galena, and American Flag. Another shaft 130 feet deep was sunk on the Red Bandanna claim, and adits were developed on all the other claims. The nearly vertical lode in the Red Bandanna is a zone in which the porphyry has been fractured and sheeted. Some galena was found in veins on the Galena and American Flag claims. In all, several thousand dollars worth of ore were produced (Pettit, p. 40-41). The Red Bandanna mill still stands and can be reached by driving up Grouse Gulch. The cyaniding plant had a daily capacity of 25 to 50 tons.

The Sheridan mine is in Humbug Gulch on the Sheridan, Justice, and Sixty-Eight claims. It was developed by a shaft and several adits.

The Tomboy prospect, at the head of Little Negro Gulch, carried ore in pockets. The Chester claim is 1,200 feet north of the west portal of the Deep Tunnel. Pettit (p. 41) said the ore occurred at the Pierre-Raton contact, but because dark shale occurs above this contact higher up the mountainside, the quartzitic sand may be in the upper part of the Pierre, as previously described.

An abortive attempt was made to reopen the west end of the Deep Tunnel at the head of Big Negro Gulch in the summer of 1965. Apparently, the interest was in molybdenum reported by Pettit (p. 43). Much earlier, this tunnel had been driven completely through Baldy Mountain to Copper Park, a distance just less than two miles. Near the east end of Deep Tunnel was the famous Aztec mine (Lee, 1916), the largest lode producer in the whole Elizabethtown-Baldy district. Missaghi (1968a, p1. 1) shows anomalous base metal, molybdenum, and arsenic values recovered from sediment samples taken in streams draining the east flank of Baldy.

The Legal Tender property lies on the east side of willow Creek and explored a vein that strikes about N10°E and dips approximately 60ºW. In the upper workings, the vein is five to six feet wide but pinches to one and one half feet with depth. Silver and lead minerals were noted in the vein material. A total production of $25,000 has been reported.

The Ajax claim lies across Willow Creek just south of the Legal Tender. The best ore occurred in a zone with a north-south direction and steep dip to the west. The mineralization lies between porphyry and much altered shale; the rock is a contact-metamorphosed shale. The minerals present included pyroxene, hornblende, scapolite, epidote, calcite, specularite, quartz, oligoclase, and pyrite.

The Hidden Treasure, on the west slope of Willow Creek above the Legal Tender, opened a narrow vein in porphyry, a little of which was treated in an arrastre.

The Gold Dollar and Only Choice claims, just west of the Legal Tender, exposed quartz veinlets in baked and much epidotized shales.

The Mystic claim lies just below the summit of Baldy Mountain and can be reached by a jeep trail from the Moreno Valley, coming up Mexican Gulch and around the east side of Iron Mountain. The Mystic was the only mine in the Baldy Mountain area that was worked solely for copper. Just above the adits is a distinctive buff layer of quartzitic sandstone that dips to the east but underlies dark, metamorphosed shale exposed at the summit of Baldy. The copper occurred as oxides, in veins with iron oxide, and along fractures in the shale. Cuprite, malachite, chrysocolla, and molybdenite have been observed. A total of 1,000 tons of ore ranging from 20 to 25 percent copper was shipped to Pueblo, Colorado. According to Pettit (p. 39), values of samples gathered from the Mystic dumps ranged as follows: gold, 0.04 to 0.18 ounce; silver, 0.09 to 0.14 ounce; and copper, 20.54 to 25.67 percent.

Just south of the Mystic on the Monarch No. 2 claim, an open cut exposed a two-foot vein of iron ore.

Placer Deposits

Placer mining recovered the gold of secondary origin. This gold was derived from the primary deposits by erosion, transportation, and concentration processes. Placer mining was conducted along Moreno Creek by dredging and in the tributary gulches by hydraulicking, sluicing, and underground methods. In the Moreno district, the most important side gulches were Grouse and Humbug. However, all the creeks between Willow Creek and Big Negro Gulch were profitably worked, although farther north the creeks contained considerably less gold.

Placer work in the Elizabethtown district was suspended not for lack of gold, but lack of water! The poor runoff on the western slope of Baldy Mountain has already been mentioned. The Big Ditch was built for this reason. This transmountain aqueduct, 41 miles long, took water from the west fork of Red River across Red River Pass northward to Costilla Pass and southward down the east side of the Moreno Valley to Mills Divide, ending at Humbug Gulch. The Big Ditch began at an elevation of 10,100 feet, gradually losing elevation to 9,600 feet at its terminus. In effect, this ditch followed the contours, which accounts for its tremendous length. In a straight line from the beginning to the point of delivery, the distance is only 10 miles. Over much of its length, the aqueduct was dug by hand by Mexican labor. The ditch traversed the divides of Red River Pass and Costilla Pass by a 40-inch pipe raised on trestles. In other parts, where the mountainsides became unusually rocky, the ditch was channeled into wooden flumes, also supported by trestles (Clark, 1966a, fig. 23B). Timber for this purpose was cut in Sawmill Park. Work began in May 1868 and was completed in six months; the first water was delivered in July 1869. The total cost of construction was $230,000 (Jones, p. 145).

At its head, it carried 1,000 miner's inches (approximately 1,500 cubic feet a minute), but the loss by seepage and evaporation amounted to 60 to 80 percent, resulting in the delivery of 200 to 300 inches at the placer workings (Preston, 1899). Difficulty was incurred through this loss and the constant expense of repairs and maintenance. Although the ditch has not conveyed water for many years, it can easily be traced in the field and has been plotted on plate 1. It stands today, over 100 years later, as a monument to the energy and ingenuity of those early prospectors in the Elizabethtown district.

Water from the Big Ditch was fed into the workings in Humbug and Grouse gulches where sluicing and. hydraulicking was extensive. The Lynch placers in Humbug Gulch were among the most active workings. The supply was supplemented by other ditches bringing water from less distant sources. The water was fed into reservoirs on the hillsides, from which it was later withdrawn.

Work on the Blue Bandanna and Reservation claims showed that the auriferous gravel reached a depth of at least 440 feet. This figure was determined by sinking a shaft and then drifting 700(?) feet to the east where bedrock was finally encountered. However, bedrock must shelve abruptly to the south, because quartz porphyry diorite is found in a series of hills immediately south of Grouse Gulch (pl. 1). At such depths, the gravel is well below present stream deposits and must be part of the earlier gravel of the Moreno Valley fill. Present-day drainage at the surface has been locally deranged by the placer work.

Spanish Bar, just below the mouth of Grouse Gulch and on the opposite side of Moreno Creek, was also a rich piece of ground, which probably derived its gold by transport from the flanks of Baldy.

The bulk of placer production from these activities was attained by 1881. Some placer work was conducted as late as 1930 by W. M. Lowrey, and a hydraulic operation in Big Negro Gulch was recorded in the mid-1940's by Pettit (p. 44). Water for these operations was obtained locally; in part,. from the gulch itself. According to Murphy (1964, p. 54), small, successful operations-were carried out in 1941 by using a dragline to remove the gravel. The cream of the placer ground has been taken, but some localized areas might still be profitably worked (personal communication, W. M. Lowrey, 1966).

By 1905, the Big Ditch had fallen into a state of disrepair. In 1901, dredging operations had begun in Moreno Creek by the "Eleanor." Materials for this dredge were brought from Denver by rail to Springer and thence by mule to Elizabethtown where the dredge was constructed at a cost of $100,000. Moreno Creek was dammed; the dredge was floated off its stocks and proceeded to dig its own pond (personal communication, Adolf Mutz, 1965). It had a bucket capacity of five cubic feet, working at the rate of about 19 per minute, 24 hours a day. The average daily amount handled was a little over 3,000 cubic yards. The operation was conducted by El Oro Dredging Company of Chicago and continued for four years, until 1905. The ground dredged was below Grouse Gulch between Iron Mountain and Scully Mountain (map 5). About a mile of the creek bottom had been dredged, but above the mouth of Grouse Gulch, the gravel became too poor to be worked, and the operation was discontinued. The dredge was mortgaged to raise funds for a new one at Breckenridge, Colorado, but foreclosure of the mortgage forced its disposal at a sheriff's sale. In later years, it gradually lay lower in the water and finally disappeared from view.

The value of the ground worked varied. The dredging ground was said to yield from 30 cents to $3 a cubic yard. Elsewhere, the sluicing and hydraulic operations encoun-tered gravel varying in value from ten cents to $2 a cubic yard. The area around Humbug and Grouse gulches had been worked from grass roots to a depth of five to eight feet, the so-called "bedrock," a fine red clay (Preston, p. 1). Many of the fissure deposits were said to have averaged $10 to $20 a ton.

Both the placer ground and the vein deposits had spotty values, as indicated in private reports to the Maxwell Land Grant Company. Average values in the placer ground, based on the results of later test drilling, showed that some of the placers were worthless and others marginal, although a few could be expected to be worked with profit, based on current mining costs.

The total value of metal production in Colfax County to 1948 was about $10,000,000 (Pettit, p. 44), most of which came from the Elizabethtown district. Production prior to 1904 was estimated at $4,400,000, of which placer work ac-counted for $2,250,000 (Jones, p. 145). The average fineness was 885. Up to 1948, lode and placer operations contributed about equal proportions.

Today, the district is completely idle. Mining activity continues on the other side of the mountains in Red River. For the time being, the Elizabethtown district has to rest on memories of the past.

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Appendix—*descriptions of measured sections*

MISSISSIPPIAN

No. 1, Bear Lake, sec. 35, T. 27 N., R. 14 E.

Unit	Lithology	Thick. (ft)
	Magdalena Group above sedimentary contact	
	Espiritu Santo Formation	
4	Limestone, medium gray, medium bedded, sandy, becoming shaly at top	10
3	Limestone, dark gray, thin bedded	9
2	Shale, dark gray	12
1	Sandstone, brown, medium bedded, medium grain size, cemented	10
	Total	41
	Precambrian mafic gneiss below thrust contact	

No. 2; Old Mike, sec. 25, T. 27 N., R. 14 E.

	Magdalena Group above sedimentary contact	
	Espiritu Santo Formation	
4	Shale, dark gray	5
3	Limestone, light gray, medium to thick bedded	11
2	Limestone, medium gray, thin bedded	11
1	Sandstone, brown pebbly, hard	1
	Total	28
	Precambrian granite gneiss below sedimentary contact	

No. 3, Wheeler Peak, sec. 24, T. 27 N., R. 14 E.

Unit	Lithology	Thick. (ft)
	Magdalena Group above sedimentary contact	
	Tererro Formation	
7	Limestone, medium to light gray, medium bedded, aphanitic, brecciated at top	5
6	Limestone, pale green, thin bedded, sandy at top with calcareous shale, slightly irregular surface at top	1½
5	Limestone, light gray, breccia, cherty, erosional contact above and below, distinct rounded ledge	9
	Espiritu Santo Formation	
4	Limestone, light gray, medium bedded, cryptocrystalline	10
3	Limestone, medium gray, thin bedded, sandy and oolitic in part	17
2	Sandstone, brown, well cemented, pebbly	4½
1	Regolith, weathered surface to underlying rock, cracks filled with sand	½
	Total	47½
	Precambrian mafic gneiss below sedimentary contact	

No. 4, Horseshoe Lake, sec. 14, T. 27 N., R. 14 E.

	Magdalena Group above sedimentary contact	
	Tererro Formation	
6	Limestone, pale green, medium bedded, fine grained, some fragments of red jasper	5
5	Limestone, greenish, thin bedded, irregular surface at base	9
4	Limestone, light gray, cherty, irregular surface at top, karst surface at base, distinct rounded ledge	19
	Espiritu Santo Formation	
3	Limestone, light gray, thick bedded	11
2	Limestone, dark gray, thin bedded	12
1.	Sandstone, brown, pebbly	2
	Total	58
	Precambrian mafic gneiss below sedimentary contact	

No. 5, Lost Lake, sec. 13, T. 27 N., R. 14 E.

	Magdalena Group above deformational (?) contact	
	Tererro (?) Formation	
8	Shale, buff colored	5
7	Sandstone, conglomeratic, medium bedded	2
6	Shale, maroon and buff	3
5	Sandstone, conglomeratic, cherty, thin bedded	3
4	Shale, green and maroon	3
	Espiritu Santo Formation	
3	Limestone, gray, medium bedded	6
2	Limestone, brown, thin bedded, fine grained	4
1	Sandstone, brown, pebbly, hard	6
	Total	32
	Precambrian mafic gneiss below sedimentary (?) contact	

PENNSYLVANIAN

No. 1, Larkspur Point, sec. 1, T. 26 N., R. 14 E.

	Magdalena Group (?) *beneath erosion surface*	
32	Arkose, gray, pebbly, thin to medium bedded	2
31	Conglomerate, arkosic matrix, medium to coarse	16

Unit	Lithology	Thick. (ft)
30	Shale, greenish gray, fissile	3
29	Arkose, gray white, coarse grained	7
28	Limestone, dark gray, argillaceous, with red shale at top	12
27	Limestone conglomerate, gray, nodular	11
26	Siltstone, greenish gray, thin bedded	10
25	Limestone conglomerate, gray, pebbly, thin bedded	4
24	Siltstone, red, thin bedded	2
23	Conglomerate, gray to red, coarse	2
22	Siltstone, red, thin bedded	18
21	Limestone, reddish, thin bedded, fine grained, becoming arkosic at top	4
20	Arkose, medium bedded, coarse grained, pebbly	5
19	Conglomerate, reddish gray, coarse	12
18	Siltstone, reddish, thin bedded	19
17	Arkose, gray, pebbly, medium bedded	9
16	Siltstone, reddish, thin bedded	11
15	Arkose, reddish brown, medium bedded	3
14	Siltstone, reddish, has conglomerate horizons	11
13	Arkose, gray, coarse grained, medium bedded	2
12	Conglomerate, reddish, coarse, red siltstone at top	16
11	Siltstone, red, conglomeratic, variable bedding	21
10	Limestone, medium to dark gray, thin bedded	2
9	Conglomerate, reddish brown, coarse	13
8	Limestone, dark gray, thin bedded, fine grained	4
7	Conglomerate, reddish, coarse fragments	35
6	Siltstone, green or red, thin bedded	11
5	Limestone, light gray, thin to medium bedded	7
4	Siltstone, red, micaceous, thin bedded	4
3	Limestone, gray, medium bedded	2
2	Siltstone, greenish gray, thin bedded	4
1	Conglomerate, reddish, coarse, contains angular fragments of chlorite schist, sandy and silty horizons are present, variable bedding	61
	Total	343

Precambrian chlorite schist below concealed con-tact

No. 2, Red Dome, sec. 25, T. 27 N., R. 14 E.

Precambrian magic gneiss above thrust contact

Magdalena Group

Unit	Lithology	Thick. (ft)
51	Limestone, medium gray, thin bedded, sandy	8
50	Covered interval	26
49	Limestone, medium gray, thin bedded	9
48	Covered interval	165
47	Limestone, medium to dark gray, thin bedded, and nodular	8
46	Sandstone, brown weathering, thin bedded, medium to fine grained	42
45	Covered interval	110
44	Limestone, dark gray, thin bedded, fine grained	6
43	Sandstone, gray brown, medium bedded, medium to fine grained	37
42	Limestone, medium to dark gray, thin bedded, fine grained	17
41	Covered interval	15
40	Sandstone, light gray, thin bedded, medium grained	5
39	Shale, gray, fissile	8
38	Sandstone, light gray, thin bedded, medium grained, pebbly	9
37	Shale, medium gray, fissile	15
36	Sandstone, medium to light gray, thin bedded, medium grained, conglomerate	8
35	Shale, medium gray, sandy	16
34	Sandstone, gray brown, thin bedded, medium grained	11
33	Shale, medium gray, thin sandy horizons	21
32	Sandstone, gray brown, thin to medium bedded, medium grained, pebbly	8
31	Shale, medium to dark gray, sandy layers	41
30	Sandstone, gray, conglomeratic, bedding variable	16
29	Covered interval	27
28	Shale, reddish, micaceous, silty	31
27	Limestone, dark gray, medium to thin bedded, fine grained	10
26	Covered interval	16
25	Sandstone, light gray weathering, thick bedded	4
24	Covered interval	10
23	Siltstone, gray and purple, thin bedded	11
22	Limestone, dark gray, thin bedded, nodular	15
21	Sandstone, medium gray, thin to medium bedded	4
20	Limestone, medium gray, medium bedded, fine grained	5

Unit	Lithology	Thick. (ft)
19	Siltstone, dark gray, thin bedded, with sandy and calcareous horizons at top	23
18	Sandstone, medium gray, light weathering, thin bedded, fine grained	19
17	Limestone, light gray, medium grained, sandy, fossiliferous	40
16	Siltstone, purple, micaceous	14
15	Sandstone, gray, poorly sorted, conglomeratic at base	34
14	Shale, brown and gray	10
13	Limestone, medium gray, nodular, shaley partings, thin bedded, corals	5
12	Covered interval	58
11	Sandstone, light weathering color, thick bedded, medium to fine grained	38
10	Covered interval	28
9	Sandstone, gray, conglomeratic	29
8	Covered interval	29
7	Sandstone, gray, conglomeratic	4
6	Limestone, gray, medium gray, clastic	21
5	Shale, dark gray, some sandy calcareous horizons, fossiliferous, corals	45
4	Sandstone, weathering medium gray, medium bedded, calcareous	17
3	Limestone, medium gray, medium bedded, sandy	12
2	Shale, dark gray, thin bedded, fossiliferous	10
1	Sandstone, light weathering color, medium bedded, medium grained, feldspathic	13
	Total	1,183

Precambrian mica quartzite below concealed con-tact

No. 3, Old Mike, sec. 25, T. 27 N., R. 14 E.

Magdalena Group *below erosion surface*

Unit	Lithology	Thick. (ft)
12	Sandstone, medium gray, pebbly, medium to thin bedded	5
11	Limestone, medium to light gray, thin bedded, upper part contains breccia	39
10	Shale, dark gray, calcareous, fine grained	28
9	Sandstone, weathering gray brown, medium bedded, coarse grained, feldspathic	20
8	Covered interval	15
7	Sandstone, gray, thin bedded, medium grained	3
6	Shale, medium to dark gray	5
5	Sandstone, thin bedded, medium gray brown	2
4	Shale, medium gray	8
3	Sandstone, medium to light gray, medium to fine grained	4
2	Shale, medium gray	4
1	Sandstone, brown, medium bedded, occasional pebbles	16
	Total	149

Espiritu Santo Formation below sedimentary con-tact

No. 4, Taos Cone Trail, base of section, one mile SSE of Sawmill Park

Upper part of Magdalena Group above sedimentary contact

Unit	Lithology	Thick. (ft)
30	Limestone, dark gray, medium bedded, arkosic	16
29	Siltstone, brown, thin bedded, micaceous, sandy at base	80
28	Limestone, dark gray, medium bedded, cryptocrystalline, veined with calcite	17
27	Shale, brown, some sandstone layers, poorly exposed	60
26	Limestone, medium to light gray, medium bedded, fine grained, sandy fossiliferous	18
25	Shale, dark gray	54
24	Limestone, dark gray, thin bedded, cryptocrystalline	9
23	Shale, dark gray, calcareous, some thin limestone included, poorly exposed	137
22	Limestone, dark gray, thin to medium bedded, veined with calcite	5
21	Arkose, light gray, thin to medium bedded, medium grained	4
20	Shale, dark gray, calcareous	125
19	Limestone, weathering brown, thin bedded, medium grained, fossiliferous	5
18	Shale, greenish gray, fossiliferous	77
17	Limestone, dark gray, medium thick bedded, medium grained, fossiliferous	45
16	Arkose, light colored, medium bedded, coarse grained, calcareous	9
15	Siltstone, green gray or purple, thin bedded	135
14	Limestone, light gray, thin bedded, medium to coarse grained, pebbly	8
13	Shale, greenish gray, micaceous	51
12	Limestone, medium to dark gray, thin bedded, medium grained, oolitic	94
11	Limestone, medium gray, thick bedded, arkosic	24
10	Shale, greenish gray, micaceous	94
9	Limestone, medium gray, medium to thick bedded, arkosic	31

Unit	Lithology	Thick. (ft)
8	Shale, medium to dark gray, micaceous, intruded by rhyolite dike	19
7	Limestone, medium gray, medium bedded, medium grained, fossiliferous	8
6	Shale, medium to dark gray, micaceous, fossiliferous	22
5	Limestone, light gray at base, very thick bedded, becoming darker, medium to coarse crystalline above, fossiliferous, oolitic in part	105
4	Shale, greenish gray, medium to thin bedded, fossiliferous	158
3	Arkose, gray brown, medium bedded, medium to coarse grained	9
2	Siltstone, greenish gray, thin bedded, micaceous, fossiliferous	41
1	Arkose, gray brown, medium bedded, medium grained	29
	Total	1,489

Magdalena Group below fault contact

No. 5, Sawmill Park Trail, base of section, half a mile ESE of Sawmill Park

Uppermost part of Magdalena Group above sedimentary contact

Magdalena Group

Unit	Lithology	Thick. (ft)
44	Limestone, medium to dark gray, medium to thick bedded, fine grained, arkosic, Locality *574 Fusulina, Fusulinella-Fusulina*	55
43	Shale, gray, limonitic, micaceous, nodular at top	81
42	Limestone, weathering light gray, thin bedded, medium to fine grained, arkosic	3
41	Arkose, gray, thick bedded, medium to coarse grained	115
40	Limestone, medium gray, thin to medium bedded, medium grained	4
39	Arkose, gray, thick bedded, medium to coarse grained	97
38	Limestone, medium to light gray, medium to thin bedded, medium grained	10
37	Covered interval	214
36	Siltstone, red, thin bedded, micaceous	100
35	Limestone, medium gray, medium to thin bedded	18
34	Siltstone, red, thin bedded, micaceous	125
33	Limestone, dark gray, thin bedded, fine grained	19
32	Siltstone, red, thin bedded, micaceous	142
31	Covered interval	88
30	Limestone, medium to dark gray, medium to thin bedded, oolitic	21
29	Shale, dark gray, calcareous, fossiliferous	133
28	Limestone, medium to light gray, thin bedded, very fine grained	9
27	Covered interval	64
26	Arkose, medium to light buff, thick bedded, medium grained, micaceous	2
25	Covered interval	203
24	Limestone, medium to dark gray, thin bedded, fine grained shaly partings, fossiliferous, fusulinids	21
23	Covered interval	34
22	Arkose, buff weathering, medium bedded, rhyolite dike at top	12
21	Covered interval	136
20	Limestone, dark gray, medium bedded, shaly	24
19	Siltstone, red, thin bedded, intruded by rhyolite in middle part of interval	35
18	Arkose, light buff, thick bedded, medium to coarse grained, micaceous	40
17	Covered interval	45
16	Limestone, light gray, gray-white weathering, thin bedded, fine grained	5
15	Covered interval	21
14	Arkose, buff, medium to thick bedded, medium to coarse grained	40
13	Shale, dark, fine-grained limestone stringers near base	150
12	Sandstone, gray, medium bedded	17
11	Covered interval	62
10	Arkose, buff, medium bedded, medium to coarse grained	19
9	Covered interval	42
8	Limestone, light gray, thin bedded, conglomerate	19
7	Covered interval	37
6	Shale, limonitized, fossiliferous, poorly exposed	200
5	Arkose, light buff, thick bedded, medium grained	77
4	Shale, dark, fossiliferous, poorly exposed	25
3	Covered interval	152
2	Shale, medium gray, poorly exposed	150
1	Limestone, medium gray, thin bedded, fossiliferous	29
	Total	2,920

Magdalena Group below sedimentary contact

No. 6, Lower East Fork Red River, sec. 7, T. 27 N., R. 15 E.

Upper part of Magdalena Group above sedimentary contact

Magdalena Group

Unit	Lithology	Thick. (ft)
42	Limestone, medium gray, thin bedded, oolitic in part, fossiliferous	16
41	Shale, dark gray, platy weathering	53

Unit	Lithology	Thick. (ft)
40	Limestone, medium gray, thin bedded, nodular	2
39	Arkose, brown buff, medium bedded, medium grained, ripple marked	10
38	Shale, black, light weathering, calcareous, with thin limestones	26
37	Limestone, medium to dark gray, medium bedded, fine grained	5
36	Shale, brown weathering	17
35	Arkose, buff, thick bedded, medium grained, shale partings at base	54
34	Shale, dark gray '	24
33	Limestone, medium gray, thin bedded, medium grained clastic, shaly at top	15
32	Shale, brown, thin bedded, silty	53
31	Arkose, light colored, medium bedded, medium to coarse grained	34
30	Limestone, dark gray, thin bedded, shaly	6
29	Arkose, buff, thin bedded, fine to medium grained arkose, shaly partings	15
28	Limestone, dark gray, thin bedded, fine grained, calcareous shale partings	6
27	Arkose, light weathering, medium bedded, ledge, conglomeratic	19
26	Shale, greenish, with sandy limestone at top	10
25	Sandstone, light weathering, medium bedded	3
24	Shale, brown and gray, micaceous	50
23	Limestone, light colored, thick bedded, sandy	11
22	Limestone, medium gray, thin bedded at base, thick bedded at top, fossiliferous	43
21	Arkose, brown, medium bedded, medium to coarse grained, some mica	48
20	Limestone, medium gray, medium bedded, fine grained	22
19	Shale, gray and purple, micaceous	5
18	Arkose, light brown, thick bedded, ledge former, medium grained, contains pyrite cubes	50
17	Shale, dark gray, some thin dark limestones becoming nodular	20
16	Arkose, greenish, thick bedded, medium to coarse grained	11
15	Shale, dark gray, calcareous, interbedded with thin limestone	34
14	Limestone, dark gray, thin bedded, with shale partings	7
13	Shale, dark colored, micaceous, fossiliferous	73
12	Limestone, medium gray, thin bedded, shaly	10
11	Shale, dark colored, micaceous, fossiliferous	9
10	Limestone, medium gray, medium bedded, fine grained, fossiliferous	24
9	Conglomerate, light colored, arkosic matrix	15
8	Arkose, greenish, thin bedded, medium grained	8
7	Limestone, dark colored, medium bedded	5
6	Shale, dark colored, fossiliferous	10
5	Limestone, dark gray, thin bedded, fine grained, becoming thick bedded and sandy at the top. Locality 580, *Fusulina*	12
4	Shale, dark gray, micaceous, fossiliferous	48
3	Arkose, greenish, thick bedded, medium grained, pebbly	39
2	Covered interval	615
1	Limestone, medium gray, thick bedded, medium grained, sandy, crinoid columnals	30
	Total	1,567

Magdalena Group below contact concealed by alluvium

No. 7, Upper East Fork Red River, sec. 19, T. 27 N., R. 15 E.

Magdalena Group *below erosion surface*

Unit	Lithology	Thick. (ft)
22	Siltstone, red, green, or gray, thin bedded, some pyritic	225
21	Limestone, purplish gray, thin bedded, nodular	8
20	Siltstone, brown, thin bedded	18
19	Limestone, dark gray, thin bedded, fine grained	2
18	Siltstone, greeny gray, platy, micaceous	117
	(FAULT)	
17	Limestone, brown, medium bedded, fossiliferous	14
16	Arkose, light weathering, veined and brecciated, medium grained	16
15	Siltstone, light brown, thin bedded, micaceous	42
14	Arkose, buff, medium bedded, medium grained, pebbly at base, small angular unconformity, siltstone below	14
13	Siltstone, gray and red, becoming greenish gray at top, some horizons of fine grained arkosic sandstone, micaceous, unconformity 76 feet above underlying arkose	383
12	Arkose, buff, medium grained	4
11	Shale, dark gray, nodular, calcareous	7
10	Siltstone, greenish gray, thin bedded, fine grained, micaceous	10
9	Limestone, medium to dark gray, thin bedded, fine grained	2

Unit	Lithology	Thick. (ft)
8	Siltstone, medium gray, calcareous, micaceous	27
7	Arkose, thin bedded and silty at top	26
6	Limestone, medium gray, medium bedded, oolitic	13
5	Siltstone, dark gray, thin bedded, micaceous	27
4	Arkose, buff, thin bedded at top, medium to coarse grained, pebbly	16
3	Siltstone, greenish gray and red, medium bedded, ledges, micaceous, minor unconformity 24 feet from base of interval	152
2	Covered interval	33
1	Limestone, gray, medium to thin bedded, oolitic (base of section below rocky spur just above timber line)	5
	Total	1,161

Magdalena Group below sedimentary contact

PENNSYLVANIAN AND PERMIAN

No. 8, Comanche Creek, base of section, one mile WNW of G. Mutz ranch

Dockum Group above sedimentary contact

Sangre de Cristo Formation

Unit	Lithology	Thick. (ft)
46	Covered interval	138
45	Sandstone, red, blotchy, thin to medium bedded, medium grained, friable	7
44	Covered interval	1,635
43	Rhyolite dike	30
42	Covered interval	774
41	Sandstone, red, thin bedded, silty, arkosic	2
40	Covered interval	129
39	Arkose, dark red, thin to medium bedded, fine grained, ledge	18
38	Covered interval	102
37	Arkose, reddish, medium to thick bedded, medium grained	13
36	Covered interval	21
35	Shale, reddish, thin to medium bedded, fine grained, arkosic	17
34	Covered interval	70
33	Sandstone, reddish, thin to medium bedded, silty, arkosic	13
32	Covered interval	428
31	Siltstone, reddish	10
30	Covered interval	39
29	Siltstone, reddish, arkosic	2
28	Covered interval	22
27	Siltstone, red to magenta, thin to medium bedded, fine grained, micaceous, ledge	58
26	Covered interval	149
25	Arkose, greenish brown, variable bedding, fine to medium grained	20
24	Conglomerate, gray, pebbly, limy, unconformably overlies shale below	8
23	Shale, greenish gray, thin bedded	4
22	Covered interval	62
21	Sandstone, olive green, thin bedded, fine grained	5
20	Covered interval	12
19	Limestone, reddish gray, ledge, pebbly, arkosic and clay matrix	9
18	Covered interval	58
17	Siltstone, magenta, greenish gray blotches, fine grained, occasional plant stems	2
16	Covered interval	110
15	Shale, red, thin bedded, silty	3
14	Covered interval	117
13	Siltstone, dark magenta, thin bedded, fine grained, micaceous	4
12	Covered interval	398
11	Sandstone, buff, thin bedded, pebbly	20
10	Limestone, gray, conglomerate poorly exposed, sandy matrix	2
9	Covered interval	70
8	Conglomerate, reddish, thick bedded, coarse	4
7	Siltstone, dark colored, medium bedded, conglomerate layers	56
6	Covered interval	41
5	Shale, dark red	2
4	Covered interval	35
3	Conglomerate, medium to thick bedded, silty horizons	4
2	Siltstone, dark colored, arkosic, micaceous	12
1	Conglomerate, reddish, thick bedded, silty layers, poorly sorted pebbles and cobbles, some quite angular	74
	Total	4,809

Precambrian biotite gneiss below high-angle thrust contact

(PERMIAN) TO CRETACEOUS

No. 1, Scully Mountain, base of section, 4,000 feet SE of G. Mutz ranch

Quartz diorite porphyry sill above, intrusive contact

Carlile (?) Shale

Unit	Lithology	Thick. (ft)
40	Covered interval	53
39	Shale, dark gray, weathers to fine particles	22

Greenhorn Limestone

Unit	Lithology	Thick. (ft)
38	Limestone, dark gray, medium bedded, fine grained, fossiliferous	16

Unit	Lithology	Thick. (ft)
37	Covered interval	84
	(FAULT)	
	Morrison Formation	
36	Shale, purple, some gray nodular limestone at top	41
35	Covered interval	13
34	Sandstone, pale purple, thin bedded, medium grained, partly nodular	14
33	Sandstone, buff weathering, medium to thin bedded, fine-grained sandstone, with clay cement, ledge former	12
32	Covered interval	13
31	Shale, blotchy gray and brown, nodular	17
30	Sandstone, gray-white, medium bedded, ledge, fine grained, clay cement	8
29	Shale, reddish brown, maroon, sandy in part, with maroon partings	7
28	Sandstone, white, rounded ledge, fine grained, clay cement	5
27	Covered interval	29
26	Sandstone, white, thin bedded at top, fine grained, some clay cement, ledge former	5
	Wanakah equivalent	
25	Limestone, medium gray, thin bedded, fine grained, red jasper fragments	3
24	Shale, red and buff, alternating laminations, fine grained	14
23	Covered interval	9
22	Shale, reddish brown, nodular	4
	Entrada Sandstone	
21	Sandstone, gray white, rounded ledge, fine grained, clean	12
20	(Rhyolite(?) Dike)	29
	Dockum Group	
19	Covered interval	5
18	Shale, red, some limonite stained, includes two ledges of buff, thin bedded, fine-grained sandstone; unconformity above first ledge	38
17	Limestone, gray, pebble conglomerate, thin bedded	7
16	Covered interval	24
15	Sandstone, light weathering, thin bedded, medium- to fine-grained sandstone	3
14	Covered interval	27
13	Shale, red, some buff, laminated, small mica plates	72
12	Sandstone, light colored, laminated, fine grained	27
11	Covered interval	38
10	Sandstone, gray, thin bedded, fine grained	3
9	Covered interval	12
8	Limestone, gray, pebble conglomerate	1
7	Covered interval	6
6	Sandstone, white, laminated, fine grained, clayey, some red shale at base	17
5	Shale, red and buff, fine grained, micaceous	6
4	Covered interval	26
3	Sandstone, gray-white, medium to thick bedded, fine grained, some clay, laminated at top	17
2	Limestone, gray, pebble conglomerate, ledge former	8
1	Sandstone, light buff, laminated at top, medium to thick bedded at base, fine grained	5
	Total	752

Sangre de Cristo Formation below sedimentary contact

LOWER CRETACEOUS

No. 2, Elizabethtown, base of section, one mile WNW of Elizabethtown

Quartz diorite porphyry sill and Upper Cretaceous above intrusive contact

	Carlile (?) Shale	
11	Shale, dark gray	8
10	Covered interval	16
	Greenhorn Limestone	
9	Limestone, dark gray, blocky weathering, medium bedded, some dark shale, *Inoceramus labiatus*	22
	Graneros (?) Shale	
8	Covered interval	284
7	(Rhyolite dike)	12
6	Covered interval	108
	Dakota Group	
5	Sandstone, buff, medium to thin bedded, medium grained	27
4	Shale, medium gray	30
3	Sandstone, buff, medium bedded, ledge, medium grained	30
2	Shale, medium to dark gray, sandy	25
1	Sandstone, light buff, medium bedded, prominent ledge, medium grained, crisscrossed by quartz veinlets that weather out as ribs	28
	Total	590

Variegated Morrison shale below poorly exposed sedimentary contact

UPPER CRETACEOUS

No. 3, Iron Mountain, base of section on New Mexico 38, 6,000 feet SE of Elizabethtown

Quartz diorite sill above intrusive contact

Unit	Lithology	Thick. (ft)
Smoky Hill Marl		
8	Shale, dark gray, calcareous, interbedded with dark-gray limestone ledges, platy hornfels at top	164
7	Quartz diorite porphyry sill	122
6	Shale, dark gray, calcareous, interbedded with dark-gray, fine-grained limestone up to 10 inches thick, numerous pelecypods	191
5	Covered interval	16
4	Shale, dark gray to black, platy-weathering siltstone, sparingly calcareous, a little limestone and calcareous shale above	96
3	Covered interval	25
2	Shale, dark gray, with ledges of limestone, thin bedded, fine grained	15
Fort Hays(?) Limestone		
1	Limestone, dark gray, medium to thick bedded, fine grained, slabby weathering, *Inoceramus sp.*	21
	Total	650

Carlile (?) Shale below contact concealed by alluvium

CRETACEOUS TO PALEOCENE

No. 4, Mills Divide, base of section, 9,000 feet ENE of LeSage ranch

Poison Canyon Formation above sedimentary con-tact

Unit	Lithology	Thick. (ft)
Poison Canyon Formation		
7	Conglomerate, coarse, unconsolidated	1
6	Covered interval	64
5	Quartz diorite porphyry sill	5
4	Covered interval	200
Carlile Shale		
3	Shale, dark gray, calcareous, contains numerous concretions 1 to 2 feet in diameter, confined to lower part of interval	184
2	Shale, dark gray to black, platy weathering	11
1	Shale, dark gray, calcareous, some thin limestones up to 4 inches thick	102
	Total	567

Lower Cretaceous shale below sedimentary(?) con-tact

PALEOCENE

No. 5, Idlewild, base of section, 2,000 feet west of Gallagher Ranch

Pediment (?) gravel above normal contact

Unit	Lithology	Thick. (ft)
Poison Canyon Formation		
6	Conglomerate, gray, some brownish, coarse, loose boulders and cobbles, arkosic matrix	73
5	Covered interval	120
4	Conglomeratic sandstone, gray, consolidated in several ledges	31
3	Covered interval	11
2	Sandstone, gray, medium to coarse grained, conglomeratic, sandy matrix	6
1	Covered interval	61
	Total	302

Dakota Sandstone below unconformable(?) sedimentary contact

OLIGOCENE(?)

No. 6, Stella mine, sec. 3, T. 28 N., R. 14 E.

Latite above normal contact

Unit	Lithology	Thick. (ft)
9	Limestone, gray white, medium bedded, finely crystalline, fresh water	2
8	Siltstone, purple, laminated	3
7	Sill, latite(?)	6
6	Siltstone, purple and gray, thin bedded, medium to fine grained, tuffaceous(?)	14
5	Sandstone, gray white, medium bedded, arkosic, pebbly, Precambrian fragments	5
4	Siltstone, dark red, blocky weathering	
3	Sill, latite(?)	42
2	Sandstone, greenish gray, medium bedded, medium grained, arkosic, with red siltstone partings	15
1	Mudstone, buff, medium bedded, calcareous	4
	Total	97

Precambrian below obscured contact

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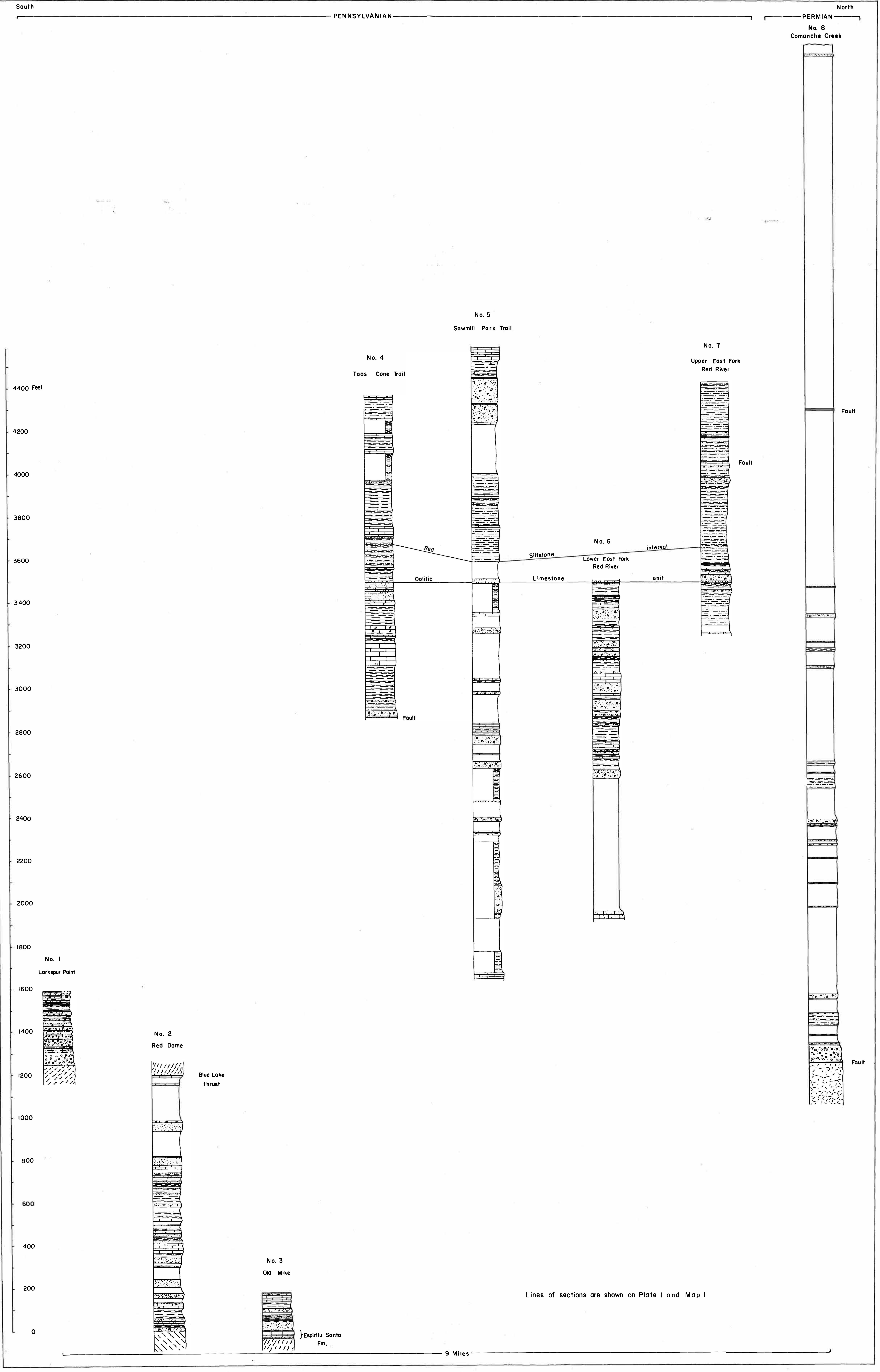
2—Distribution of metals in Elizabethtown-Red River-Rio Hondo districts

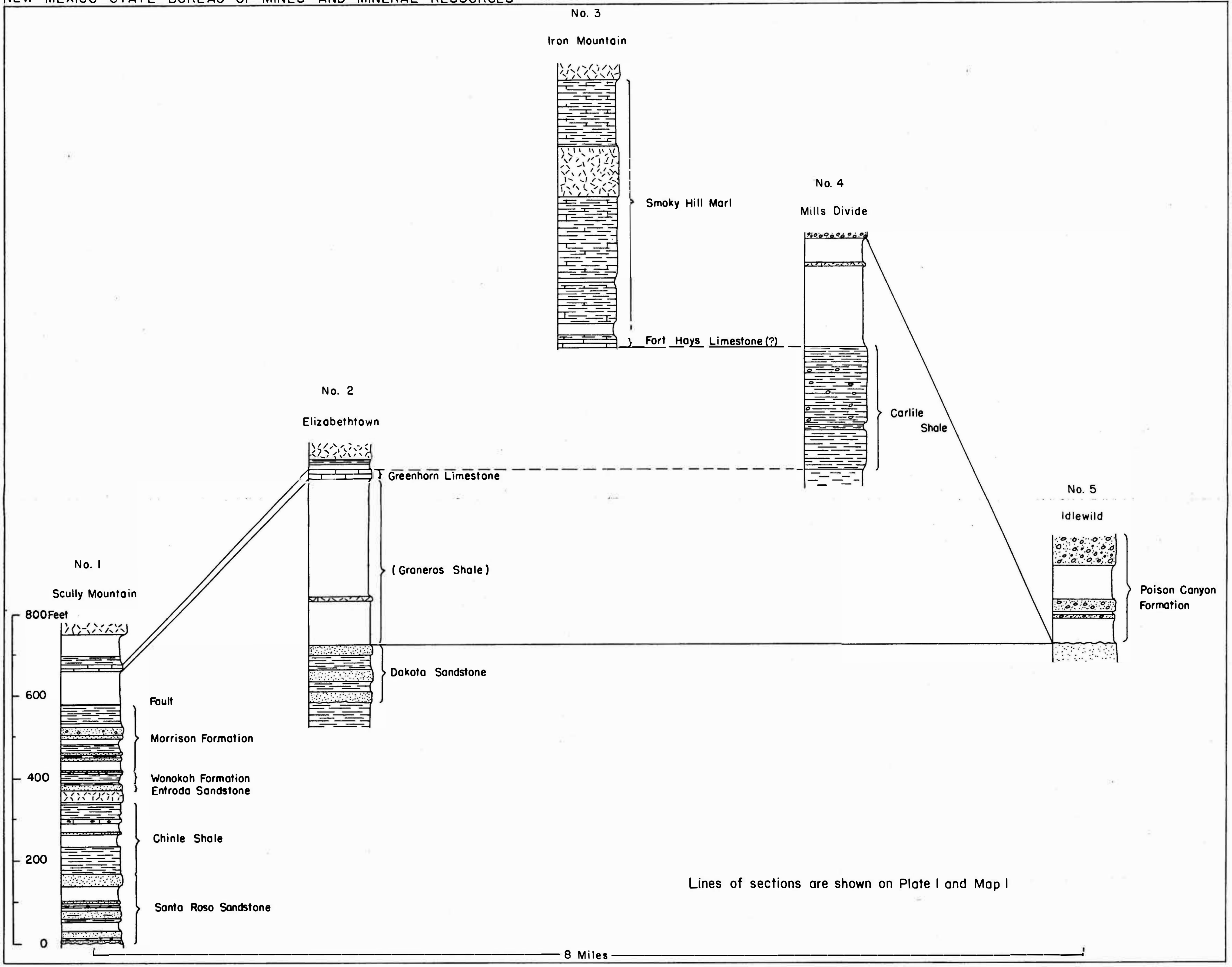
3—Claims in Hematite Creek district

4—Claims in Comanche Creek area

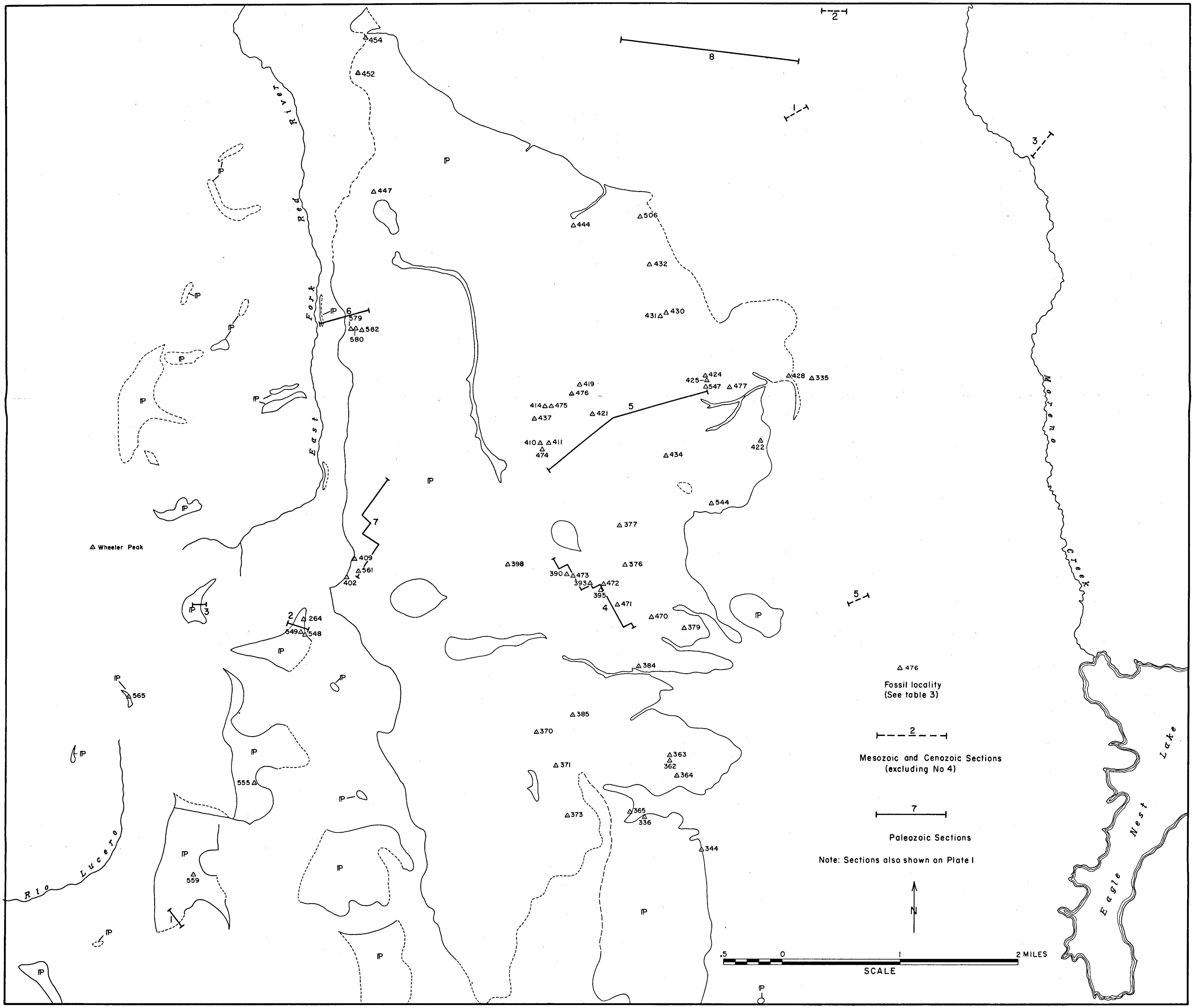
5—Claims in Elizabethtown-Baldy Mountain area



STRATIGRAPHIC COLUMNS OF PENNSYLVANIAN AND PERMIAN ROCKS IN THE EAGLE NEST AREA

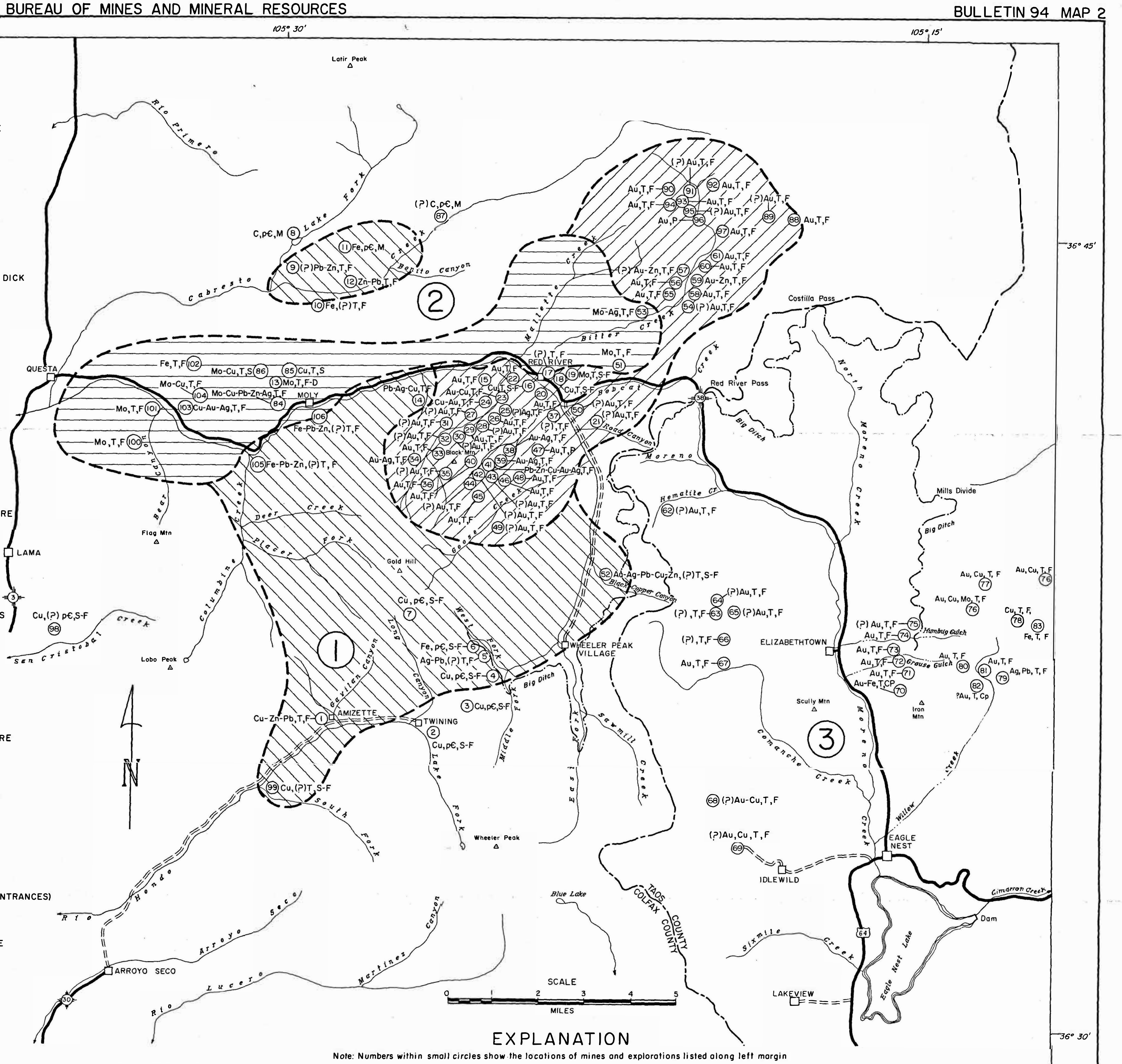


STRATIGRAPHIC COLUMNS OF TRIASSIC, JURASSIC, CRETACEOUS, AND TERTIARY ROCKS IN THE EAGLE NEST AREA



PENNSYLVANIAN FOSSIL LOCALITIES AND LINES OF MEASURED SECTIONS, EAGLE NEST AREA

1. JACKPOT
2. FRAZER
3. HIGHLINE
4. COMSTOCK
5. SILVER STAR
6. IRON DYKE
7. COMMODORE
8. CABRESTO LAKE
9. JENKINS
10. SILVER KING
11. IRON KING
12. HORNET
13. QUESTA
14. VICTOR NO. 2
15. SAMPSON
16. COPPER KING
17. ETHEL
18. ESTHER
19. GRANITE
20. WILLARD
21. RAGGED PANTS DICK
22. ENTRANCE
23. AJAX
24. DYKE
25. SILVER TIP
26. CREEK
27. HILLSIDE
28. MOBERG
29. MIDWAY
30. STELLA
31. ANDERSON
32. CROWE
33. INFERNO
34. CARIBEL
35. RATON
36. BUNKER HILL
37. PURKAPILE
38. BUFFALO
39. BLUE ROCK
40. SYLVIA
41. JAY HAWK
42. GOLDEN TREASURE
43. GOLD REEF
44. GOLDEN CALF
45. NASHVILLE
46. SCARLET
47. HILLTOP
48. JEFFERSON
49. GOLDEN GOOSE
50. BEVERLY
51. JACKS AND SIXES
52. BLACK COPPER
53. ENDERMAN
54. DOROTHY
55. JUNE BUG
56. SILVER QUEEN
57. NEPTUNE
58. MEMPHIS
59. CORA GIBSON
60. INDEPENDENCE
61. DELDOSSO
62. HIDDEN TREASURE
63. GOLD LEAF
64. HARMON
65. PRICHARD
66. LUCIA
67. DENVER - CLIMAX
68. PAY ORE
69. KLONDIKE
70. IRON MOUNTAIN
71. DENVER
72. CENTENNIAL
73. RED BANDANA
74. SHERIDAN
75. TOMBOY
76. DEEP TUNNEL (2 ENTRANCES)
77. CHESTER
78. MYSTIC
79. LEGAL TENDER
80. HIDDEN TREASURE
81. GOLD DOLLAR
82. AJAX
83. MONARCH NO. 2
84. BERNHARDT
85. HORNER
86. HERCULES
87. SPANISH MAIN
88. AZTEC
89. CRITERION
90. MIDNIGHT
91. EDISON
92. KEYSTONE
93. LITTLE CREM
94. CASHIER
95. BIG FIVE
96. GRANGER PLACER
97. DENMARK
98. PORTORICO
99. SOUTH FORK
100. LOG CABIN
101. BEAR CANYON
102. GRAY HAWK
103. HANOSH
104. B. & B.
105. NICKEL PLATE
106. SILVER BELL



EXPLANATION

Note: Numbers within small circles show the locations of mines and explorations listed along left margin

DISTRICTS

① RIO HONDO DISTRICT
② RED RIVER DISTRICT
③ ELIZABETHTOWN DISTRICT

TERTIARY HYPOGENE ZONES

▤ Molybdenum
▨ Pyrite - Gold, Chalcopyrite
▧ Galena - Sphalerite - Silver

ELEMENTS

Mo	Molybdenum
Au	Gold
Cu	Copper
Fe	Iron
Pb	Lead
Zn	Zinc
Ag	Silver
C	Carbon

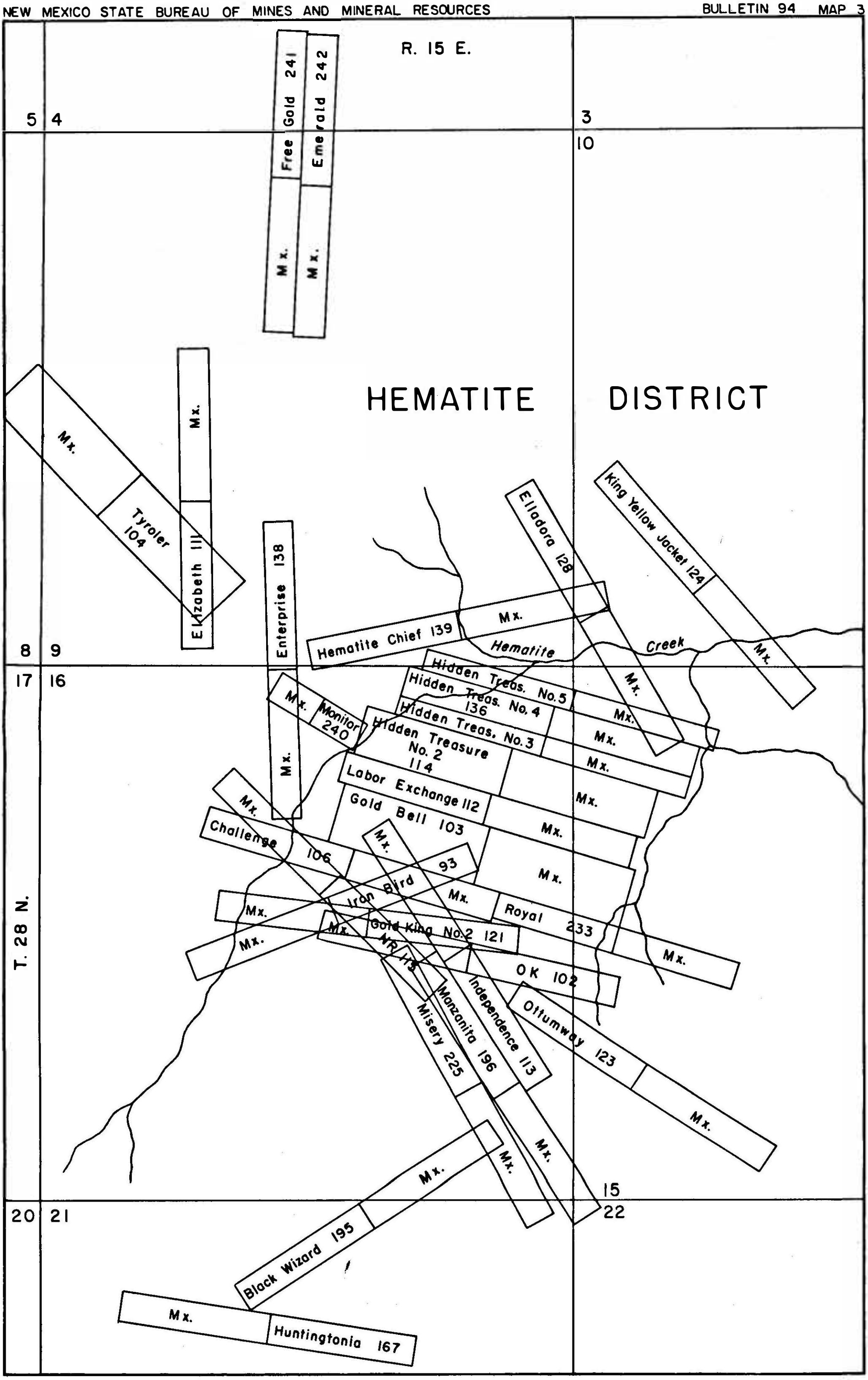
AGE AND FORM

T	Tertiary
pЄ	Precambrian
Cp	Contact pyrometosomatic
D	Disseminated
F	Fissure
S	Shear
M	Metamorphic
P	Placer

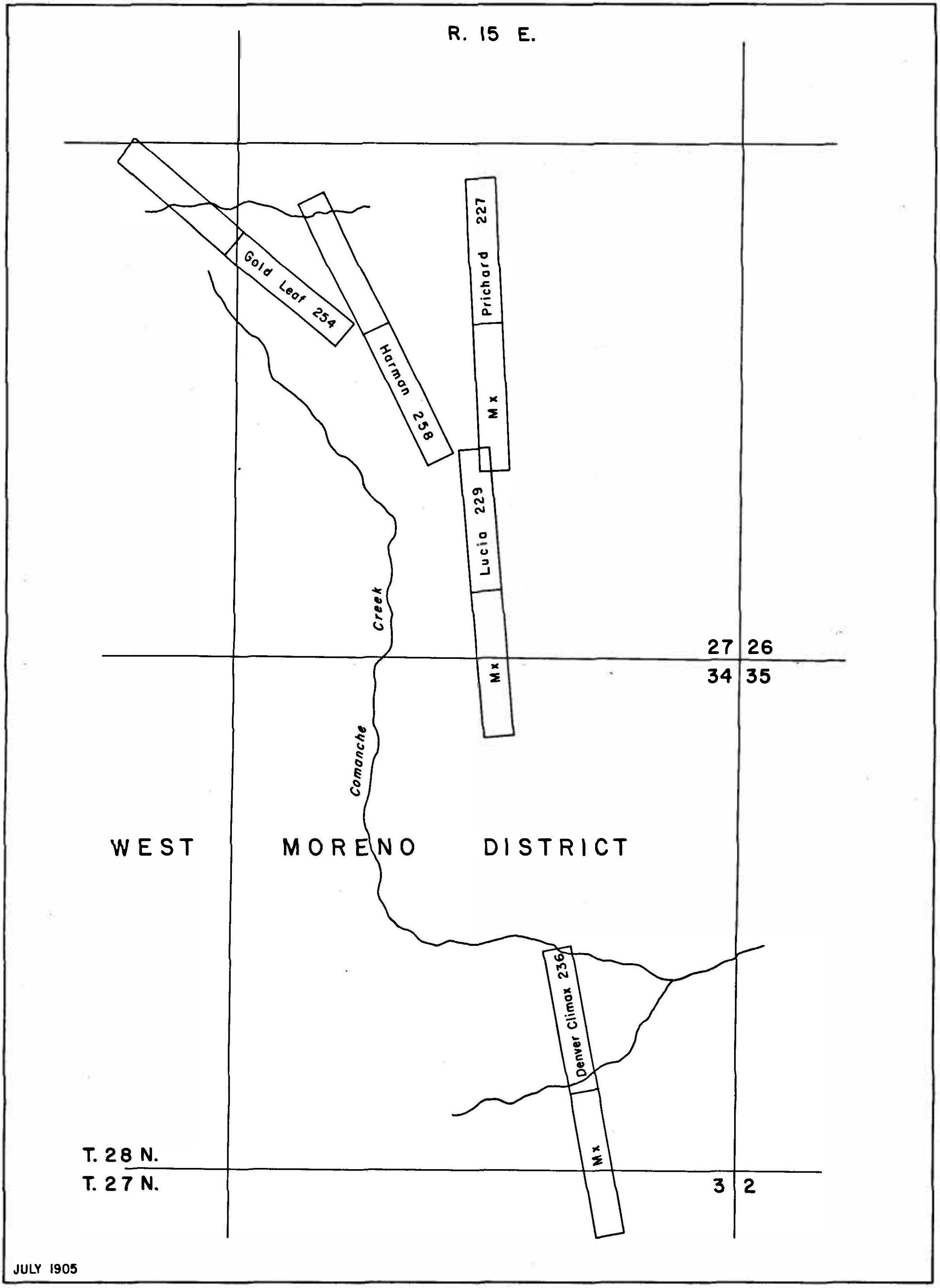
Base: Taos and Vicinity, 1945

Compiled by K. F. Clark, 1966, after Lindgren and others (1910), Petit (1946), Schilling (1960).

DISTRIBUTION OF METALS IN THE ELIZABETHTOWN-RED RIVER-RIO HONDO DISTRICTS

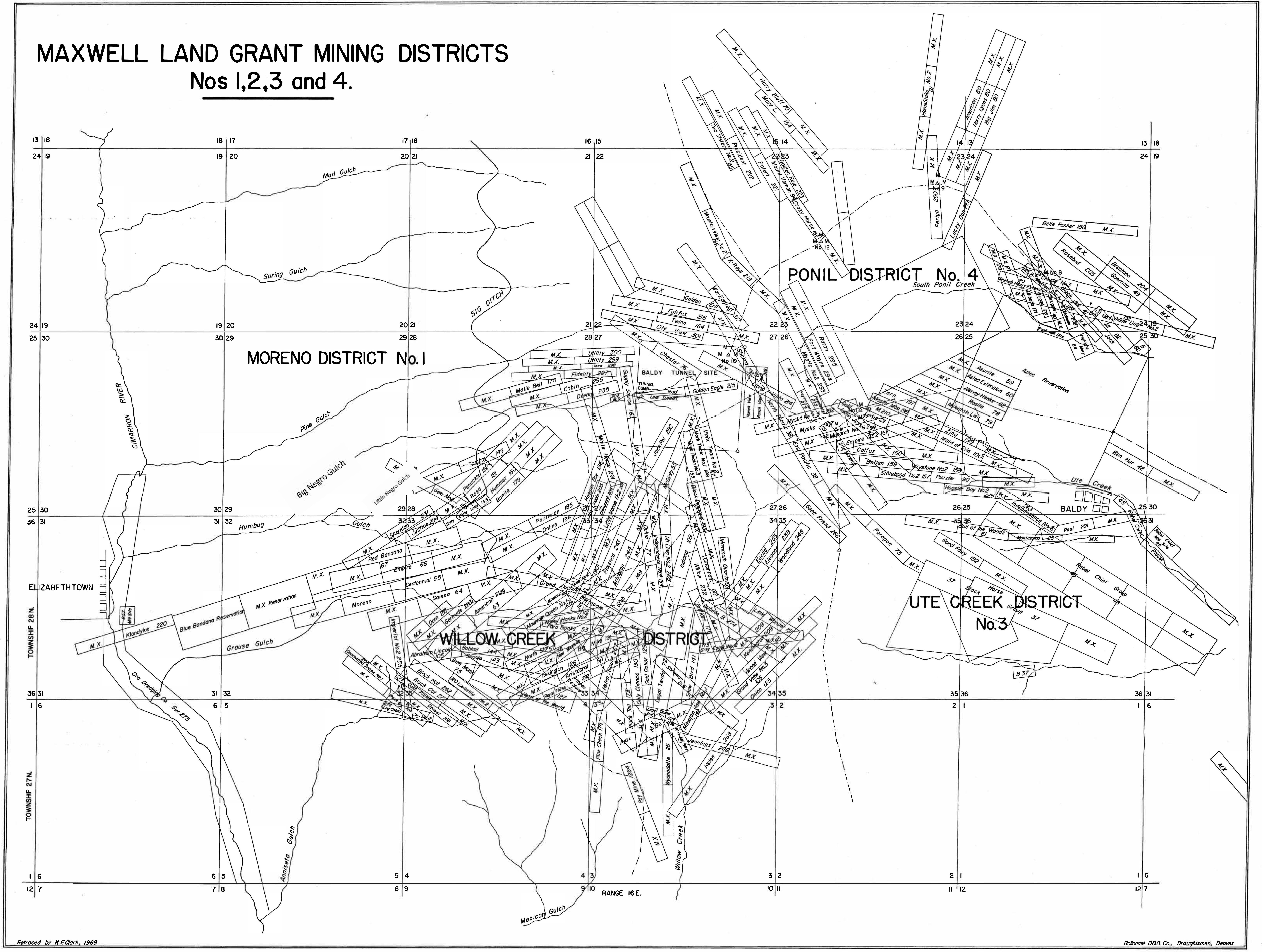


CLAIM MAP OF HEMATITE CREEK DISTRICT, EAGLE NEST AREA

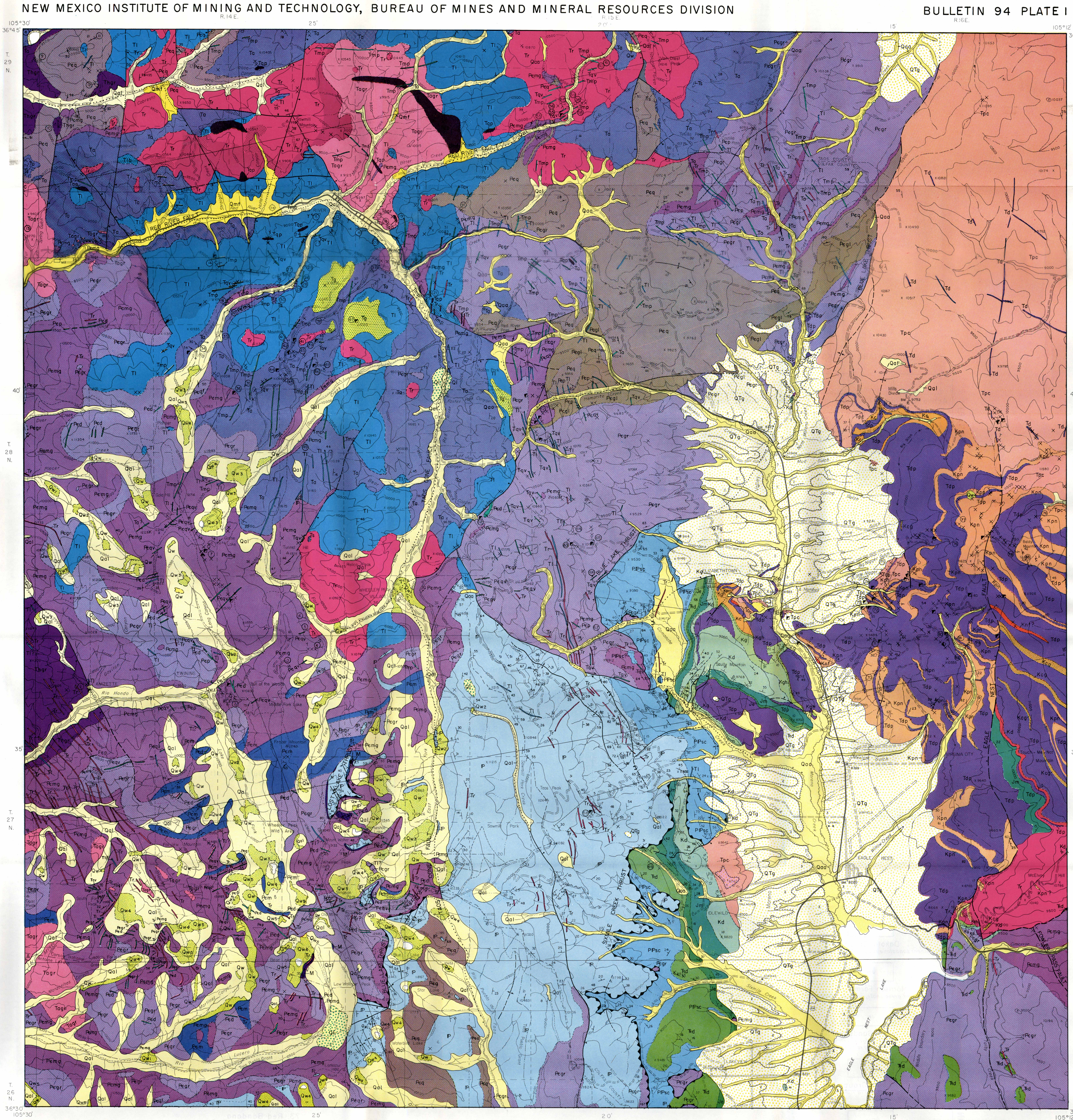


CLAIM MAP OF COMANCHE CREEK AREA, WEST MORENO DISTRICT

MAXWELL LAND GRANT MINING DISTRICTS
Nos 1,2,3 and 4.



CLAIM MAP OF PART OF THE ELIZABETHTOWN-BALDY MOUNTAIN AREA



For complete
EXPLANATION
see other side

SEDIMENTARY ROCKS

QUATERNARY
- Qaa Active alluvium
- Qal Alluvium undifferentiated
- Ql Landslide
- Qmf Mudflow
- Qw Wisconsin moraines
- QTg Quaternary-Tertiary gravel

TERTIARY
- Tg Tertiary gravel
- Tpc Raton and Poison Canyon Formations

CRETACEOUS
- Kpn Pierre Shale
- Knf Fort Hays Limestone
- Kc Kcg Carlisle Shale
- Kgh Greenhorn Limestone
- Kg Graneros Shale
- Kd Dakota Group

JURASSIC
- Jm Morrison Formation
- Je Entrada Sandstone

TRIASSIC
- Ƚd Dockum Group

PERMIAN-PENNSYLVANIAN
- PIPsc Sangre de Christo Formation
- IP Magdalena Group
- M Mississippian

IGNEOUS ROCKS

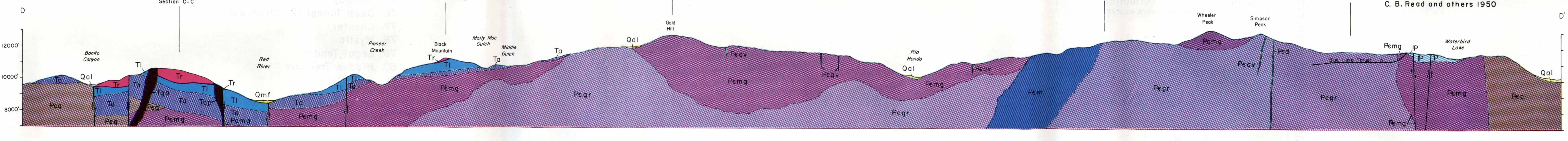
TERTIARY
- Tqp Quartz porphyry
- Tmp Monzonite porphyry
- Tqv Quartz veins
- Tagr Biotite aplite granite
- Tr Rhyolite
- Tl Tlb Latite
- Tdp Td Quartz diorite porphyry
- Ta Ts Andesite
- Thgr Hornblende granite

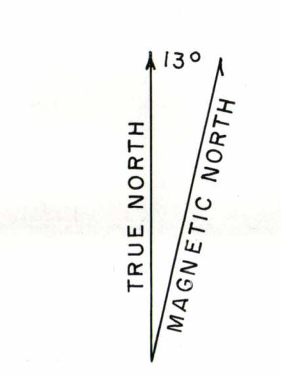
METAMORPHIC ROCKS

PRECAMBRIAN
- Ped Diabase
- Peqv Pep Pegr
  - Peqv - quartz vein
  - Pep - pegmatite
  - Pegr - granite dike
- Pegr Granitic rocks
- Pem Migmatite
- Pemg Mafic gneiss
- Peq Pegl Metaquartzite

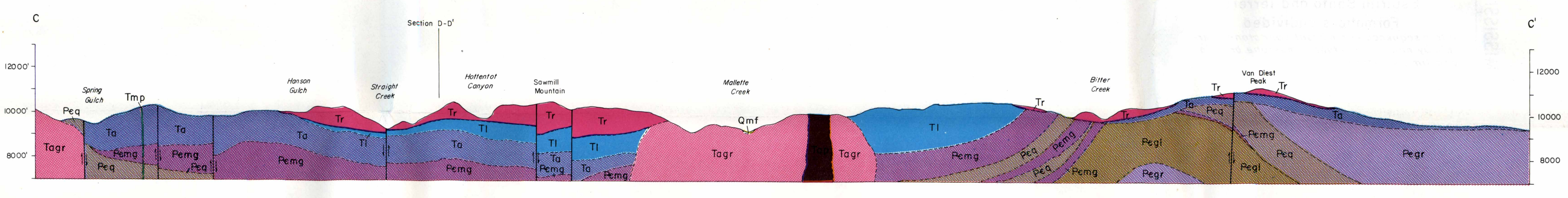
Base and topography adapted from U.S. Geological Survey
Advance proof Eagle Nest quadrangle 1964

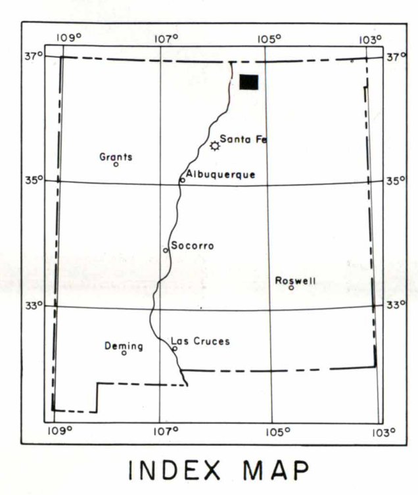
Geology by K. F. Clark 1968;
C. B. Read and others 1950



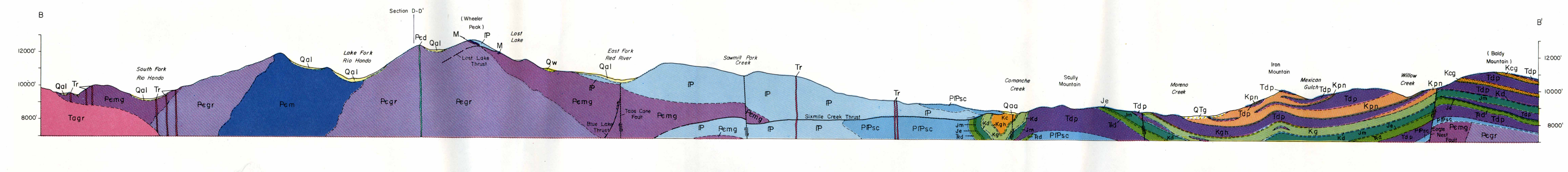


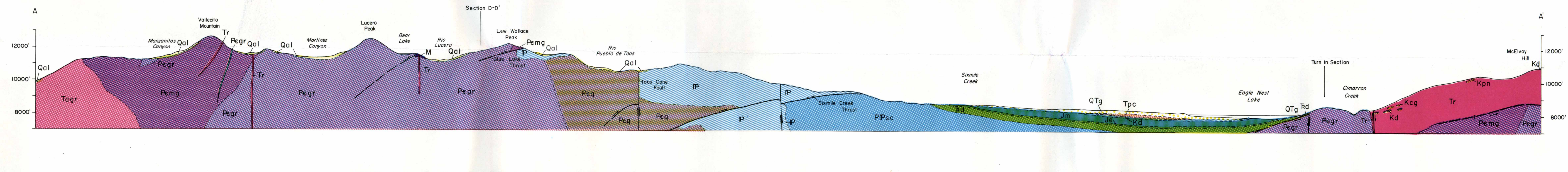
APPROXIMATE MEAN
DECLINATION 1965





INDEX MAP





GEOLOGIC MAP AND SECTIONS OF THE EAGLE NEST AREA, NEW MEXICO

by Kenneth F. Clark

SCALE - 1:48000

CONTOUR INTERVAL 500 FEET

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY

Qaa Active Alluvium

Qal Alluvium undifferentiated

Ql Landslide

Qmf Mud flow

Qw1-5 Wisconsin Moraines
Numbered in order of decreasing age

QTg BV Quaternary–Tertiary gravel
Moreno valley fill. BV *(broad valley) and the figures beside the hachures show stages of erosional surfaces*

TERTIARY

Tg Tertiary gravel
High terrace gravels

Tpc Raton and Poison Canyon Formations
Gray and red sandstone, conglomerate, and gray shale

CRETACEOUS

Kpn Pierre Shale and upper part of Niobrara Formation
Gray marine shale overlying dark-gray shale and thin limestone

Knf Fort Hays Limestone Member of Niobrara Formation
Gray marine limestone

Kc Kcg Carlile Shale
Dark calcareous shale containing concretions
Kcg-*Carlile, Greenhorn, and Graneros formations undifferentiated*

Kgh Greenhorn Limestone
Dark-gray, blocky weathering limestone

Kg Graneros Shale
Gray shale and minor cream bentonite beds

Kd Dakota Group
Prominent sandstone ledges with interbedded shale

JURASSIC

Jm Morrison Formation
Red and green shale, some sandstone

Je Entrada Sandstone
Light-gray sandstone ledge overlain by limestone intervals containing red jasper

TRIASSIC

TRd Dockum Group
Brown or buff sandstone and limestone conglomerate overlain by red shale

PENNSYLVANIAN-PERMIAN

PIPsc Sangre de Christo Formation
Red conglomerate, arkose, shale, and thin nonmarine limestone

IP Magdalena Group
Buff-gray arkose and micaceous sandstone, shale and dark-gray limestone. Some conglomerate, fossiliferous, oolitic limestone and siltstone at top

MISSISSIPPIAN

M Espiritu Santo and Terrero Formations undivided
A thin sequence with a basal sandstone overlain by cherty limestone, limestone breccia and limy siltstone

IGNEOUS ROCKS

TERTIARY

Tqp Quartz porphyry
Light-gray, strongly altered

Tmp Monzonite porphyry
Green or gray dikes

Tqv Quartz veins

Tagr Biotite granite
Texture includes inequigranular, aplitic and porphyritic

Tr Rhyolite
Light-gray or cream, small phenocrysts, flow strucuture may be present. Also includes tuff and welded tuff

Tl Tlb Latite
Dark-gray quartz-biotite latite porphyry
Tlb-*latite breccia*

Tdp Td Quartz diorite porphyry
Sills, dikes, and intrusive gray quartz-hornblende porphyry
Td-*augite diorite porphyry*

Ta Ts Andesite
Purple and green hornblende andesite breccias, tuffs, and flows.
Ts-*hard conglomerate overlain by red siltstone*

Thgr Hornblende granite
Coarsely porphyritic to inequigranular

METAMORPHIC ROCKS

PRECAMBRIAN

p€d Diabase
Dark-brown to black, blocky weathering

p€qv p€p p€gr Dikes and veins
p€qv-*quartz vein*
p€p-*pegmatite*
p€gr-*granite dike*

p€gr Granitic rocks
Includes gray biotite granite and granitic gneiss, pink biotite granite and granitic biotite gneiss

p€m Migmatite
Mixed granitic and metamorphic rocks

p€mg Mafic gneiss
Includes quartz-biotite schist, hornblende gneiss, amphibolite, hornblende tremolite-actinolite schist, and chlorite schist

p€q p€gl Metaquartzite
Includes micaeous quartzite, graphite-mica gneiss, sillimanite-mica gneiss.
p€gl-*mucovite-hematite granulite locally at base*

SYMBOLS

Contact
Dashed where uncertain; dotted where concealed

High angle normal fault
Dashed where uncertain; dotted where concealed
Arrow indicates lateral movement

High angle thrust fault
Dashed where uncertain; dotted where concealed

Overthrust fault
Barbs on side of upper plate

Anticline
Showing trace of axial plane and direction of plunge

Overturned anticline
Showing trace of axial plane and direction of plunge

Syncline
Showing trace of axial plane and direction of plunge

Overturned syncline
Showing trace of axial plane and direction of plunge

40
Strike and dip of beds

15
Strike and dip of overturned beds

Strike and dip of vertical beds

⊕
Horizontal beds

63
Strike and dip of foliation

Strike of vertical foliation

Erosion surface
Numbered inorder of increasing age

Hydrothermal alteration

Propylitic alteration

3
Line of measured section

×
Prospect pit

Adit

◪
Shaft

㉗
Listed mine or prospect

MINES AND PROSPECTS

RIO HONDO DISTRICT

1. Jackpot
2. Frazer
3. Highline
4. Comstock
5. Silver Star
6. Iron Dyke
7. Commodore

RED RIVER DISTRICT

8. Cabresto Lake
9. Jenkins
10. Silver King
11. Iron King
12. Hornet
13. Questa Mine
14. Victor No. 2
15. Sampson
16. Copper King
17. Ethel
18. Esther
19. Granite
20. Willard
21. Ragged Pants Dick
22. Entrance Tunnel
23. Ajax
24. Dyke Tunnel
25. Silver Tip
26. Creek Tunnel
27. Hillside Tunnel
28. Moberg No.2
29. Midway
30. Stella
31. Anderson
32. Crowe
33. Inferno
34. Caribel
35. Raton
36. Bunker Hill
37. Purkapile
38. Buffalo
39. Blue Rock Tunnel and Buffalo Shaft
40. Sylvia
41. Jay Hawk
42. Golden Treasure
43. Gold Reef
44. Golden Calf
45. Nashville
46. Scarlet
47. Hilltop
48. Jefferson
49. Golden Goose
50. Beverly
51. Jacks and Sixes
52. Black Copper Mine
53. Enderman
54. Dorothy
55. June Bug
56. Silver Queen
57. Neptune
58. Memphis
59. Cora Gibson
60. Independence
61. Deldosso

ELIZABETHTOWN DISTRICT

62. Hidden Treasure
63. Gold Leaf
64. Harmon
65. Prichard
66. Lucia
67. Denver-Climax
68. Pay Ore
69 Klondike
70. Iron Mountain
71. Denver
72. Moreno Centennial Shaft
73. Red Bandana
74. Sheridan
75. Tomboy
76. Deep Tunnel (2 entrances)
77. Chester
78. Mystic
79. Legal Tender
80. Hidden Treasure
81. Gold Dollar
82. Ajax
83. Monarch No. 2