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Geology and Mineral Resources of Dwyer Quadrangle, Grant, Luna, and Sierra Counties, New Mexico

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Abstract

Dwyer quadrangle is a 15-minute quadrangle located in southwestern New Mexico, southeast of the town of Santa Rita.

The major part of this report deals with the Tertiary volcanic history of the quadrangle and the petrology of the volcanic rocks. Up to 8,000 feet of volcanic rocks lie on a basement of Precambrian crystalline rocks and about 2,500 feet of sedimentary rocks ranging in age from Cambrian to Upper Cretaceous. The older volcanic rocks change with time from andesine-pyroxene andesites, via andesine-amphibole latites, to quartz-sanidine-oligoclase-biotite rhyolites. The rhyolites include a large proportion of tuffs and ignimbrites (welded tuffs). The later volcanic rocks are separated from the earlier rocks by a prominent unconformity, showing a discontinuous succession from contaminated andesites to a rock on the rhyolite-latite-trachyte boundary, to iddingsite basalts or andesites, followed by minor rhyolites. The earlier volcanic rocks appear to have developed by some process of fractional crystallization from a granodioritic magma chemically similar to that of numerous Laramide intrusives. The later volcanic rocks apparently have been derived from basaltic magma, in part by assimilation of silicic material.

Normal faulting during, and particularly after, deposition of the volcanic rocks divided the quadrangle into several northwestward trending fault blocks of Basin and Range type, broken by northeastward trending transverse faults. The upthrown blocks invariably dip away from the faults, and the prevailing dip throughout the quadrangle is to the southwest. Much of the region is covered by late Tertiary or early Pleistocene fanglomerates and conglomerates, Quaternary terrace gravels, pediment gravels, and alluvium, all derived from uplifted areas.

The White Eagle fluorite mine is the only mine now being worked in the quadrangle. Mineralization in the rich Santa Rita-Central mining area immediately to the northwest is confined to prevolcanic rocks. The problem of finding areas favorable for future mineral exploration is, therefore, one of structure and volcanic stratigraphy. The thickness of the volcanic rocks varies considerably, but almost everywhere it is too great to permit potentially profitable prospecting.

Introduction

PURPOSE AND SCOPE

The geology of Dwyer quadrangle, previously undescribed, is the subject of this report. In the handling of material, special emphasis has been given to the Tertiary volcanic history of the quadrangle and the petrology of its volcanic rocks.

METHODS OF INVESTIGATION

No topographic map of Dwyer quadrangle was available when the geologic map was made. All geologic features were marked on aerial photographs taken in 1937 by the Soil Conservation Service, and were later projected on a planimetric sheet. A scale of 1:31,680 was used throughout.

Altitudes of points on the structure profile were determined with two aneroid barometers, one of them stationary. Shorter traverses were measured by tape and Brunton compass.

As rock exposures are excellent throughout the quadrangle, it was possible to trace almost all contacts.

The summers of 1950, 1951, and 1952 were spent in the field. Considerable time during 1952 and early 1953 was devoted to office and laboratory studies at Columbia University.

PREVIOUS WORK

The geology of Dwyer quadrangle has not been described previously, although information is available relating to adjacent areas.

Dwyer quadrangle is bordered on the west by the southern part of Silver City quadrangle (Paige, 1916). The mining districts around Santa Rita have been the subject of several recent studies (e.g., Lasky and Hoagland, 1949; Ordonez et al., 1955). To the south, Dwyer quadrangle borders Deming quadrangle (Darton, 1917-a). Lake Valley quadrangle, on the east, has been described by Jicha (1954). The area to the north has not been studied, but fanglomerates, gravels, and associated volcanic rocks of Dwyer quadrangle have been correlated with those near San Lorenzo described by Kuelimer (1954).

No comprehensive survey has been made of the volcanic rocks of southwestern New Mexico. Paleozoic and Mesozoic rocks have received more attention (Darton, 1917-b, 1928; Entwistle, 1944; Flower, 1953-a, 1953-b; Jicha, 1954; Kelley, 1951; Kelley and Bogart, 1952; Lasky, 1938; Laudon and Bowsher, 1941, 1949; Stainbrook, 1947; Thompson, 1942). Later Tertiary fanglomerates and conglomerates are described by Knechtel (1936) and Heindl (1952), among others.

Lindgren et al. (1910) devote a chapter to the Cooks Peak mining district. The White Eagle fluorite mine is discussed by Johnston (1928), Talmage and Wootton (1937), Rothrock and Johnson (1946), and Soule (1946).

GEOGRAPHIC FEATURES

LOCATION AND ACCESSIBILITY

Dwyer quadrangle is located in southwestern New Mexico, northwest of Deming and southeast of Silver City. The 15-minute quadrangle includes an area of about 250 square miles in Grant, Luna, and Sierra Counties, and is bounded by longitudes 107°45' W. and 108° W., and latitudes 32°45' N. and 32°30' N. (pl. 2).

The population of about 300 is concentrated in the Mimbres Valley, chiefly around Dwyer, where Faywood post office is located. The northern part of the area lies in the Sherman postal district. Cattle ranching, farming, fruit growing, and mining are the chief occupations.

Underflow of the Mimbres River, dry for much of the year, supplies ground water for numerous irrigation wells. Stock wells are distributed widely throughout the quadrangle and are accessible by truck.

State Highway 61 roughly follows the course of the Mimbres Valley. U. S. Highway 260 cuts the southwestern corner of the quadrangle. All other roads are of graded-dirt construction and may become impassable after torrential summer rains. The Silver City branch of the Atchison, Topeka & Santa Fe Railway parallels U. S. Highway 260; there is a loading point at Faywood station.

PHYSICAL FEATURES

Much of the quadrangle is hilly, with the highest peaks in the northwest, northeast, and southeast portions. The highlands in the northwest are structurally simple, consisting of a great, dissected wedge of Tertiary volcanic rocks dipping to the southwest in a gentle homocline. Caballo Blanco, the highest point in the quadrangle, has an altitude of 7,558 feet (msl). The hills in the northeast belong to the Black Range and consist of structurally complex volcanics and postvolcanic fanglomerates. Cooks Range, in the southeast, is a complex of sedimentary and intrusive rocks extending in age from Precambrian to Tertiary. All high areas are tilted fault blocks of the Basin and Range type.

The southwestern part of the quadrangle has low relief. It is underlain by alluvium, terrace gravels, and almost horizontal tuffs and flows. A prominent mesa shows relics of overlying beds. Faults have no topographic expression. These features are typical of the Colorado Plateau.

Drainage is of the interior, intermittent variety. The Mimbres River runs through the center of the area in a north to south direction, forming its base level. The river descends from 5,550 feet (msl) in the north to 4,800 feet in the south.

CLIMATE

The quadrangle lies in a semiarid region. Vegetation is typical of the Lower and Upper Sonoran life zones. Rainfall averages 12 inches a year, with a rainy season during the summer.

ACKNOWLEDGMENTS

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The writer is grateful to the following persons for their help: Dr. Eugene Callaghan, former director of the New Mexico Bureau of Mines and Mineral Resources, for originating the project and for stimulating field criticism; Professor Charles **H.** Behre, Jr., of Columbia University, for valuable advice in field and office; the late Dr. Robert Balk, of the New Mexico Bureau of Mines and Mineral Resources, and Professor Arie Poldervaart, of Columbia University, for criticism of the manuscript; Mr. Norman Cohen, field assistant in 1950; and Mr. George Stoertz, field assistant during the summer of 1951. Information was exchanged with members of the New Mexico Bureau of Mines and Mineral Resources and the U. S. Geological Survey.

Special thanks are due to my wife, who typed the original manuscript and assisted in the preparation of illustrations.

Stratigraphy

GENERAL STATEMENT

Because they cover 95 percent of Dwyer quadrangle, Cenozoic rocks will be discussed in this report in much greater detail than earlier rocks. Paleozoic and Mesozoic stratigraphy has been treated adequately by many authors; the reader is referred especially to Flower (1953-b) and Jicha (1954) for faunal lists, measured sections, and other details. The petrography and field relations of Tertiary volcanic rocks are described in a later chapter.

Pre-Tertiary rocks crop out in Cooks Range and near the northwest boundary of the quadrangle. Figure 1 shows a composite section of Cooks Range compiled from the literature, and an original section half a mile north of Dwyer quadrangle, and west of the Mimbres fault, measured by Dr. H. L. Jicha, Jr. and the writer.

Paleozoic and Mesozoic sedimentary rocks are only about 2,500 feet thick. Long periods are represented by disconformities. Angular unconformities are slight; within Dwyer quadrangle they can barely be measured.

Regionally, the findings of Kelley and Bogart (1952) cast doubt on the existence of the late Pennsylvanian or early Permian tectonic disturbance postulated by Thompson (1942) and Eardley (1951). A regional unconformity at the base of the Beartooth (Sarten) sandstone (Lower Cretaceous) was described by Entwistle (1944). Relative crustal stability ended after deposition of the Colorado shale (Upper Cretaceous). Faulting and intrusive igneous activity, probably of Laramide age, were succeeded by erosion and the eruption of 7,000 feet or more of volcanic rocks. Renewed uplift in late Tertiary time was followed by deposition of several series of valley-fill sediments.

PRECAMBRIAN ERA

Precambrian rocks are exposed at the northern end of Cooks Range. They consist mainly of coarse quartz-microcline-biotite granite and granite gneiss, cut by pegmatites and Tertiary(?) rhyolite dikes. In the center of sec. 28, T. 19 S., R. 9 W., granite gneiss grades into hornblende-chlorite schist. Precambrian rocks are much fractured and altered, particularly in the vicinity of fluorite mineralization. Their age is established by position below Bliss quartzite.

CAMBRO-ORDOVICIAN SYSTEMS

BLISS QUARTZITE

Bliss quartzite is exposed in the northern part of Cooks Range. In sec. 3, T. 19 S., R. 9 W., where a thickness of 71 feet was measured by

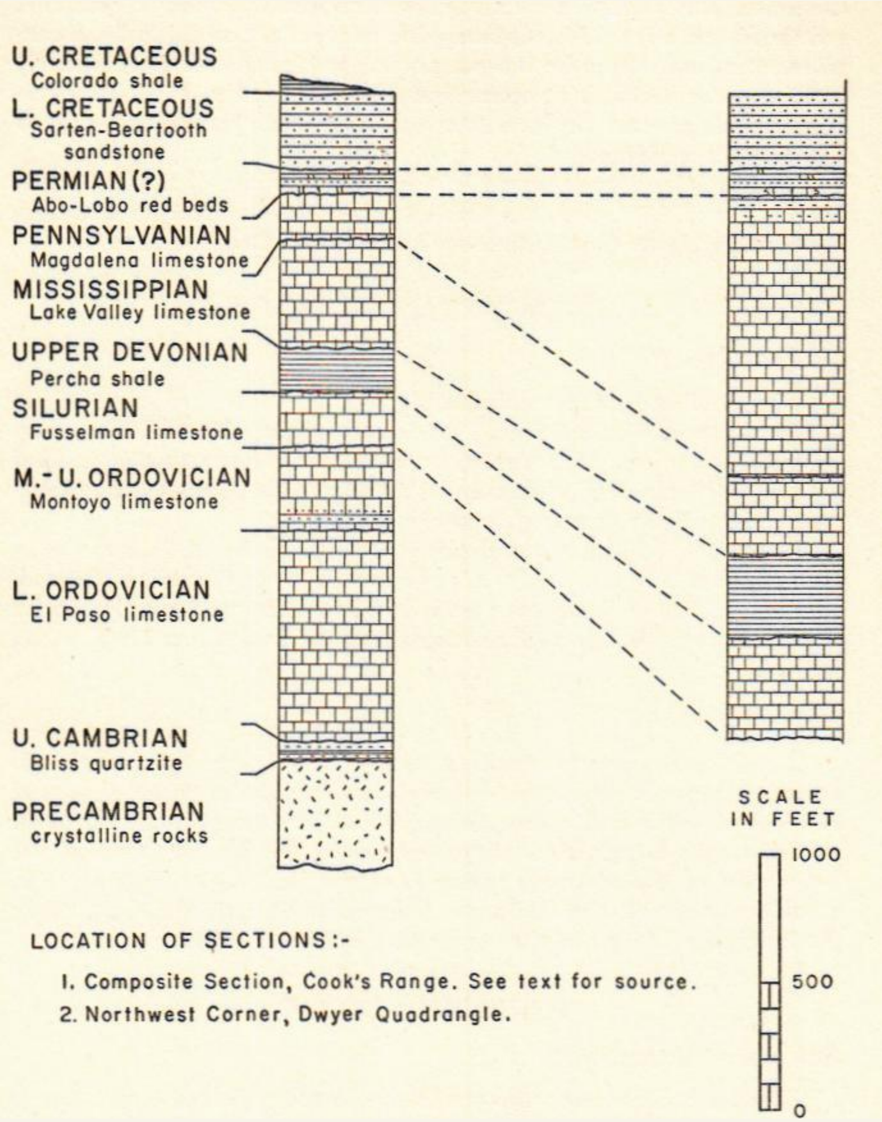


Figure 1

COMPARATIVE PRE-TERTIARY STRATIGRAPHIC SECTIONS OF DWYER QUADRANGLE AND ADJACENT AREAS the writer, the formation consists of well-cemented hematitic quartzite, red sandstone, a few beds of glauconitic sandy shale, and, locally, a conglomeratic base. Hematite is never present in concentrations sufficiently high to make the rock a commercial iron ore (Kelley, 1949). The unconformable contact between Bliss quartzite and Precambrian crystalline rocks is well exposed.

No fossils have been found in the Bliss quartzite of Cooks Range, but Flower (1953) has shown that elsewhere in New Mexico the Bliss contains an Upper Cambrian as well as a Lower Ordovician unit.

ORDOVICIAN SYSTEM

EL PASO GROUP

The El Paso group conformably overlies Bliss quartzite in the northern part of Cooks Range. The contact is sharp. The El Paso group includes dolomites, calcarenites, stromatolitic reefs, and thin-bedded lime muds (Jicha, 1954), but consists mainly of bluish-gray slabby limestone, with siliceous partings between beds.

Flower (1953-b) has given detailed sections of the El Paso group in New Mexico. The fauna of the lower part is lower Canadian (Gasconade) in age; that of the upper part is middle and upper Canadian. Jicha (1954) measured 831 feet of El Paso limestone in S½ sec. 17, T. 19 S., R. 9 W.

MONTOYA GROUP

The Montoya group is not exposed within Dwyer quadrangle, although it is probably present below the surface. Jicha (1954) measured 321 feet of sandy and cherty dolomite and limestone in the northern part of Cooks Range. According to Flower (1953-b), the fauna of the lower part of the Montoya group is of the Red River-Bighorn type, considered either Richmondian or Trentonian (Twenhofel et al., 1954); the brachiopod fauna of the upper part is Richmondian.

SILURIAN SYSTEM

FUSSELMAN LIMESTONE

Fusselman limestone crops out in the northern part of Cooks Range and along the northern boundary of Dwyer quadrangle, west of the Mimbres fault, disconformably overlying the Montoya group. Fusselman limestone is dark gray and has a characteristic fractured appearance. It is host to many small ore deposits. Near faults and mineralized areas, the formation is silicified, especially at the top, and may also be dolomitized. In the Cooks Range fault zone a single species of *Pentamerus* sp. is abundant in small bioherms. Several corals, including *Halysites* sp. and *Heliolites* sp., are found in the northwestern part of Dwyer quadrangle. Darton (1917-a) measured 212 feet of limestone in

Cooks Range; the writer found a minimum of 400 feet in NW¼ sec. 7, T. 18 S., R. 10 W., and NE% sec. 12, T. 18 S., R. 11 W.

DEVONIAN SYSTEM

PERCHA SHALE

The distribution of the Percha shale is similar to that of the Fusselman limestone, which it overlies disconformably. The formation consists of two members, a lower black highly fissile shale and an upper gray shale with calcareous nodules; these were named, respectively, Silver and Bella members by Keyes (1940), and Ready Pay and Box members by Stevenson (1945). Stainbrook (1947) uses Keyes' classification, whereas Weller et al. (1948) and Laudon and Bowsher (1949) use that of Stevenson. No fossils were found in Percha shale of Dwyer quadrangle, but fossils found elsewhere place the formation in the Upper Devonian. Stainbrook (1947) uses the Percha fauna to illustrate the difficulty of establishing a consistent boundary for the Devonian and Mississippian systems. Laudon and Bowsher (1949) measured 173, 171, and 141 feet of Percha shale in Cooks Range. The writer measured 320 feet in N½ sec. 12, T. 18 S., R. 11 W.; of this, 220 feet belong to the Ready Pay member and 100 feet to the Box member.

MISSISSIPPIAN SYSTEM

LAKE VALLEY LIMESTONE

The Lake Valley limestone is mineralized at Lake Valley and in the Central mining area, but not, so far as known, in Dwyer quadrangle. Its unusual reefs and crinoid faunas have aroused much interest (Laudon and Bowsher, 1941, 1949).

Of the Mississippian formations and members defined by Laudon and Bowsher (1949), the Andrecito, Alamogordo, Nunn, and Tierra Blanca members of the Lake Valley formation have been recognized on Cooks Range and along the northern boundary of Dwyer quadrangle. The Andrecito and Nunn members are particularly well developed, representing the Fern Glen stage (Osagian) of southwestern Missouri. Bates et al. (1942) recognized 30 feet of Caballero limestone (Kinderhookian) on Cooks Range, but Laudon and Bowsher (1949) believe this to be reworked material, part of the Andrecito member of the Lake Valley formation. The 0-30 feet of doubtful Kelly limestone (Lower Burlingtonian) described by Laudon and Bowsher (1949) was assigned by Jicha (1954) to the Tierra Blanca member of the Lake Valley formation.

Detailed sections measured in Cooks Range within Lake Valley quadrangle are given by Laudon and Bowsher (1949). Each member has its characteristic lithology, including argillaceous or silty limestones and dolomites. Thicknesses range from 375 to 455 feet. About 300-400 feet was measured by the writer just outside the northwest boundary of Dwyer quadrangle.

PENNSYLVANIAN SYSTEM

MAGDALENA LIMESTONE

Jicha (1954) measured 183 feet of Magdalena limestone in the central and southern parts of Cooks Range. In the northwest part of Dwyer quadrangle the dip of this formation is so changeable that its thickness can only be estimated at about 1,000-1,200 feet. It consists of fossiliferous gray limestones, commonly cherty, and becoming silty toward the top. Fossils collected by Jicha (1954) on Cooks Range were identified by Bowsher as Upper Desmoinesian and Lower Missourian in age.

The term Magdalena is used in New Mexico synonymously with the term Pennsylvanian (Thompson, 1942). Earlier workers, notably Dar-ton (1917-b, 1928), considered all or some of the Pennsylvanian in Cooks Range and the Florida Mountains (Gym limestone) to be Permian, equivalent to the Chupadera formation of central New Mexico. Recent studies by Kelley and Bogart (1952) and Jicha (1954) have cast doubt on this correlation. It is considered now unlikely that fossiliferous Permian exists in Dwyer quadrangle.

PERMO-TRIASSIC(?) SYSTEMS

Abo-Lobo "RED BEDS"

Unfossiliferous "red beds" crop out between Pennsylvanian and Cretaceous marine sediments in Cooks Range and near the northwest corner of Dwyer quadrangle. Darton (1928) measured 90-95 feet of conglomerates, red shales, and reddish-brown sandstones in Cooks Range. The conglomerates consist of rounded limestone and chert fragments, a red calcareous matrix. Similar lithologies occur in Abo "red beds" northwest of Dwyer quadrangle; here the thickness of the beds is about 90 feet, but exposures are poor.

The "red beds" appear to be conformable with beds above and below, but underlying Pennsylvanian limestones thin from 1,000 or 1,200 feet, in the northwestern part of the quadrangle, to 180 feet in Cooks Range. In the Florida Mountains, south of Deming, the "red beds" are strongly unconformable with older sediments (Darton, 1917-a).

In the Silver City area these "red beds" originally were correlated with the Permian Abo formation by Paige (1916). In Luna County they were considered possible correlatives of the Triassic Moenkopi formation by Darton (1928), who gave them the name Lobo. Recent revisions of late Paleozoic stratigraphy (Kelley and Bogart, 1952; Jicha, 1954) indicate that Abo and Lobo "red beds" need no longer be considered separate formations. The writer could find no differences in lithology or stratigraphic position between "red beds" in the northwest and southeast parts of Dwyer quadrangle. Being unfossiliferous, they might be of any age from Pennsylvanian to Cretaceous. Permian "red beds" are widespread in southern New Mexico, whereas Triassic and later "red beds" are generally absent.

CRETACEOUS SYSTEM

SARTEN-BEARTOOTH QUARTZITE

The Sarten-Beartooth formation lies stratigraphically above AboLobo "red beds" and, like these, crops out in the central and southern parts of Cooks Range and along the northwestern boundary of Dwyer quadrangle. It consists of well-cemented sandstones or quartzites, interbedded in the northwestern area with a few lenses of unfossiliferous limestone. The quartzite is light gray and massive to slabby. Cross-bedding is common. The rock tends to weather into cubic or rectangular blocks, with red concentric color bands. According to Darton (1917-b), the disconformable contact between Sarten quartzite and Lobo "red beds" is marked by channeling. About 300 feet of Sarten quartzite is present in Cooks Range; about 280 feet was measured by the writer in sec. 10, T. 18 S., R. 11 W.

The name Beartooth was coined by Paige (1916) for rocks in the Silver City area which he considered possible equivalents of the Dakota sandstone. In Luna County, Darton (1917-a) found Comanchean fossils in limestone interbedded with the quartzite and named the formation Sarten, considering it equivalent to the Beartooth quartzite. Comanchean age has been accepted by all subsequent workers, but the exact stratigraphic position remains in doubt. Bates et al. (1942) believed the Sarten quartzite to be Washitan or Fredricksburgian, and Lasky (1938) considered it Upper Trinitian. Cobban and Reeside (1952) placed the Sarten and Beartooth formations in identical stratigraphic positions (Washitan and Fredricksburgian) but indicated their upper and lower time boundaries as unknown.

COLORADO SHALE

Cretaceous rocks younger than the Sarten-Beartooth quartzite do not crop out in Dwyer quadrangle; either they were removed by erosion or are covered by later rocks. Upper Cretaceous (Bentonian?) black shales of the Colorado formation are well known in surrounding areas (Paige, 1916; Jicha, 1954).

TERTIARY SYSTEM

GENERAL STATEMENT

Tertiary rocks in Dwyer quadrangle are mainly volcanic; they are described in the separate section on petrography and stratigraphy of Tertiary volcanic rocks. Of the two clastic Tertiary formations, the

Piloncillo sediments are interbedded with volcanic rocks in the upper part of the Lower Volcanic series and the lower part of the Upper Volcanic series; the Santa Fe fanglomerates are postvolcanic, except for minor interbedded basalts.

PILONCILLO SEDIMENTS

Piloncillo sediments were named after a hill in sec. 18, T. 18 S., R. 10 W. They occur as small alluvial fans, wind-blown tuffaceous dune sands, tuffs, and stream-channel sandstones and conglomerates. At Piloncillo, tuffaceous and fluvial sediments reach their maximum thickness of 400 feet in a buried valley cut through Caballo Blanco and Razorback rhyolites and possibly part of the Bear Springs basalt. At the bottom of the section, conglomeratic fragments are derived entirely from Kneeling Nun and Box Canyon rhyolite; at the top, from Razorback rhyolite. This indicates that the valley persisted for some time, and that the sediments are contemporaneous with volcanic rocks above the Box Canyon rhyolite and below the Bear Springs basalt. All elastic sediments of similar age and lithology have been mapped as Piloncillo, even where their outcrops are not continuous with the type locality.

In Box Canyon the sediments decrease in thickness from 400 feet, at Piloncillo, to 0-50 feet, south of the Box Well graben. They increase again to 100 feet for half a mile, north of the graben, and then pinch out. Their base consists of fine-grained, white, crossbedded, tuffaceous sandstones without topset and bottomset beds; the top consists of coarse fanglomerates. In some places sands and fanglomerates are separated by Caballo Blanco rhyolite tuff. In the Box Well graben (NW¼NW¼ sec. 8, T. 19 S., R. 10 W), the Piloncillo formation consists of fanglomerates and a buff massive sand containing fragments of silicified wood. Larger fragments in the fanglomerates are 1-3 inches in diameter and tend to be subangular; smaller fragments are rounded. In SW¼ sec. 6, T. 19 S., R. 10 W., Piloncillo fanglomerates are replaced abruptly by Caballo Blanco rhyolite tuff. Fanglomerates appear to have filled irregular depressions formed by erosion of soft tuff, which explains their erratic distribution. Throughout the area described so far, Piloncillo sediments lie on Box Canyon rhyolite. The contact surface is dissected by shallow stream channels.

Elsewhere, the Piloncillo formation is either absent or thin. In SWIA sec. 22, T. 18 S., R. 11 W., sedimentary material up to 6 feet thick locally separates Kneeling Nun rhyolite from Caballo Blanco rhyolite. This material consists of well-consolidated conglomerates deposited in minor stream channels, a few feet of crossbedded sandy tuffs, and sun-cracked, impure red or yellow sandstones interpreted as fossil soils.

Up to 40 feet of conglomerate and sandstone commonly separate the Razorback and Bear Springs formations. They are best exposed at the junction of Seneca and Live Oak Canyons (E½ sec. 5, T. 19 S., R. 11 W.). They consist of crossbedded fine-grained yellow or cream-colored tuffaceous sandstone. Sediments at this horizon are more widespread than indicated on the map, but generally are covered by basalt float. In a few places, such as NW¼ sec. 22, T. 18 S., R. 10 W., thin sandy beds are interbedded with volcanic rocks of the Razorback formation.

Fragments of Rubio Peak latites and andesites, Kneeling Nun rhyolite, Mimbres Peak rhyolite, and Razorback rhyolite and andesite have been identified in Piloncillo sediments. The coarse rocks are consolidated; the cement is noncalcareous. Sandy members are semiconsolidated, fractured, and transected by sand veinlets. Near Kingston, New Mexico, early Miocene to early Pliocene plant fossils have been found in lake beds of about the same stratigraphic position as the Piloncillo sediments (Kuellmer, 1954).

SANTA FE CONGLOMERATES

The end of volcanism in Dwyer quadrangle was followed by a period of fault movement, which is responsible for most of the present relief. Erosion of uplifted areas resulted in deposition of large alluvial fans in the Upper Mimbres Valley. The fanglomerates have been correlated with the Santa Fe formation.

The stratigraphic term Santa Fe, first used by Hayden, has been applied to fanglomerates, conglomerates, sandstones, clays, gypsiferous lacustrine deposits, and volcanic rocks in the Rio Grande Valley. Upper Miocene or Lower Pliocene vertebrate fossils were found near Santa Fe, and Upper Pliocene fossils near Socorro. The formation has been described as equivalent to the Upper Miocene to Pleistocene(?) Ogalalla formation to the east, and to the Upper Miocene to Pleistocene(?) Gila conglomerate in southeastern Arizona (Bates et al., 1936; Knechtel, 1936; Heindl, 1952).

The formation name Gila may be as applicable to rocks of Dwyer quadrangle as the name Santa Fe. The Mimbres River terminates now in an interior basin. It is unknown where it flowed in late Tertiary time, although the direction of its flow was probably toward the Rio Grande depression. The term Santa Fe, therefore, is used in this report; it includes all consolidated valley-fill sediments younger than the Upper Volcanic series.

In the northern part of Dwyer quadrangle the Santa Fe formation is confined to the eastern side of the Mimbres fault, but east and southeast of the mouth of Tom Brown Canyon it covers the Mimbres fault zone and all other major structures. A small area of Santa Fe or Piloncillo fanglomerates occurs in the Blue Mountain fault zone, in sec. 24, T. 19 S., R. 11 W.

Dips steepen to a maximum of about 36 degrees near the sources of alluvial fans. Calculations, assuming true dips, yield improbable thicknesses of the order of 10,000 feet. In some places where maximum thicknesses might be expected, underlying volcanic rocks are exposed.

Such discrepancies might be explained by faulting. This, however, would be difficult to prove, because outcrops are mantled almost everywhere by residual gravels or terrace gravels. Faulting probably explains dips of 58 degrees measured near the mouth of Hot Springs Canyon, of 38 degrees in Donahue Canyon, and of almost 90 degrees southwest of Blue Mountain. According to Heindl (personal communication, 1952), the Gila conglomerates of southeastern Arizona almost invariably are in fault contact with their source rocks, but faults may be hidden under normal unconformable contacts involving only the uppermost beds of Gila conglomerate.

The writer believes that steep dips result partly from contemporaneous faulting, particularly near sources of fans, and partly from a deltaic type of deposition, like crossbedding on an enormous scale. Steep dips would be found only in foreset beds, which flatten at depth. Topset beds are thin or absent. On this hypothesis, the conspicuously flat topography of areas underlain by the Santa Fe formation might be ascribed to the original surface of an advancing deltaic fan rather than to beveling. The maximum thickness of the fanglomerates may not exceed 1,000 feet.

The Mimbres River flows along the junction between eastward and westward dipping alluvial fans, except where the junction follows the mouth of Gallinas Canyon (possibly a former stretch of the Mimbres). Erosion has reduced eastward dipping fans to isolated patches, but westward dipping fans remain widespread.

The fanglomerates generally are well consolidated by siliceous cement. Fragment sizes decrease, and sorting increases, with distance from the source. For example, unsorted boulders as much as 5 feet across are found in sec. 21, T. 18 S., R. 10 W., near the Mimbres fault. In contrast, south and east of Gallinas Canyon the rock is well bedded, crossbedded, and well sorted, and contains subangular to subrounded cobbles measuring 1 foot or less.

The composition of fragments changes abruptly where two fans meet. West of Gallinas Canyon and east of the Mimbres, in sec. 16, T. 18 S., R. 10 W., Paleozoic limestones and Tertiary volcanic rocks from the northwest predominate. Southeast of Gallinas Canyon, limestones are absent, Upper Series volcanic rocks are abundant, and Mimbres Peak rhyolites are scarce. Between Donahue Canyon and Windmill Draw, there is a preponderance of Mimbres Peak rhyolite originating in the Black Range to the northeast. East of Cooks Range, in secs. 15, 16, 22, 27, 34, T. 19 S., R. 9 W., the fanglomerates are derived largely from the Rubio Peak formation but also contain large boulders of Bear Springs basalt. Their source lies to the east. In NE¼ sec. 20, T. 18 S., R. 10 W., fanglomerates cover the contact between Razorback rhyolite and Bear Springs basalt, and the composition of the boulders changes abruptly with that of the bedrock.

Flows, tuffs, and agglomerates of iddingsite andesite are interbedded with Santa Fe fanglomerates in Gavilan Canyon, in SE¼ sec. 27, T. 18 S., R. 9 W., and NEN sec. 34, T. 18 S., R. 9 W. They dip 25° SW. conformably with Santa Fe sediments. Iddingsite basalts or andesites also are interbedded with Santa Fe sediments north of the quadrangle, east of San Lorenzo (Kuellmer, personal communication, 1952).

Petrographically the Santa Fe iddingsite andesites resemble Bear Springs basalt. Kuellmer (1954) reports pigeonite in Santa Fe olivine andesites from San Lorenzo, New Mexico, but in Dwyer quadrangle they contain only clinopyroxene with 2V=53°, together with iddingsite, zoned orthopyroxene of composition (Mg81Fe19)SiO_3 — (Mg74Fe26) SiO_3 and zoned plagioclase (An_{58} An_{48}). Chemical analyses are given in Table 5, n. 3 and 4.

QUATERNARY SYSTEM

GENERAL STATEMENT

The distribution of Quaternary gravels is related to that of Santa Fe fanglomerates. The top of the Santa Fe formation is a nearly flat surface, which dips gently toward the Mimbres Valley. It may be depositional in origin or the result of later pedimentation. On the alluvial flats west of Cooks Range, it is undissected and covered by Recent alluvium. To the north, dissection is more advanced, but some flat areas remain between valleys with southwestward flowing streams.

West of the Mimbres fault, dissection is more mature. The cover of Santa Fe fanglomerates has been stripped off, if it ever existed.

Dissection of the Santa Fe surface took place in at least three stages. The two earlier stages led to the formation of valleys with gravel terraces at two distinct levels. The last stage caused modern streams to be entrenched as gullies in Recent alluvium. While streams were dissecting the Santa Fe surface, pediment gravels and bolson deposits spread over the remaining flat areas.

TERRACE GRAVELS AND PEDIMENT GRAVELS

Terrace and pediment gravels are widespread in New Mexico. They are well rounded, well sorted, graded, well bedded, crossbedded, and unconsolidated, and differ only in elevation from Recent alluvium. Boulders 2 feet in diameter are common.

East of the Mimbres River, gravel terraces have been found in Gallinas, Cold Springs, Hot Springs, Donahue, Juniper, Carisa, Carrizo, Gavilan, and Windmill Canyons. Their height increases northward. In the Mimbres Valley, terraces have largely been obscured by cultivation. In Windmill Draw they are only a few feet higher than the present stream and are difficult to distinguish from Recent alluvium. In Donahue Canyon the terraces are 35 feet high. In Gallinas Canyon two terraces can be recognized, about 20 and 45 feet above the valley floor, respectively.

Two terrace levels exist in many parts of the quadrangle. The lower, and younger, has been mapped as Qtg 1; the higher as Qtg 2. In the flat southwestern part of the quadrangle, two gravel pediments correspond to the two terraces. At Faywood Hot Springs, they lie on beveled volcanic rock and stand, respectively, 125 and 15-25 feet above the present-day drainage.

A gravel pediment buried underneath Recent alluvium is exposed on the western edge of the flats west of Cooks Range. It lies on beveled Santa Fe fanglomerates and is topographically higher than other terrace and pediment gravels in the quadrangle.

Interesting comparisons can be made of the compositions of Santa Fe fanglomerates, terrace and pediment gravels, and alluvium of Recent age. In the northeast part of the quadrangle, terrace gravels and alluvium are derived largely from Santa Fe fanglomerates. In the southwest part of the quadrangle, terrace and pediment gravels consist chiefly of Bear Springs basalt, but Recent alluvium contains a greater proportion of older volcanic rocks. This is due to increasing erosion and headward growth of streams.

Pediment gravels on the alluvial flats west of Cooks Range are composed largely of Bear Springs basalt. Underlying Santa Fe fanglomerates are noticeably more angular and fine grained than pediment gravels and consist mostly of Mimbres Peak rhyolite. Recent alluvium contains Rubio Peak andesite, reworked Santa Fe material, and pre-Tertiary rocks from Cooks Range.

ALLUVIUM

Alluvium is being deposited in present-day streams, and on fans west of Cooks Range. It consists of sorted, bedded, and crossbedded sands, silts, and gravels, with water-worn fragments. On bolson flats its thickness may be great. The alluvium supplies most of the ground water of the region.

Alluvium is derived locally. The Mimbres River carries a heavy load of clay and silt-size particles in the spring. Larger particles are transported during torrential summer rains. Smaller arroyos may carry boulders several feet wide for long distances in brief summer floods; in the spring they maintain a mere trickle of surface water.

TALUS

Talus accumulates on steep slopes and grades into alluvium. It has been mapped separately where it mantles underlying rocks, and where it is separable from alluvium by a break in slope.

Petrography and Stratigraphy of Tertiary Volcanic Rocks

GENERAL STATEMENT

In this chapter the stratigraphy, petrography, and primary structures of Tertiary volcanic rocks are described in stratigraphic order. Petrology and petrogenesis are described in separate sections. Certain special problems of rhyolites, common to several rhyolite formations, also are presented, under a separate heading, in order to avoid needless repetition.

DEFINITIONS

A few petrographic terms are defined below in the sense in which they are used in this bulletin. They follow the simple rock names used by Turner and Verhoogen (1951), but the dassification also corresponds fairly well with that of Johannsen (1931) and Daly (1933).

ANDESITE: A volcanic rock of intermediate composition (Si02, 52-66 percent), in which Na_20 exceeds K_20. In Dwyer quadrangle, pyroxene andesites are common in the Lower Volcanic series, and olivine andesites in the Upper Volcanic series.

BASALT: A volcanic rock of mafic (basic) composition ($Si0_2$, less than 52 percent).

IGNIMBRITE: A tuff formed by incandescent pumice particles, shards, and phenocrysts deposited from a cloud (or "nuee ardente") of hot gases. The term was coined by Marshall (1935). It is more or less synonymous with "sillar" and "welded tuff." All supposed ignimbrites in Dwyer quadrangle have rhyolitic composition.

LATITE: A volcanic rock of intermediate composition (SiO_2, 52-66 percent), in which Na_20 and K_20 are about equal.

OLIVINE ANDESITE: An andesite containing appreciable amounts of olivine or its alteration products, such as iddingsite, in addition to pyroxene and plagioclase.

PERLITE: A rhyolitic volcanic glass with perlitic fractures. Perlites contain 2-10 percent water and decrepitate into a pumicelike material on heating.

PYROXENE ANDESITE: An andesite containing appreciable amounts of pyroxene but little or no olivine or iddingsite.

RHYOLITE: A volcanic rock of felsic (acidic) composition ($Si0_2$, greater than 66 percent), in which K_20 exceeds Na20.

GENERAL STATEMENT ON FIELD RELATIONS

Volcanic rocks cover over half of Dwyer quadrangle. Being unfossiliferous, their exact age is unknown, but they are separated from underlying Cretaceous rocks and overlying late-Tertiary(?) Santa Fe fanglomerates by profound unconformities. The division into Upper and Lower Volcanic series must be regarded as tentative, until more work is done in surrounding regions.

The stratigraphic section in Table 1 is probably complete. The standard section of Tertiary volcanic rocks crops out north and northwest of Mimbres Peak. It consists of gently dipping flows, pyroclastic rocks, and detrital sediments, all being well bedded and well exposed, so that there can be no doubt as to the stratigraphic succession. The Tertiary of the entire Dwyer quadrangle west of the Mimbres fault can be related directly to the type locality simply by "walking out" all contacts. East of the Mimbres fault, some minor units are absent, but all major rock types are represented in the same stratigraphic sequence as in the type locality. Thus it was found that volcanic rocks could be correlated, on the basis of lithology, across structural complexities. In other regions, as is known, lavas of differing compositions erupted simultaneously from one volcano (Williams, 1935), but no evidence of this was found in Dwyer quadrangle.

Thicknesses of volcanic units vary greatly. A formation hundreds or even thousands of feet thick may pinch out completely within a few miles. Fortunately, exposures are excellent throughout the quadrangle, and it is possible to establish the shape and extent of most formations. Some flows were traced to intrusive sources, so that the relative ages of several intrusive bodies could be established.

Several minor volcanic formations (the Swartz, White Eagle, Fay-wood, and Pollack rhyolites) do not occur in the type locality but crop out locally east of the Mimbres fault. The Swartz rhyolite is known to be younger than any formation at the type locality, but the stratigraphic positions of the other formations are uncertain.

METHODS OF STUDYING VOLCANIC ROCKS

In classifying the volcanic rocks of Dwyer quadrangle, chemical analyses were used if available. Mineral identifications were handicapped by the fine-grained textures of volcanic rocks. Phenocrysts can be studied with the microscope, but usually they are not in equilibrium with the groundmass.

About 200 thinsections were examined. The compositions of plagioclases were determined by the Rittmann zone method, using curves for high-temperature plagioclase (Van der Kaaden, 1951). The compositions of olivines, orthopyroxenes, and clinopyroxenes were determined by the optical methods of Poldervaart (1950), Hess and Phillips (1940),

TABLE 1. GENERALIZED CENOZOIC STRATIGRAPHIC SECTION

AGE		FORMATION	LITHOLOGY	THICKNESS* (in feet)
Quaternary		Alluvium	Bolson deposits, stream gravels, etc.	0-200 +
		Terrace gravels	Stream gravels on raised terraces	0-125
		Unconformity		
Tertiary	Upper Volcanic Series	Santa Fe formation	Consolidated fanglomerates and minor andesites	0-500 +
		Unconformity, major faulting		
		Swartz rhyolite	Intrusive banded rhyolite, with associated flows, breccias, and tuffs	0-75
		Disconformity		
		Bear Springs basalt	Flows, breccias, and agglomerates	0-650 +
		Disconformity		
		Razorback rhyolite member† Razorback andesite member†	Flows, tuffs, and breccias	300-800
		Major disconformity		
	Lower Volcanic Series	Caballo Blanco rhyolite†	Pumiceous porphyritic ignimbrite	0-300
		Rustler Canyon basalt†	Flows and breccias (local)	0-50
		Box Canyon rhyolite	Massive porphyritic ignimbrite	0-75
		Mimbres Peak formation	Banded pinkish rhyolite flows and intrusive bodies, red tuff, bedded pumiceous tuff, pitchstone, perlite, and perlite breccia	0-2,500 +
		Disconformity		
		Kneeling Nun rhyolite	Rhyolitic ignimbrite	0-500
		Sugarlump rhyolite and latite	Tuffs, sandy tuffs, tuffaceous sandstones, ignimbrites, conglomerates, etc.	50-1,300
		Unconformity, faulting		
		Rubio Peak andesite and latite	Andesite and latite flows, tuffs, agglomerates, breccias, conglomerates, red sandy shale at base	600-5,000 ?
		Disconformity		
(Early Tertiary?)‡		Macho andesites	Present in Lake Valley quadrangle; probably absent in Dwyer quadrangle	
		Unconformity, Laramide faulting		

* Thicknesses given for composite extrusive-intrusive formations refer to extrusive members only.

† Interbedded with Piloncillo sediments (sandstone, fanglomerate, and conglomerate; 0-400 ft).

‡ Tertiary(?) volcanic rocks of unknown stratigraphic position: White Eagle rhyolite, Pollack rhyolite, Faywood rhyolite.

and Hess (1949). The wide range of ionic substitution in amphiboles and biotites makes it impossible to relate their optical properties to chemical composition (Hall, 1941-a, 1941-b; Vande Putte, 1939). Femic minerals are described by generalized structural formulas, which are simpler and chemically more significant than mineral names based on solid-solution series. The classification of plagioclases in terms of the end members albite and anorthite, however, is hallowed by long usage and is followed here.

The accuracy of compositions depends largely on the reliability of curves relating optical to chemical properties. For example, the compositions of clinopyroxenes are correct only if the aluminum content is assumed to be less than 2 percent (Hess, 1949).

Fourteen chemical analyses were prepared by Dr. H. B. Wiik, of Helsinki, Finland. They include 7 rocks from Dwyer quadrangle, 6 from Lake Valley quadrangle collected by Dr. H. L. Jicha, Jr., and 1 from the San Lorenzo, New Mexico, area collected by Dr. F. J. Kuellmer. An analysis of Cooks Peak granodiorite was taken from Lindgren et al. (1910).

Grain counts were made with a Chayes counter (Chayes, 1949). Normative pyroxene was calculated after the method of Barth (1931). Certain fine-grained minerals were identified with a Philips X-ray diffractometer.

LOWER VOLCANIC SERIES

GENERAL STATEMENT

The rocks of the Lower Volcanic series are a typical calc-alkaline eruptive suite, grading upward from clinopyroxene-orthopyroxenelamprobolite andesites (with andesine, labradorite, or both) to clinopyroxene-lamprobolite-andesine andesites to lamprobolite-andesine latites to sanidine-oligoclase-quartz-biotite rhyolites.

Chemical changes within the Lower Volcanic series are all gradational. Abrupt stratigraphic breaks are numerous, but they are either local (e.g., the Rubio Peak-Sugarlump contact) or not accompanied by significant changes in rock type (e.g., the erosion surface on top of the Kneeling Nun rhyolite). The rocks of the Lower Volcanic series appear to have originated from a common magma source, distinct from the source of the more calcic Upper Volcanic series (cf. p. 51).

The early(?) Tertiary Macho andesites of Lake Valley quadrangle (Jicha, 1954) appear to be missing in Dwyer quadrangle.

RUBIO PEAR ANDESITES AND LATITES

The Rubio Peak formation is named after a prominent butte located in secs. 9, 10, 15, and 16, T. 9 S., R. 10 W. It includes andesite and latite flows, agglomerates, tuffs, breccias, tuffaceous sandstones, and conglomerates. The most common colors are dark gray, brown, purple, or black, but some tuffs are light cream or green. Individual flows or tuff beds have limited extent, and no attempt has been made to map them separately. Pyroclastic rocks are as abundant as flows. Andesites tend to grade upward into latites, but there are local exceptions.

In hand specimens most latites can be identified by their black elongate lamprobolite (basaltic hornblende) phenocrysts, whereas andesites characteristically contain short greenish phenocrysts of augite.

The Rubio Peak formation crops out in a broad belt west of the Mimbres fault and in scattered outcrops east of the Cooks Range and Mimbres Hot Springs faults. Outcrop areas, approximate thicknesses, and rock types are shown in Fig. 2. The generalization that Rubio Peak pyroxene andesites grade upward into amphibole latites is shown (fig. 2) to have local exceptions. It is not known to what extent the rock-type distribution is due to eruption from different centers.

The andesites and latites fill a structural basin that reaches its maximum depth in the northwest part of Dwyer quadrangle. Faulting has broken the basin into segments that dip to the southwest.

The Rubio Peak formation is absent south of the Chino mine, at Santa Rita (Hernon, personal communication, 1952), and measures 600 feet or less in the northwest corner of Dwyer quadrangle. About 5 miles to the east (from NE¼ sec. 25, T. 18 S., R. 11 W., to SW% sec. 7, T. 18 S., R. 11 W.), the writer measured about 3,200 feet dipping 10^{0}-15° SW. Further thickening to the east is possible, but outcrops are terminated by the Mimbres fault. In the northern part of the quadrangle, the entire section consists of pyroxene andesites, but amphibole latites make their appearance at the top of the formation west of Caballo Blanco. In the Mimbres Peak area, the Rubio Peak formation probably reaches its maximum thickness. About 2,000 feet of amphibole latites was measured from SE¼ sec. 17, T. 19 S., R. 10 W., to SE¼ sec. 3, T. 19 S., R. 10 W.; they grade downward into an unknown thickness of pyroxene andesites and dip about 10° SW. Farther south, the formation again thins and consists exclusively of pyroxene andesites. Near Faywood Hot Springs, it is domed by a rhyolite plug, and underlying Paleozoic limestones are exposed. The thickness of andesites at this location probably does not exceed 600-1,000 feet, not including interbedded tuffs mapped with the Sugarlump formation. East of the Cooks Range and Mimbres Hot Springs faults, the Rubio Peak formation consists of amphibole latites dipping 30° SW.

West of the Mimbres fault, near the north boundary of Dwyer quadrangle, the Rubio Peak formation lies unconformably on an undulating surface of older rocks ranging in age from Silurian (Fusselman limestone) to Cretaceous (Beartooth quartzite). The base of the volcanic complex is a red sandy shale. Elsewhere the base of the Rubio Peak formation is not exposed.

Flows are characterized by low primary dips, the lavas evidently

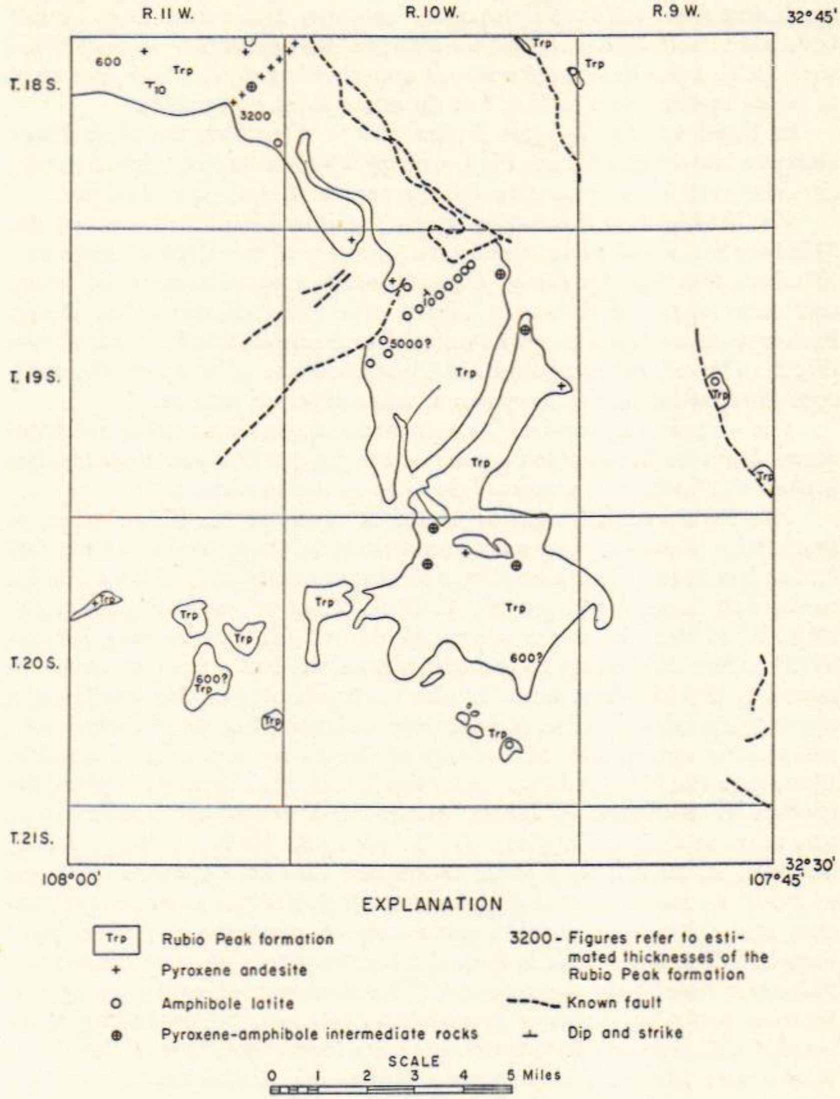


Figure 2

Map showing relative distribution of andesites and latites in the Rubio Peak formation having been rather fluid. Individual flows or breccia lenses are up to 50 feet thick. Flow breccias commonly grade into flow rock. The pyroclastic rocks consist of bedded and reworked tuffs, crystal tuffs, sandy tuffs, and conglomeratic tuffs with boulders as large as 5 feet in diameter. The conglomeratic tuffs contain subrounded fragments of all earlier flows. As a result of reworking, some tuffs resemble detrital sediments. Andesite or lathe breccias that show no evidence of reworking were deposited usually in irregular mounds or in beds of short lateral extent. Where flows overrode obstacles, such as mounds of breccia, flow folds are common. Flow rocks tend to cleave parallel to the ground over which they flowed. Vesicular and amygdaloidal structures are less abundant than in basalt.

Several dikes of pyroxene andesite, all trending to the northeast, crop out in San Jose Canyon. They cut Rubio Peak flows and interbedded Sugarlump tuffs.

TABLE 2. GRAIN COUNTS OF PYROXENE ANDESITE AND AMPHIBOLE LATITE*
(In percent)

	A†	B‡
Groundmass	77	83
Plagioclase	5	7
Orthopyroxene	1.5	n.d.
Clinopyroxene	11.5	n.d.
Lamprobolite	} 5§	7
Opaque minerals		3
	100.0	100.0

* The table illustrates differences between typical pyroxene andesites and amphibole latites. All gradations exist between the two types, and wide variations may exist in the proportions of porphyritic minerals.

† Pyroxene andesite, base of Rubio Peak formation, Dwyer quadrangle. Spec. 413 B-a 37-2. Location: SW¼SW¼ sec. 7, T. 18 S., R. 10 W.

‡ Amphibole latite, top of Rubio Peak formation, Dwyer quadrangle. Spec. 413 B-d 2. Analysis in Table 6, no. 5. Location: NE¼NE¼ sec. 17, T. 19 S., R. 10 W.

§ Includes alteration products.

Most andesites and latites are porphyritic. Phenocrysts, as large as 4.0 mm, make up 0-50 percent of the rock. The groundmass typically is fine grained (0.2 mm or less), with trachytic texture; individual mineral grains commonly are difficult or impossible to identify and measure. The proportions of different phenocryst minerals are variable, even in rocks of similar chemical composition. Grain counts, therefore, are not representative (table 2).

Visible magmatic quartz is rare, but quartz consistently appears in norms. Quartz phenocrysts may be surrounded by reaction rims of small iron-stained hornblende prisms in a matrix of spherulitic tridymite and alkali feldspar. As in the San Juan volcanic rocks, tridymite is characteristic of porous matrices of rocks containing partially resorbed quartz (Larsen et al., 1936). Deuteric and hydrothermal quartz in small veinlets are common.

Plagioclase is abundant in phenocrysts and as a groundmass mineral. The average composition of phenocryst plagioclase (An_{49}) does not appear to vary significantly throughout the andesite-latite sequence. Zoned crystals have cores as calcic as An_{62}. A few phenocrysts have unusual compositions, such a labradorite (An_{60}) found in the basal andesite flow of the Rubio Peak formation in NE% sec. 25, T. 18 S., R. 11 W. More than one type of plagioclase phenocryst may be present in a single flow, but andesine of approximate composition $_{An49}$ is in every case the most abundant. Phenocryst plagioclase is always more calcic than ground-mass plagioclase, and modal plagioclase is always more calcic than normative plagioclase.

Potash feldspar, probably in the form of sanidine, is an abundant groundmass mineral, especially in latites. One specimen, an andesite, contains a partially resorbed phenocryst of orthoclase, but it may be a foreign inclusion. Normally no sanidine phenocrysts are found in andesites or latites.

Lamprobolite is the only primary amphibole in these rocks. It is the characteristic, and in some cases only, femic mineral of the latites (pl. 5A). In some andesites it is absent; in others it is as abundant as pyroxene. Resorption of lamprobolite is almost universal. In earlier stages, magnetite forms rims around lamprobolite crystals (pl. 5A); in later stages, the entire crystal becomes a pseudomorph of magnetite. In some rocks minute clinopyroxene crystals form outside the magnetite rims, whereas in others light-green biotite replaces the cores of lamprobolite grains. Hematite commonly forms stains around magnetite. Magnetite, as pseudomorphs after lamprobolite, small grains scattered throughout the groundmass, or both, may replace lamprobolite entirely; in some latites it is the only femic mineral.

Biotite is rare and is always partly altered to magnetite. Some magnetite pseudomorphs may represent original biotite rather than lamprobolite.

Augite of average composition $(Ca_{86}Mg_{84}Fe_{30})Si_20_6$ is characteristic of andesites and is present in smaller amounts in some latites. Crystals are zoned and vary slightly in composition, but there is no evidence of systematic change of average composition with time or variations in rock type. Augite grains range in form from euhedral crystals to corroded remnants, the largest measuring 4 mm in length. Orthopyroxene crystals are smaller, more- elongate, and better formed. In the basal andesite flow in SW% sec. 7, T. 18 S., R. 10 W., the ratio of orthopyroxene to clinopyroxene is 1:7; in most other rocks orthopyroxene is even scarcer. Generally speaking, orthopyroxene is sparse in older andesites, absent or rare in younger andesites, and absent in latites. Crystals are zoned and range in composition from $(Mg_{78}Fe_{22})SiO_s$ (core) to $(Mg_{76}Fe_{24})SiO_3$ (rim). Pyroxenes, particularly orthopyroxenes, are replaced in many instances by chlorite, serpentine (antigorite?), or both. Alteration may prevent identification of orthopyroxene; consequently, the range of this mineral may have been underestimated.

Accessory iddingsite was detected in a few older andesites. Zircon, apatite, and sphene are accessory groundmass minerals in both andesites and latites. Epidote, probably deuteric, occurs in fine-grained aggregates and crystals as much as 0.1 mm in length.

Tuffs have the same phenocryst minerals as flows, but the crystals are better formed; many have a sharply angular appearance, as if they had been fractured mechanically. Groundmasses consist of uncompressed shards, vitreous in some specimens and devitrified in others. Perlitic fractures are common.

The chemical compositions of andesites and latites are given in Table 7.

SUGARLUMP LATITE AND RHYOLITE TUFFS

Sugarlump tuffs, named after a hill in NE¼ sec. 5, T. 19 S., R. 10 W., are transitional between the volcanic rocks of intermediate composition that form the lower part of the Lower Volcanic series, and the rhyolites that form its upper part. They are exposed in San Jose Canyon north of the Blue Mountain fault and beneath the rhyolite cap rock on Rocky Ridge, Mimbres Peak, Blue Mountain, and Tabletop. West and southwest of Dwyer they cover a large area.

The Sugarlump tuffs consist of many units, some local and others widespread. They include both massive and bedded pyroclastics of latitic or rhyolitic composition. Primary dips are always low. In bedded tuffs, crossbedding and small symmetrical ripple marks give the impression of reworked, water-laid material. Trails and casts of living organisms are common, but no fossils were found. At least one member shows varvelike graded bedding. Many tuffs are conglomeratic or sandy. Colors are strikingly bright, usually green or white, with occasional pink or brown layers. Several beds of massive vitric crystal tuffs 20-50 feet thick are intercalated with bedded tuffs. These beds are interpreted as ignimbrites and are described on p. 49-51. In the northwest part of the quadrangle, one of these beds forms the top of the Sugarlump formation. In the southwest part of the quadrangle, three similar units constitute the base, middle ledge, and cap rock of Tabletop.

Generally there is an angular unconformity between Sugarlump tuffs and Rubio Peak flows on the upthrown blocks of the Blue Mountain and Mimbres faults, but in downthrown blocks, or at a considerable distance from faults, the two formations are conformable. This suggests a period of faulting near the end of the lathe volcanic phase.

Locally lathe or rhyolite tuffs and latite flows are interbedded, and it is impossible to map the latite-rhyolite boundary. The boundary lies somewhere within a great thickness of fine-grained, reworked tuffs, with few recognizable mineral grains. As it is desirable to establish some sort of mappable boundary, all flows are included arbitrarily in the Rubio Peak formation, and all tuffs in the Sugarlump formation. Some inconsistency is inevitable. For example, latite tuffs at the base of the Sugarlump formation in San Jose Canyon do not differ from tuffs in SE¼ sec. 3, T. 19 S., R. 10 W., and SW% sec. 34, T. 18 S., R. 10 W., which are mapped with the Rubio Peak formation because 2,000 feet of latite flow separates them from the Sugarlump formation.

Like the Rubio Peak formation, the Sugarlump tuffs reach their maximum around Mimbres Peak and thin toward the south, north, and northwest. They are not so thick as the Rubio Peak volcanic rocks but are more persistent. At Santa Rita, where Rubio Peak andesites and lathes are absent, Sugarlump tuffs are still 200-600 feet thick.

At Sugarlump, 1,400 feet of tuffs was measured. Their top consists of cream, white, and green bedded or massive silicic tuffs; the bottom is composed largely of bedded conglomeratic tuffs of intermediate composition. The tuffs pass below into flows, breccias, and tuffs of the Rubio Peak formation, all dipping about 10° SW. Immediately north of Sugarlump, the tuffs are split into two members by several flows, the highest an amphibole lathe and the lowest a pyroxene andesite. The lower tuff member thins northward and finally pinches into discontinuous lenses not mapped apart from the Rubio Peak formation. The upper member thins to 50-300 feet but can be traced continuously to the edge of the quadrangle.

South of the Blue Mountain fault, Sugarlump tuffs lie on silicified and brecciated Rubio Peak latites with marked angular unconformity. The dip of the tuffs is up to 80° W. for a short distance from the contact. This dip may result from a small fault subsidiary to the Blue Mountain fault. Normal dips are 10° SW. Here, too, the lowest tuffs are latitic and the highest rhyolitic. The thickness is about 1,300 feet. Conglomerates, with boulders 18 inches across, are common at the base, and ignimbrites appear at the top. Farther south, tuffs and flows again are interbedded, as can be seen at the Mimbres River, near Dwyer Church, and around the Mimbres Mountain and Faywood domes. The southwest part of Dwyer quadrangle is underlain largely by horizontal bedded reworked tuffs, massive pumiceous tuffs, and cliff-forming ignimbrites of the Sugar-lump formation.

On the upthrown side of the Mimbres fault, in secs. 2, 11, and 12, T. 19 S., R. 10 W., red, brown, green, and white bedded tuffs lie on Rubio Peak andesites with strong angular unconformity. The dip of the Rubio Peak flows is less than 10° SW. At the contact the tuffs dip as much as 35° NE. but flatten to about 10° NE. within a few hundred feet. The tuffs are mapped with the Sugarlump formation, although they may belong to the Mimbres Peak formation. In the absence of Kneeling Nun rhyolite, their true position cannot be determined.

The general petrographic characteristics of the Sugarlump rhyolite tuffs are typical of all rhyolite tuffs of the Lower Volcanic series. They range from vitric crystal tuffs (25-50 percent phenocrysts) to vitric tuffs (less than 25 percent phenocrysts) (Wentworth and Williams, 1932). The groundmass is glassy, cryptocrystalline, or recrystallized, and minerals are generally unidentifiable. Angular glass shards or pumice fragments are common. They may show perlitic fractures and devitrification structures. In some of the supposed ignimbrites, glass shards are elongated and welded; in others, the entire groundmass has been recrystallized into spherulitic aggregates. Clay minerals were formed in part by decomposition of glass but appear to be primary where aggregated into lithic inclusions. The green color of certain Sugarlump tuffs results from a chlorite(?) formed by alteration or replacement of glass shards.

Phenocryst minerals in latite tuffs at the base of the Sugarlump formation are similar to those of Rubio Peak latite flows. In rhyolitic tuffs and ignimbrites they consist of quartz, sanidine, oligoclase, biotite, and minor augite and lamprobolite (or green hornblende). Grains tend to be euhedral but frequently have a sharply angular appearance, as if they had been fractured.

Plagioclase generally is a less abundant phenocryst mineral than quartz or sanidine. Normative plagioclase falls into the albite range. Modal plagioclase is zoned and varies from median andesine (cores) to calcic oligoclase (rims). Sodic sanidine (2V = 5°, sign negative) forms crystals as much as 4 mm long, which may enclose earlier crystallized plagioclase. Quartz may be euhedral but commonly is rounded and em-bayed, even where other minerals are angular or euhedral.

The dominance of biotite over amphibole probably reflects increasing K_20 and decreasing CaO. Biotite and lamprobolite are partly altered to magnetite, but less so than in andesites and lathes. Fresh biotite is pleochroic from yellow to black, deep brown, or reddish brown. Unaltered biotite and green hornblende are present in some glasses and vitric tuffs. Augite is rare, and orthopyroxene is absent.

The proportion of lithic inclusions varies greatly. Reworked Sugar-lump conglomerates consist mainly of rounded to subangular latite and andesite fragments. Fine-grained sorted tuffs are free of lithic inclusions.

KNEELING NUN **RHYOLITE TUFF**

The Kneeling Nun rhyolite is named after the Kneeling Nun at Santa Rita, a column of rhyolite that forms a well-known landmark overlooking the town.

In Dwyer quadrangle the Kneeling Nun formation consists of at least two distinct rhyolite beds. These form a cliff known as Rocky Ridge, which extends from the northwest corner of the area to Mimbres Peak, broken only by the Box Well graben. South of Mimbres Peak the escarpment is terminated by the Blue Mountain fault, but Kneeling Nun rhyolite is exposed again as the cap rock of Blue Mountain. East of the Mimbres fault, the formation is missing, except in a small area near Mimbres Hot Springs (N½ sec. 13, T. 18 S., R. 10 W.).

Kneeling Nun rhyolite is conformable with Sugarlump tuffs and could be considered their uppermost member. Because of its distinctive appearance, the Kneeling Nun rhyolite is a good stratigraphic marker and has been mapped separately. It has been interpreted as an ignimbrite (a true welded tuff) and is much thicker than any similar rock in the quadrangle. The color is a distinctive grayish purple. At the base, irregular cavities as much as 8 inches in diameter and 1½ inches high give some zones the peculiar "sheeted" appearance descriptive of the formation at Santa Rita (Kerr et al., 1951). Above the sheeted zone, columnar joints are prominently developed. Inclusions of foreign rock and angular crystal fragments are abundant in all zones. The exposures near Mimbres Hot Springs lithologically resemble Kneeling Nun rhyolite but lack sheeted zones and columnar joints; instead, they show faint horizontal banding.

The base of the Kneeling Nun rhyolite locally grades into Sugar-lump tuffs, as if the unconsolidated tuffs had been stirred up by passage of the Kneeling Nun nuee ardente. There is a characteristic break in slope between cliff-forming ignimbrite and soft tuffs. An overhanging ledge may form at the contact, and landslides are common. A slumped block of Kneeling Nun rhyolite several hundred feet long lies halfway down the northern slope of Blue Mountain, in N1/2 sec. 19, T. 19 S., R. 10 W.

Kneeling Nun rhyolite is conformable with well-bedded, ripple-marked, and crossbedded reworked Sugarlump tuffs, and must have been nearly horizontal at the time of deposition. In the comparative Tertiary stratigraphic sections (pl. 3), the base of the Kneeling Nun rhyolite was used as base level. Throughout the northwest part of the quadrangle, the formation dips about 10° SW.

Because of erosion following deposition, the thickness of the Kneeling Nun formation ranges from 200 feet, at Caballo Blanco, to about 400 feet, to the west and south. Prolonged erosion is indicated also by buried stream channels and a discolored and silicified weathered zone at the top of the formation.

The phenocryst minerals of Kneeling Nun rhyolite are similar to those of other rhyolites of the Lower Volcanic series. Grain counts are given in Table 8.

The plagioclase composition ranges from An_{25} (rims) to An_{se} (cores). The groundmass consists of radiolites and spherulites of fibrous cristobalite and feldspar, identified by X-ray diffraction. No vestiges of fragmental tufflike structures remain.

No systematic study was made of grain-size distribution, but it appears that the sizes of phenocrysts and foreign inclusions decrease within a single bed from bottom to top and from north to south. In a specimen from the top of the formation, at Caballo Blanco (NE¼ sec. 25, T. 18 S., R. 11 W.), the maximum diameter of phenocrysts is 3.0 mm, most crystals measuring less than 2.0 mm. At the bottom of the same

TABLE 3. GRAIN COUNTS OF KNEELING NUN RHYOLITE*
(In percent)

	A+	B++
Groundmass	68.9	67.5
Quartz	16.5	21.5
Sanidine	4.7	7.9
Plagioclase	7.9	1.6
Biotite	1.5	1.0
Opaque minerals	0.5	0.5
	100.0	100.0

• Data from Jicha (1954, p. 45).

+ Base of Kneeling Nun rhyolite, Dwyer quadrangle. Locality: South slope of Mimbres Peak, SE¼NW¼ sec. 17, T. 19 S., R. 10 W.

++ Kneeling Nun rhyolite, Lake Valley quadrangle; locality not given.

unit, the maximum grain size is 4.2 mm, and grains of 3.0 mm are abundant. On the east slope of Blue Mountain, 5½ miles south of Caballo Blanco, the maximum phenocryst size at the base of Kneeling Nun rhyolite is 2.6 mm, and the proportion of "fines" appears to be higher than at Caballo Blanco. The source of this rock probably lies to the north, where it reaches maximum thickness. In the Black Range, west of Kingston, a petrographically identical rock in a similar strati-graphic position reaches thicknesses of 1,300-1,800 feet. Kuellmer (1954) has mapped zones of xenoliths averaging 10-20 feet in diameter, interpreted as a vent agglomerate. This may be the source area of the Kneeling Nun rhyolite.

Phenocrysts are unsorted, but their distribution is not necessarily random. In a single thinsection, grains tend to be small in one part and relatively large in another. Oligoclase characteristically is clustered in lenses. In a specimen collected 3 miles northwest of Caballo Blanco, the lenses are as much as 25 mm long. Constituent crystals measure 2.5 mm or less. They are fractured and filled with groundmass material.

Reasons for considering this rock an ignimbrite are given on p. 49-51. A chemical analysis appears in Table 8, no. 2.

MIMBRES PEAK FORMATION

The Mimbres Peak formation derives its name from a hill located in sec. 8, T. 19 S., R. 10 W. It is made up of rhyolitic flows and their intrusive equivalents, abundant pumiceous tuffs, and local tuffaceous sandstones, conglomerates, sandy tuffs, and perlite. All rock types are genetically related. The formation does not cover large contiguous areas. Its many occurrences are all within 1 mile of a major fault. They show definite alinement along faults and generally trend to the northwest. The Box Well graben, with which the deposits on Mimbres Peak are associated, trends to the northeast.

Flow rocks and intrusive rocks have identical lithologies. In hand specimens, they show alternating gray and pink bands, 1-2 mm wide and strongly flow folded. In thinsections, they appear as fine-grained irregular aggregates of quartz, sanidine, and oligoclase, with sparse (in a few flows, abundant) phenocrysts of oligoclase (pl. 5B). Pumiceous tuffs are stratified distinctly in beds 2-6 feet thick. They are white, cream, light yellow, or pink. Lithic inclusions, mostly of silicified Mimbres Peak flow rhyolite, are plentiful, particularly in distinct conglomeratic zones. These zones can be traced for tens of feet. Where Kneeling Nun rhyolite is absent, the lower boundary of the Mimbres Peak formation has been placed at the lowest bed containing these characteristic inclusions. Tuffs below that level are mapped as Sugar-lump and Mimbres Peak formations (undifferentiated). The pumiceous tuffs contain only a few phenocrysts of quartz, oligoclase, sanidine, and green hornblende, but aggregates of yellowish-green clay (montmorillonite?), as much as 5 cm in diameter, and small fragments of perlite are common.

Intrusives of Mimbres Peak rhyolite, as much as 1 mile long and 1/2 mile wide, arc alined along all major northwestward trending faults. They were shallow seated and in many places continued on the surface as flows. Near the contacts, intrusive rhyolite generally is brecciated, showing that it must have been solid while the plug as a whole was still mobile. The contacts resemble faults in that they are brecciated and slickensided. Internally the intrusions show complex flow folds. Intrusion and extrusion of Mimbres Peak flow rhyolite invariably followed the eruption of large volumes of pumiceous rhyolite tuff. The significance of these features is discussed in the section on structural geology (p. 63). The following section may be considered typical:

TABLE 4. SECTION OF MIMBRES PEAK RHYOLITE (sec. 3, T. 19 S., R. 10 W.)

DESCRIPTION	THICKNESS (feet)
Pink-and-gray-banded flow rhyolite	160+
Massive gray spherulitic flow rhyolite	0-30
Black perlitic flow rock	0-50
Bedded pumiceous rhyolite tuffs, with fragments of silicified rhyolite	60
Bedded tuffs and tuffaceous sandstones	150+
Total	450±

The lowest member may belong to the Sugarlump tuffs. This sequence is common to most deposits along the Mimbres and Mimbres Hot Springs fault zones. Some units may be lacking locally. Elsewhere greater variations exist. In SE¼ sec. 34, T. 18 S., R. 10 W., and NW¼NW¼ sec. 12, T. 19 S., R. 10 W., crudely bedded red tuffs are welded locally into perlitic glass. Flow rhyolites are unknown in this area, but dikes and plugs are abundant. On Mimbres Peak, bedded pumiceous tuffs are overlain by 100 feet or more of perlite breccia in a pumiceous matrix, capped in a few spots by perlite flows. In the Box Well graben, about 15 feet of perlite flow rock and 35 feet of spherulitic devitrified perlite cap the perlite breccia. In Box Canyon, pumiceous tuffs are overlain by a few feet of tuffaceous sandstone and conglomerate, with fragments of perlite and silicified rhyolite. Pumiceous tuffs disappear 1 mile north of Box Well, but tuffaceous sandstones continue to the head of Box Canyon. Similar rocks separate Kneeling Nun and Box Canyon rhyolites as far south as the Blue Mountain fault.

On the west wall of Box Canyon (sec. 6, T. 19 S., R. 10 W.), the Mimbres Peak formation lies on an irregular surface of silicified Kneeling Nun rhyolite. On Rocky Ridge, just north of the Box Well graben, several pockets of Mimbres Peak tuffs have been preserved in old stream channels cut in Kneeling Nun rhyolite.

The 600+ feet of bedded pumiceous tuffs exposed in Donahue Canyon is correlated with the Mimbres Peak formation on the basis of structure, lithology, and the position of this unit above Kneeling Nun rhyolite at Mimbres Hot Springs. The tuffs dip 30° SW. and are capped and intruded by flow rhyolites.

A thick sequence of rhyolite tuffs and flows is exposed in the northeast corner of the quadrangle. Dips of 70° SW. are common. Widespread brecciation and slickensiding indicate that the regional structures are complex. In the absence of marker horizons, it was not possible to measure sections, but thicknesses of 2,500 feet or more are not improbable. The rocks are of several different types; many are identical with those on Mimbres Peak. Their base is not exposed, and they are capped by Pollack rhyolite. In Lake Valley quadrangle they are capped locally by Razorback andesite, indicating that they belong to the upper part of the Lower Volcanic series and that they are probably equivalent to the Mimbres Peak formation.

BOX CANYON RHYOLITE TUFF

Box Canyon rhyolite is found only in the upper 4 miles of Box Canyon, but similar rocks occupy the same stratigraphic horizon near Santa Rita (Hernon, personal communication, 1952). The largest outcrop is on the southeast slope of Mimbres Peak, where its thickness is about 75 feet. It also forms a cliff on the western wall of Box Canyon, north of the Blue Mountain fault. Isolated and fractured blocks occur in the Blue Mountain fault zone near Piloncillo, indicating an underground extension at least 1 mile west of Box Canyon. To the south, outcrops of Box Canyon rhyolite are terminated by the Blue Mountain fault; to the north, the unit ends abruptly in a cliff now buried by Caballo Blanco tuff.

Throughout its occurrences the Box Canyon rhyolite forms a plate 40-75 feet thick. It lies conformably on Mimbres Peak rhyolite, except in its northernmost exposures, where it lies on Kneeling Nun rhyolite.

The Box Canyon rhyolite tuff is a typical ignimbrite or welded tuff.

Its structure is massive, its color cream, gray, or pink. Microscopically its groundmass consists of glass shards in early stages of devitrification, about .02 mm long, strongly compressed and welded together, giving the rock unusual toughness. Phenocrysts of quartz, sanidine, oligoclase, and biotite are abundant, as are lithic inclusions as much as 3 cm in diameter. The inclusions are less resistant to weathering than the groundmass, and their decay gives the rock a characteristic pitted appearance.

RUSTLER CANYON BASALT

This basalt is named after Rustler Canyon, in the northwest corner of the quadrangle. Basalts at this stratigraphic level are confined to two localities. On the west side of Box Canyon, for about ¼ mile north of the Box Well graben, a single amygdaloidal flow about 18 feet thick is separated from Box Canyon rhyolite by a covered zone about 55 feet thick. In one place 15 feet of basalt breccia is exposed beneath the flow, which is covered by Piloncillo sediments.

The other occurrence of Rustler Canyon basalt is a small lens in secs. 20 and 21, T. 18 S., R. 11 W., consisting of vesicular and amygdaloidal flows, flow breccias, and minor sandy tuffs between Kneeling Nun and Caballo Blanco rhyolites. Its maximum thickness is 50 feet. According to Hernon (personal communication, 1952), the unit is widespread south of Santa Rita.

The rock is black, vesicular, and finely crystalline. It contains sparse flakes of iddingsite. Some vesicles are filled with opaline silica. Under the microscope it resembles Bear Springs basalt.

CABALLO BLANCO RHYOLITE TUFF

Almost everywhere in Dwyer quadrangle the Lower Volcanic series is capped by a porphyritic rhyolite tuff interpreted as an ignimbrite. The name Caballo Blanco is taken from a mountain in secs. 25 and 36, T. 18 S., R. 9 W. Deposits east and west of the Mimbres River may have been continuous at one time, but it is possible that they erupted from different sources. All occurrences have a common stratigraphic position at the top of the Lower Volcanic series, and a similar lithology. Locally the formation may represent several successive eruptions.

The rock is white, cream, or light gray. Phenocrysts of quartz, sanidine, oligoclase, and biotite, as much as 4 mm in diameter, make up 25-35 percent of the rock. The matrix is partly pumiceous and less compact than that of the Kneeling Nun or Box Canyon rhyolites. In part it consists of drawnout, compressed, and welded glass shards. De-vitrification ranges from fine featherlike crystallites to spherulitic or axiolitic areas that obscure the original shard structure. Locally Caballo rhyolite contains sparse geodelike hollow spheres, as much as 8 inches in diameter, composed on the outside of hardened tuff and lined on the inside with opaline silica. Lithic inclusions are common.

Columnar joints are well developed, especially in the middle part of the formation (pl. 6D). West of Caballo Blanco the basal 6-12 inches of tuff is usually compressed and dense.

The Caballo Blanco rhyolite tuff readies its maximum thickness of 325 feet at Caballo Blanco. It thins to the west and pinches out toward the south, near Box Well. The thickness depends on erosion of the upper surface and slight irregularities in pre-Caballo Blanco relief. Throughout the northwest part of Dwyer quadrangle, the tuff dips about 10° SW.

East of the Mimbres River, the Caballo Blanco rhyolite tuff is exposed in secs. 24, 25, and 36, T. 18 S., R. 11 W., and secs. 19 and 30, T. 19 S., R. 9 W. In Donahue Canyon its thickness is about 250 feet. It pinches out toward the north; to the south, it is covered by Santa Fe fanglomerates. The prevailing dip is 30° SW.

The Caballo Blanco rhyolite is found in several places in the Mimbres fault zone, but all outcrops are small because of complex structures.

UPPER VOLCANIC SERIES

GENERAL STATEMENT

Eruption of the calcic Upper Volcanic series began at a time when talc-alkaline volcanism of the Lower Volcanic series had become feeble. The last members of the Lower Volcanic series (Mimbres Peak, Box Canyon, and Caballo Blanco rhyolites) represent local eruptions, each followed by long periods of quiescence, erosion, and local deposition of Piloncillo sediments.

There is a marked chemical difference between rocks of the Lower and Upper Volcanic series. In the former the most mafic rocks are pyroxene andesites, and the most felsic rocks calc-alkaline rhyolites. In the Upper Volcanic series, on the other hand, the most mafic rocks are olivine basalts, and the most felsic rocks rhyolites considerably richer in CaO than those of the Lower Volcanic series. (In table 8, compare analyses 1-3 with analyses 4-6.) The felsic members of both series are here called rhyolites, in order to maintain a simple nomenclature.

In the field it is easy to see the striking contrast between light-colored rhyolites of the Lower Volcanic series and dark-colored rocks of the Upper Volcanic series. In Dwyer quadrangle, the contact is irregular and marked locally by Piloncillo gravels; in Lake Valley quadrangle, it is unconformable (Jicha, 1954, p. 47). The chemical difference between these rocks is equally clear (pl. 8F, fig. 5). Nevertheless, there was a certain overlap in time between the two volcanic suites. The first basalt (Rustler Canyon basalt) appeared before the last major talc-alkaline rhyolitic eruption (Caballo Blanco rhyolite tuff). Small patches of light-colored rhyolite tuff are found in a few places interbedded with rocks of the Upper Volcanic series (NW¼ sec. 22, T. 18 S., R. 10 W., and

SW¼ sec. 17, T. 18 S., R. 10 W.). The oldest member of the Upper Volcanic series (Razorback andesite member) appears to be a hybrid basalt, or andesite contaminated by assimilation of silicic material.

A slight overlapping of two volcanic suites does not present a theoretical problem, if they are assumed to have originated from separate and independent sources. This contention will be amplified in the section on petrogenesis (p. 51).

RAZORBACK ANDESITE AND RHYOLITE

The Razorback formation consists of two superficially similar members, the lower an andesite, and the upper a rhyolite that is close to being a trachyte or latite. Both are black or dark gray and fine grained, in contrast with the white or cream rhyolites of the Lower Volcanic series.

The formation is named after a mountain in sec. 36, T. 18 S., R. 11 W. In the northwest part of Dwyer quadrangle, it lies on an irregular surface of Caballo Blanco rhyolite; near Box Well, on Piloncillo sediments. In the Mimbres fault zone, the formation lies on Caballo Blanco rhyolite; east of the fault, it lies on beveled rhyolites of the Mimbres Peak and Caballo Blanco formations.

The andesite and rhyolite members are associated in most cases, but the andesite is absent west of Mimbres Peak, and the rhyolite is missing in the Donahue Canyon area. In NW¼ sec. 22, T. 18 S., R. 10 W., the two units are separated by 20-30 feet of light-colored rhyolite tuff breccia and a few feet of coarse stream-channel conglomerate.

The total thickness of both members varies between 300 feet west of Mimbres Peak, at least 700 feet at Caballo Blanco, and 800 feet or more in Donahue Canyon. Surprisingly, the Razorback formation is absent at Santa Rita (Kerr et al., 1950; Hernon, personal communication, 1952), although fully developed in the northwest part of Dwyer quadrangle.

Razorback andesite is dark gray to black, except for small red hematite strains. Megascopically the rock has an aphanitic groundmass and sparse phenocrysts of quartz, plagioclase, and iddingsite.

The andesite occurs as alternating flows and breccias. The flows tend to split into slightly irregular layers 2 to 3 inches thick, parallel to the surface over which the andesitic lava flowed. This structure will here be called "flow layering." Locally the rock is vesicular. North of Box Well, and west of Caballo Blanco, its base consists in many instances of as much as 50 feet of red breccia, with angular or subrounded fragments as large as 5 feet in diameter. In most of its primary structures Razorback andesite resembles Rubio Peak andesite.

The only known source of Razorback andesite is located in sec. 19, T. 18 S., R. 10 W. It is a dike about 1 mile long and 30 feet wide trending to the northwest. Petrographically it is identical with flow rock.

Microscopic examination of Razorback andesite reveals that it is probably a hybrid rock. Its fine-grained groundmass is made up of andesine (An_{40}), clinopyroxene, iddingsite (2V small, na = 1.690, of = 1.725, ny = 1.730), orthopyroxene, and opaque minerals. Deuteric(?) epidote is present in some specimens. The grain sizes of all groundmass minerals are usually 0.1-0.2 mm. Sparse phenocrysts of andesine-labradorite and amphibole altered to magnetite are less than 1 mm long. Making up about 5 percent of the rock, and more prominent than the phenocrysts, are aggregates of plagioclase and quartz, interpreted (pl. 5C, D) as small foreign inclusions (xenocrysts). Quartz is the later mineral, filling spaces between euhedral plagioclase. Both minerals show evidence of disequilibrium with the groundmass. The plagioclase, zoned from An_{40} (core) to An_{28} (rim), is rounded by resorption. Its mantle is cloudy and is surrounded in some cases by a narrow clear rim of more calcic plagioclase. The quartz is rounded, embayed, and surrounded by reaction rims of clinopyroxene (pl. 5D). Similar clinopyroxene is scattered throughout the groundmass.

Several lines of evidence suggest that these inclusions are xenocrysts of subsurface origin. They are not a local anomaly, being found in all specimens of Razorback andesite, some collected as far as 20 miles apart, including those of Lake Valley quadrangle (Jicha, 1954). They are not sand grains picked up at the surface, since they occur also in a dike of Razorback andesite in sec. 19, T. 18 S., R. 10 W. Xenocrysts in dike rocks show the same degree of resorption as in flows, proving that they are not ordinary phenocrysts resorbed by changes in physical condition upon extrusion.

In all other volcanic rocks of Dwyer quadrangle, phenocrysts are more mafic than their groundmass. This is to be expected, since lavas are quenched at an early stage of crystallization, and reactions between phenocrysts and magma are not carried to completion. Razorback andesite alone shows the reverse, having inclusions of oligoclase-andesine and quartz in a matrix containing intermediate andesine and iddingsite. In no other rock in the area is modal (xenocrystic or phenocrystic) plagioclase more sodic than normative plagioclase. Magnesian olivine (or iddingsite) and quartz, here associated, never form together under equilibrium conditions.

A chemical analysis of Razorback andesite is given in Table 5, no. 5. The possible origins and significance of the xenoliths are discussed in the section on petrogenesis (p. 56).

The rhyolite member of the Razorback formation consists of black fine-grained trachytic, aphanitic, or glassy rock characterized by vitreous luster and perlitic or spherulitic structures. Like Razorback andesite, it is flow layered, but the layers are thinner (½-1 inch) and more regular.

The base of the Razorback rhyolite consists in most cases of a breccia of black perlitic glass. The fragments measure as much as 5 feet across. Although predominantly angular, in NE¼NE¼ sec. 21, T. 18 S., R. 10 W., they are pillow shaped.

The fragmental base is succeeded usually by a spherulitic zone (pl. 6B) as much as 10 feet thick. Exceptional spherulites measure 7 inches across.

Flow-layered rocks overlie spherulitic zones. In most cases they are intensely folded where lava met an obstacle, such as a pile of breccia, but such flow folds are able to form wherever friction forces layers into tight recumbent folds. These may be sheared by continued movement, so that a new set of layers develops (pl. 6C).

Green fine-grained and powdery tuffs are associated with Razorback rhyolite east of the Mimbres fault. They grade upward into perlitic fragmental rock overlain by perlitic or banded glass flows. These usually are followed by spherulitic and flow-cleaved rhyolite. The sequence from tuff to breccia to flow rock may be repeated a number of times. White pumiceous tuffs similar to those of the Lower Volcanic series are interbedded locally with flows, breccias, and contemporaneous Piloncillo gravels.

No source of Razorback rhyolite has been found.

Microscopically Razorback rhyolite is very different from other rhyolites of Dwyer quadrangle. The groundmass may consist in part of brown microlitic glass; minerals include oligoclase (na = 1.540, nß = 1.548), potash feldspar, orthopyroxene, minor clinopyroxene, and magnetite. Grain sizes are generally below 0.2 mm and often below 0.1 mm. A few larger crystals, commonly less than 1.0 mm long, consist of zoned oligoclase-andesine (core, An_{41}; rim, An_{29}), pseudomorphs of magnetite after amphibole, and sparse orthopyroxene of composition $(Mg_{80}Fe_{20})SiO_3$. Lamprobolite is rare, even as cores of magnetite. The predominance of orthopyroxene over clinopyroxene may be related to low CaO and $A1_20_3$. If biotite ever existed, it was altered entirely to magnetite. Other groundmass minerals are probably of late stage or deuteric. These include tridymite and an amphibole which forms fine green slightly pleochroic needles with extinction angles of 27 degrees. The texture of the rock is trachytic.

A chemical analysis of Razorback rhyolite is given in Table 8, no. 5. It is more sodic and less potassic than other rhyolites of Dwyer quadrangle, being on the boundary of the rhyolite, latite, and trachyte rock classes.

BEAR SPRINGS BASALT

The type locality of Bear Springs basalt is in Lake Valley quadrangle, in sec. 25, T. 18 S., R. 9 W. (Jicha, 1954). In Dwyer quadrangle it is composed of flows, breccias, agglomerates, conglomerates, and, rarely, chocolate-colored sandy tuffs. Its groundmass is gray to black, dense, holocrystalline, and fine grained. In vesicular or amygdaloidal material, small reddish-brown iddingsite flakes are abundant. Massive rocks may contain olivine. Amygdules consist of calcite or silica. Opal is a common secondary mineral in scoriaceous rocks.

The tops, and in some places the bottoms, of Bear Springs basalt flows are scoriaceous, fragmental, and reddish. Vesicular and amygdaloidal rock is more abundant than massive material. Flow folds, flow banding, or flow layering, ubiquitous in rhyolites and common in andesites and latites, are absent, probably because of the high fluidity of basaltic lava.

West of the Mimbres fault, Bear Springs basalt spread over large areas with low initial inclination. Ash is almost absent. East of the Mimbres fault, in and near S1/2 sec. 23, T. 18 S., R. 10 W., accumulation of ejecta around a volcanic vent resulted in steep primary dips. Flows and pyroclastic beds, 4-5 feet thick, alternate. Fine tuffs are sparse, but bombs as large as 18 inches in diameter are common. The twisted teardrop shape of the bombs, and their drawnout vesicles, indicate a viscous state at the time of eruption. Older rocks at this location dip about 30° SW., but the basalts dip 33° SE. The dip parallels the alinement of vesicles in flows.

Basaltic dikes, probably feeders of flows, occur in NE¼ sec. 34, T. 18 S., R. 11 W., and SE¼ sec. 27, T. 18 S., R. 11 W. In this area dozens of dikes appear, all maintaining a trend between N. and N. 55° E. The largest dikes are lens shaped or pipelike, and are as much as 1,000 feet long and 100 feet wide. Most dikes are only a few feet wide. Other basalt or andesite dikes crop out on both sides of Donahue Canyon, in Ey2 sec. 25, T. 18 S., R. 10 W. They trend northeast. The largest is 500 feet long and 15-30 feet wide.

About 650 feet of basalt was measured near the mouth of Tom Brown Canyon, where it is capped by Swartz rhyolite. Elsewhere the full thickness is unknown, as the top has been eroded. To judge from the outcrop pattern and the abundance of basalt gravels, 650 feet must be considered a conservative estimate.

Bear Springs basalt is black, fine to medium grained, and holocrystalline; rarely porphyritic. The chief minerals are plagioclase, clinopyroxene, rhombic pyroxene, magnetite, olivine, and iddingsite. Grains commonly are alined, owing to flowage. The average length of ground-mass plagioclase is 0.1-0.3 mm. Exceptional crystals reach 1.3 mm; almost all are zoned, their average composition being $An_{53}\pm_2$, with variations between An_{43} and An_{63}. Clinopyroxene and magnetite grains, 0.01-0.04 mm in diameter, are interstitial to plagioclase crystals. Clinopyroxene crystals occasionally are as large as 1.5 mm. Their average composition is $(Ca_{88}Fe_{30}Mg_{82})Si_20_6$. Rhombic pyroxene, composition $(Mg_{70}Fe_{30})SiO_3$, forms grains as long as 0.6 mm in rims around olivine and iddingsite, and scattered throughout the groundmass; they appear to have been formed by a reaction of magma and olivine. Unaltered olivine is common in massive rocks; in vesicular and amygdaloidal material, it is altered to iddingsite. In Bear Springs basalt, the indices of refraction of iddingsite are $n\alpha = 1.722$, $n\beta = 1.759$, and $n\gamma = 1.764$. The composition of olivine is $(Mg_{77}Fe_{23})_2SiO_4$. According to Edwards (1938) and Ross and Shannon (1925), the alteration of olivine to iddingsite is deuteric, involving hydration and oxidation of ferrous to ferric iron. The two minerals are found in euhedral and subhedral grains 0.2-2.0 mm long; in a few rocks olivine forms phenocrysts (pl. 5E). In basalt dikes olivine is fresh or slightly serpentinized, but iddingsite is absent. In a dike that marginally fused Caballo Blanco rhyolite, in NE% sec. 34, T. 18 S., R. 11 W., magnetite is the only femic mineral. Amygdules in basalt are filled with calcite or chalcedony and frequently are lined with cristobalite and a fibrous zeolite.

A chemical analysis of Bear Springs basalt is shown in Table 5, no. 2. The rock is a relatively silicic basalt, belonging to the group of rocks often called "basaltic andesites."

SWARTZ RHYOLITE

The Swartz rhyolite is named after a small abandoned settlement near the junction of Tom Brown Canyon and the Mimbres River. It is a local formation, found only in secs. 26, 27, 34, 35, 36, T. 18 S., R. 10 W. Angular unconformities separate it from Bear Springs basalt below and Santa Fe fanglomerates above.

Structurally Swartz rhyolite resembles Mimbres Peak rhyolite. Flows, tuffs, and breccias are associated with one or more domelike rhyolite intrusive bodies and small dikes. A smoothly curved intrusive contact with Bear Springs basalt is exposed in NE¼ SE¼ sec. 26, T. 18 S., R. 10 W. Rhyolite breccias, pumiceous tuffs, and light-colored glasses occur nearby. Small rhyolite flows and breccias occur west of the bridge crossing the Mimbres River, in sec. 26, T. 18 S., R. 10 W. Cemented breccias cap Bear Springs basalt in NE% sec. 34 and W½ sec. 35, T. 18 S., R. 10 W.

The rhyolite consists of alternating brown and gray bands, about 3 mm wide, containing crystals of sanidine, quartz, and plagioclase. Flow folds are common. Intrusive rocks and surface flows have identical lithologies. Under the microscope, the phenocrysts appear in a cryptocrystalline groundmass. A chemical analysis is shown in Table 8, no. 6.

VOLCANIC ROCKS OF UNCERTAIN AGE

GENERAL STATEMENT

The White Eagle, Faywood, and Pollack rhyolites occur in isolated areas and are not interbedded with volcanic rocks of known strati-graphic position; hence their relative ages are unknown. The White Eagle and Faywood rhyolites resemble Mimbres Peak rhyolite and may be of the same age, but the Pollack rhyolite is different from all other volcanic rocks in the area.

WHITE EAGLE RHYOLITE

The White Eagle rhyolite is named after the White Eagle mine, in sec. 34, T. 19 S., R. 9 W. It forms many dikes in Precambrian granite, as much as 1 mile long and 50 feet wide. Sills as thick as 56 feet occur in Bliss quartzite. Flows cap Precambrian granite gneiss northwest of the White Eagle mine. The rock is aphanitic, cream colored, flow banded, and flow folded, with slickensides on the surfaces of flow bands. It contains sparse phenocrysts of quartz and feldspar. Petrographically it resembles Mimbres Peak rhyolite. In dikes and at the bottoms of flows, rounded inclusions of Precambrian granite gneiss are common, the largest being 10 feet long. Zones of white spherulites as much as 3 feet thick mark the margin of most dikes and sills and of some zones within larger intrusive bodies. Individual spherulites are about 1.5 mm in diameter and are set in a fine-grained green groundmass. In the White Eagle mine, dikes of White Eagle rhyolite are weakly mineralized.

FAYWOOD RHYOLITE

Two domelike plugs of cream-colored, fine-grained, flow-layered rhyolite, about 11/4 miles long, are exposed in the southwest part of Dwyer quadrangle. One forms Mimbres Mountain, in an otherwise flat area in secs. 17, 18, 19, 26, T. 20 S., R. 10 W. Flow lines in the plug are complex but tend to be vertical. Horizontal rhyolites to the east may be a flow related to the intrusion. The other plug is located near Fay-wood Hot Springs, in secs. 15, 16, 21, 22, T. 20 S., R. 11 W. It does not stand out topographically and is covered largely by gravels.

Formations intruded by Faywood rhyolite are domed. Both plugs intrude Rubio Peak flows and Sugarlump tuffs, here interbedded. They must be younger than the Sugerlump formation and older than terrace gravels. Petrographically and structurally, they resemble domelike intrusives of the Mimbres Peak formation.

POLLACK RHYOLITE

The Pollack rhyolite is named after Pollack Creek in Lake Valley quadrangle. In Dwyer quadrangle this unit is found only in the northeast corner. It consists of about 400 feet of flows, locally glassy at the base. Glass grades into finely crystalline rock across a spherulitic zone. All rock types contain phenocrysts of quartz, sanidine, oligoclase, and biotite. Sanidine phenocrysts are as long as 12 mm. The rock is purplish gray. Stratigraphically it lies above Mimbres Peak rhyolite and below Santa Fe fanglomerates. In Lake Valley quadrangle it is overlain by Razorback andesite (Jicha, 1954).

A chemical analysis is shown in Table 8, no. 4. The rock is a rhyolite close to the latite boundary.

MINOR DIKES

The Vista intrusive, in sec. 21, T. 19 S., R. 9 W., is terminated to the south by a dike of rhyolite porphyry. It is three-quarters of a mile long in an east-west direction and several hundred feet wide. On the south side it is bordered by Precambrian crystalline rocks. The age is unknown. Phenocrysts of quartz, oligoclase, and magnetite are set in a pink groundmass. The rock is strongly sericitized. It resembles rhyolites of the Lower Volcanic series and is cut by minor fluorite veins, which explain the alteration.

Throughout Cooks Range there are many minor dikes and sills. Some of these appear to be related to the Cooks Peak granodiorite porphyry; others are altered diabases and rhyolites. Their ages are unknown.

Hypabyssal Intrusive Rocks

COOKS PEAK GRANODIORITE PORPHYRY

The Cooks Peak granodiorite porphyry is one of many similar intrusions in southwestern New Mexico. It is younger than the Colorado shale and older than the Rubio Peak volcanic rocks. It consists of porphyritic andesine (AN80) as much as 4 mm long and green hornblende partly altered to biotite and chlorite. The groundmass consists of andesine, quartz, orthoclase partly altered to sericite, and magnetite. A chemical analysis is given in Table 7, no. 6. Where the granodiorite porphyry is in contact with limestone, it contains patches of hornblendite, probably resorbed xenoliths.

VISTA MONZONITE OR GRANODIORITE PORPHYRY

An altered igneous rock of unknown age is exposed west of the Cooks Range fault, in sec. 21, T. 19 S., R. 9 W., near the Vista fluorite mine. Primary structures are obscured by alteration, but the grain sizes decrease toward the margins of the outcrop. This suggests that the rock is a small plug rather than a flow.

The rock is grayish green and contains sericitized oligoclaseandesine phenocrysts ranging from 1.5 to 3.0 mm. Ferromagnesian minerals are replaced entirely by chlorite aggregates, with or without quartz and magnetite. The groundmass is altered to sericite beyond recognition of the the original minerals and textures.

The rock is fractured strongly and cut by quartz-potash feldspar (adularia?)-fluorite veins. Alteration is probably related to mineralization.

Petrology and Petrogenesis

CHEMICAL PETROLOGY

BASALTS AND OLIVINE ANDESITES

Basalts and olivine andesites are confined to the Upper Volcanic series; only the Rustler Canyon basalt occupies, exceptionally, a position in the upper part of the Lower Volcanic series.

In Dwyer quadrangle, iddingsite and olivine are found in volcanic rocks containing up to 59 percent $Si0_2$. Rocks containing less than 52 percent SiO_2 are termed basalts, and those containing 52-59 percent $Si0_2$ are termed olivine andesites. The Bear Springs and Rustler Can-

TABLE 5. ANALYSES OF BASALTS AND OLIVINE ANDESITES*
Chemical analyses (oxide percentages)
(Analyst: H. B. Wiik, Helsinki, Finland; except no. 1)

	1	2	3	4	5
SiO_2	49.87	51.17	53.55	57.75	58.13
TiO_2	1.38	2.00	1.44	1.00	0.99
Al_2O_3	15.96	14.43	15.09	15.75	15.98
Fe_2O_3	5.47	4.49	3.01	5.61	3.85
FeO	6.47	5.90	5.46	2.01	3.16
MnO	0.32	0.17	0.16	0.11	0.10
MgO	6.27	6.43	5.72	3.13	3.79
CaO	9.09	8.33	8.22	6.14	6.00
Na_2O	3.16	3.05	2.90	3.81	3.53
K_2O	1.55	1.62	1.84	2.62	2.61
P_2O_5	0.46	0.55	0.35	0.33	0.45
H_2O+	—	1.68	1.14	0.85	0.97
H_2O-	—	0.19	0.28	0.57	0.50
CO_2	—	0.00	0.71	0.00	0.00
Total	99.90	100.01	99.87	99.68	100.06
		Norms			
		2†	3	4	5
Quartz		3.30	6.42	12.29	10.27
Orthoclase		9.45	10.56	15.20	17.60
Albite		25.68	24.63	33.13	30.04
Anorthite		20.85	22.80	17.65	19.20
Wollastonite		6.96	4.76	5.16	2.40
Enstatite		16.10	14.30	10.73	12.67
Ferrosilite		4.09	5.41	—	1.07
Magnetite		6.50	4.41	2.17	3.20
Ilmenite		3.80	2.75	1.77	1.73
Apatite		1.34	0.67	0.61	1.57
Calcite		—	1.60	—	—
Total		98.07	98.31	98.71	99.75
Normative plagioclase		An_{45}	An_{48}	An_{35}	An_{39}
CIPW class		III 544	II 544	II 434	II 444

TABLE 5. ANALYSES OF BASALTS AND OLIVINE ANDESITES (CONTINUED)
Modes (by volume)

	2	3	4	5
Quartz	—	—	—	pres.‡
Plagioclase	45	57	pres.	pres.
Pyroxene	37§	31‖	pres.§	pres.§
Olivine	5	1	—	—
Iddingsite	2	3	pres.	pres.
Opaque minerals	11	6	pres.	pres.
Modal plagioclase	An_{48-63}	An_{43-53}	An_{45-55}	An_{40}** An_{28-40}‡

*1. Average of 198 analyses; from Daly (1933).

2. Bear Springs basalt, Dwyer quadrangle. Spec. 413 A-b 2. Location: West of Mimbres River, SE¼SE¼ sec. 22, T. 18 S., R. 10 W.

3. Andesite or basalt interbedded with Santa Fe fanglomerates, near San Lorenzo, N. Mex. Location SW¼SE¼ sec. 8, T. 17 S., R. 10 W. Data supplied by F. J. Kuellmer.

4. Andesite interbedded with Santa Fe fanglomerates, Dwyer quadrangle. Location: SE¼ sec. 27, T. 18 S., R. 9 W.

5. Andesite member of Razorback formation, ¼ mile north of Dwyer quadrangle. Location: San Juan Canyon, SE¼ sec. 7, T. 18 S., R. 10 W.

† From Jicha (1954, p. 51).

‡ Xenocrysts.

§ Includes orthopyroxene and clinopyroxene.

‖ Pigeonite.

** Groundmass plagioclase.

TABLE 6. RATIO OF DEGREE OF FRACTIONATION IN BASALTS AND OLIVINE ANDESITES

ROCK	PERCENT SiO_2	$\frac{FeO + Fe_2O_3 \times 100}{FeO + Fe_2O_3 + MgO}$
Bear Springs basalt	51.2	61.7
Santa Fe andesite	53.6	59.6
Santa Fe andesite	57.8	70.9
Razorback andesite	58.1	64.9

yon formations are considered borderline basalts. Olivine andesites occur in the Razorback formation and in the Santa Fe formation, interbedded with fanglomerates. A few pyroxene andesites of the Lower Volcanic series also contain accessory iddingsite. Table 5 shows that all these rocks are near the basalt-andesite boundary. Besides olivine and/or iddingsite, all contain labradorite, augite, rhombic pyroxene, and magnetite.

CaO is in excess over alkalis in Bear Springs basalt and Santa Fe olivine andesite from San Lorenzo. Alkalis are slightly in excess over CaO in the Santa Fe olivine andesite from Dwyer quadrangle and in Razorback andesite, both believed to be contaminated (see pl. 5C, D and accompanying text). Na_20 exceeds K_20 in all the rocks. Generally the ratio $Fe0+Fe_20_3\times100$: $FeO+Fe_20_{3+}MgO$ increases with

SiO_2 content. Because of assimilation of SiO_2 by Santa Fe andesite (Kuellmer, personal communication, 1952) and Razorback andesite, the increase is irregular (table 6). Wager and Deer (1939) and Poldervaart (1949) hold that this ratio indicates the degree of fractionation of basaltic magma.

Comparison of analyses 4 and 5, Table 5, shows the andesite member of the Razorback formation to be almost identical with Santa Fe olivine andesite. Comparison of analyses 4 and 5, Table 5, with analysis 3 of the same table shows that certain members of the Upper Volcanic series do not differ much from the most mafic members of the Lower Volcanic series.

PYROXENE ANDESITES AND AMPHIBOLE LATITES

In Dwyer quadrangle, pyroxene andesites and amphibole latites occur together in the Rubio Peak formation. The andesites tend to grade upward into latites (fig. 2). They form a series marked by increasing K_2O and decreasing CaO and MgO. Chemical variations are paralleled by changes in the proportions of phenocryst minerals. Iddingsite is sparsely present in a few older andesites. Enstatite of composi-

TABLE 7. ANALYSES OF ANDESITES AND LATITES*

Chemical analyses (oxide percentages)
(Analyst: H. B. Wiik, Helsinki, Finland; except no. 1, 6)

	1	2†	3†	4†	5	6†
SiO_2	60.35	61.28	59.37	62.43	61.88	62.95
TiO_2	0.78	0.51	1.01	0.70	0.45	0.67
Al_2O_3	17.54	16.58	16.17	16.50	16.46	15.91
Fe_2O_3	3.37	2.49	4.49	4.32	3.48	3.30
FeO	3.17	1.58	1.20	0.43	0.72	1.37
MnO	0.18	0.06	0.07	0.08	0.10	0.08
MgO	2.78	1.76	3.00	1.78	1.66	2.18
CaO	5.87	5.42	5.12	4.55	4.75	4.46
Na_2O	3.63	4.10	3.46	4.10	4.08	4.05
K_2O	2.07	3.47	2.81	2.87	4.00	2.95
P_2O_5	0.26	0.25	0.36	0.29	0.25	0.18
H_2O+	—	1.36	1.80	1.52	0.59	1.19
H_2O-	—	1.09	0.86	0.86	0.73	0.72
CO_2	—	—	—	—	1.02	—
BaO	—	—	—	—	—	0.03
SrO	—	—	—	—	—	0.03
Total	100.00	99.95	99.72	100.43	100.17	100.07

Norms

	2†	3†	4†	5	6†
Quartz	12.58	14.70	16.50	27.13	16.56
Orthoclase	20.57	16.68	17.24	21.07	17.79
Albite	34.58	29.34	34.58	32.33	34.06
Anorthite	16.68	20.29	18.07	10.53	16.40
Wollastonite	3.36	0.93	0.81	1.22	2.09
Enstatite	4.40	7.50	4.50	5.14	5.50
Ferrosilite	—	—	—	—	—

TABLE 7. ANALYSES OF ANDESITES AND LATITES * (CONTINUED)

	2†	3†	4†	5	6†
Magnetite	3.71	1.16	—	0.73	2.55
Ilmenite	0.91	1.98	1.06	0.61	1.37
Apatite	0.67	1.01	0.67	0.24	0.34
Hematite	—	3.68	4.32	0.98	1.60
Titanite	—	—	0.39	—	—
Total	97.46	97.27	98.14	99.98	98.26
Normative plagioclase	An_{33}	An_{41}	An_{34}	An_{25}	An_{33}
CIPW class	II 424	II 424	I 424	I 423	II 424

* 1. Average of 87 andesites. From Daly (1933).

2. Macho andesite (or calcic latite), Lake Valley quadrangle. Spec. 414 A 140 A. Location: SE¼SW¼ sec. 20, T. 19 S., R. 7 W. Mineral composition: Andesine, labradorite, sanidine(?), augite, hypersthene(?), apatite, magnetite, hematite, altered amphibole(?), minor iddingsite.

3. Rubio Peak andesite (or calcic latite), Lake Valley quadrangle. Spec. 414 115 E. Location: NE¼NE¼ sec. 18, T. 18 S., R. 7 W. Mineral composition: Andesine, sanidine(?), augite, hypersthene(?), opaque minerals, lamprobolite, quartz, and secondary quartz veinlets.

4. Rubio Peak andesite, Lake Valley quadrangle. Spec. 414 A 128 E. Location: SE¼NE¼ sec. 36, T. 18 S., R. 8 W. Mineral composition: Andesine, sanidine(?), magnetite pseudomorphous after amphibole and biotite(?), minor augite.

5. Rubio Peak latite, Dwyer quadrangle. Spec. 413 B-d 2. Location: NE¼NE¼ sec. 17, T. 9 S., R. 10 W. Mineral composition: Andesine, sanidine(?), lamprobolite, opaque minerals.

6. Cooks Peak granodiorite. See Lindgren et al. (1910, p. 39). Analyst: George Steiger, U. S. Geological Survey.

† From Jicha (1954, p. 50-51).

tion $(Mg_{76\text{-}78}Fe22\text{-}24)SiO_3$ is associated with augite in the oldest andesites, is absent or rare in younger andesites, and is absent in latites. This coexistence of orthopyroxene and clinopyroxene supports current theories on the femic reaction series (Poldervaart and Hess, 1951). Augite of average composition $(Ca_{8e}Mg_{84}Fe_{30})Si_20_6$ is characteristic of andesite but is absent in some latites. It lies slightly on the calcic side of the crystallization curve of basaltic clinopyroxenes (Hess, 1949). Lamprobolite, or pseudomorphs after lamprobolite, is characteristic of latites but is present in most andesites also. It is the only primary amphibole. The proportion of pyroxene to amphibole seems to vary directly with MgO content (table 7), in agreement with the theory of Kennedy (1935). Larsen et al. (1936) use the escape of water from lava flows to explain the widespread resorption of lamprobolite and the formation of magnetite and minor amounts of biotite and clinopyroxene. No evidence for inversion of green hornblende to lamprobolite was found.

The optical properties of enstatite, augite, and lamprobolite phenocrysts do not vary significantly among specimens collected at different stratigraphic levels. Owing to zoning, greater variations exist within individual crystals. Chemical variations evidently caused changes in the proportions of femic phenocryst minerals, but not in the composition of particular minerals. This is not unexpected, because phenocrysts are derived only from the early stages of crystallization and are usually out of equilibrium with the groundmass.

Plagioclase phenocrysts are strongly zoned, but average compositions

TABLE 8. ANALYSES OF RHYOLITES*

Chemical analyses (oxide percentages)

(Analyst: H. W. Wiik, Helsinki, Finland; except no. 1)

	1	2†	3†	4†	5	6
SiO_2	73.89	71.23	76.50	66.07	66.63	70.61
TiO_2	0.49	0.44	0.12	0.48	0.59	0.40
Al_2O_3	13.69	12.72	11.46	16.11	14.57	12.32
Fe_2O_3	1.47	2.72	1.12	2.96	2.48	3.85
FeO	0.90	0.72	0.43	0.29	1.51	0.14
MnO	0.08	0.06	0.09	0.07	0.06	0.04
MgO	0.38	0.55	0.25	0.92	0.96	0.61
CaO	1.22	1.49	0.68	3.50	2.72	2.00
Na_2O	3.43	3.50	3.43	3.21	3.94	3.32
K_2O	4.53	4.81	4.46	4.24	4.04	5.25
P_2O_5	0.08	0.12	0.02	0.20	0.49	0.16
H_2O+	—	0.83	0.63	1.38	1.05	0.70
H_2O-	—	0.49	0.33	1.11	0.64	0.05
CO_2	—	—	—	—	—	0.07
Total	100.16	99.68	99.52	100.54	99.68	99.52

Norms

	2†	3†	4†	5	6
Quartz	30.12	38.15	22.56	17.99	37.30
Orthoclase	28.36	26.13	25.02	29.21	29.89
Albite	29.34	28.82	27.25	34.53	19.02
Anorthite	3.06	2.78	16.68	9.30	8.15
Corundum	—	—	0.10	—	—
Wollastonite	1.81	0.23	—	1.86	0.82
Enstatite	1.40	0.60	2.30	3.19	2.04
Ferrosilite	—	—	—	—	—
Magnetite	1.39	1.39	—	1.86	0.41
Ilmenite	0.76	0.15	0.76	1.06	0.68
Apatite	0.46	—	0.34	0.86	0.27
Hematite	1.76	0.16	3.04	0.13	1.43
Rutile	—	—	0.08	—	—
Normative plagioclase	An_9	An_9	An_{38}	An_{21}	An_{30}
CIPW class	I 412	I 412	I 422	I 423	I 323

* 1. Average of 126 rhyolites, including 24 liparites. From Daly (1933).

2. Kneeling Nun rhyolite, Dwyer quadrangle. Spec. 413 B-d 2-1. Locality: SE¼NW¼ sec. 17, T. 19 S., R. 10 W.

3. Mimbres Peak rhyolite, Lake Valley quadrangle. Spec. 414 A Tr-McK. Locality: McKinney ranch, Lake Valley, N. Mex.

4. Pollack rhyolite or quartz latite, Lake Valley quadrangle. Spec. 414 B Tgl-Tp. Locality: NW¼ sec. 7, T. 18 S., R. 8 W.

5. Razorback rhyolite, Dwyer quadrangle. Spec. 413 A-b 1. Locality: SE¼SE¼ sec. 22, T. 18 S., R. 10 W.

6. Swartz rhyolite, Dwyer quadrangle. Spec. 413 A-b 4. Locality: Donahue Canyon, NE¼NE¼ sec. 35, T. 18 S., R. 10 W.

† From Jicha (1954, p. 50-51).

are approximately An_n throughout the andesite-latite sequence. Normative plagioclase ranges from An_{25} to An_{41} and is always more sodic than modal plagioclase. The proportions of plagioclase to potash feldspar and free silica are unknown, because potash feldspar and free silica are contained entirely in the fine-grained groundmass. Quartz and potash feldspar are abundant in norms.

RHYOLITES

Rhyolites cap the Lower Volcanic series, grading downward into latites and andesites. Compared with latites and andesites, rhyolites have more $Si0_2$ and K_20, somewhat less Na_20, and considerably less of all other ingredients (table 8, no. 2, 3; table 7, no. 3, 4, 5). As a result of these chemical changes, biotite takes the place of lamprobolite, and oligoclase the place of andesine. Quartz and sanidine, present only in the groundmasses of intermediate rocks, form phenocrysts in rhyolites; usually they are more abundant than plagioclase. The plagioclase composition varies among different rock types and in individual zoned crystals, but the average compositions are near the oligoclase-andesine boundary.

High concentrations of volatile constituents in rhyolitic magmas of the Lower Volcanic series are indicated by the abundance of hydrous ferromagnesian minerals, ignimbrites, perlite and pumice, and hydro-thermal veins and alteration products.

In the Upper Volcanic series, the Swartz rhyolite (table 8, no. 6) is more mafic than rhyolites of the Lower Volcanic series, although it has a high $Si0_2$ content. Its CaO content is higher; consequently its plagioclases are more calcic (about An_n). MgO and FeO Fe_20_3 are also higher. The Pollack rhyolite or quartz latite (table 8, no. 4), of unknown stratigraphic position (possibly part of the Upper Volcanic series), is similar to the Swartz rhyolite. The Razorback rhyolite lies on the boundary of the rhyolite, latite, and trachyte classes. Compared with rhyolites of the Lower Volcanic series, it contains significantly more $FeO+Fe_20_3$, MgO, and CaO, slightly more Na_20, slightly less K_20, and considerably less $Si0_2$. K_20 is only slightly in excess of Na_20. As a consequence, potash feldspar and free silica (in the form of tridymite) are confined to the groundmass, and amphibole, largely replaced by magnetite, takes the place of biotite. Orthopyroxene is more abundant than clinopyroxene, probably because the ratio of CaO to MgO and $FeO+Fe_20_3$ is low.

If compared with the revised average chemical compositions of igneous rocks compiled by Nockolds (1954), the rhyolites of the Lower Volcanic series correspond to talc-alkaline rhyolites, and those of the Upper Volcanic series to dellenites.

INTRUSIVE ROCKS

The Cooks Peak granodiorite porphyry is the only intrusive igneous rock from Dwyer quadrangle that has been analyzed chemically (table

7, no. 6). It is older than the oldest volcanic rocks of the region (Macho and Rubio Peak andesites) but is remarkably similar chemically.

Unlike chemically similar andesites, Cooks Peak granodiorite porphyry contains visible orthoclase and quartz in the groundmass, and green hornblende rather than lamprobolite. Its modal plagioclase (andesine, An_{40}) is fairly close to its normative plagioclase (An_n). The porphyry evidently crystallized under conditions closer to equilibrium than did the volcanic rocks.

SPECIAL PROBLEMS OF RHYOLITES ORIGIN

AND ALTERATION OF RHYOLITIC GLASSES

Rhyolitic glasses of Dwyer quadrangle appear to have been formed by marginal chilling of rhyolite magmas, by fusion of tuffs during deposition, and by fusion of rhyolites along the borders of basalt dikes. These glasses are altered by spontaneous devitrification, replacement, or hydrothermal alteration. Their possible commercial uses are discussed on p. 72.

Chilled zones of black perlitic glass are common at the bases of Mimbres Peak rhyolite flows and the margins of intrusions. They are as much as 50 feet thick and three-quarters of a mile long. Similar, but smaller, glassy zones are found in the Pollack, Razorback, and Swartz rhyolites.

Glassy borders usually grade into crystalline rock by way of an intermediate spherulitic zone. In Membres Peak rhyolite, the spherulites do not show perlitic cracks, are undeformed by flowage, and commonly center around a phenocryst (pl. 5F). This suggests that they formed after the rock had ceased to flow, but before it had cooled sufficiently to develop perlitic shrinkage cracks.

The spherulites have radial-fibrous internal structures. Cristobalite (a metastable mineral) and a feldspar were identified by X-ray diffraction, confirming findings of Rogers (1921) and Hurlbut (1936). By comparison, ordinary crystalline rhyolite consists of quartz and feldspars. The spherulite zone thus forms a metastable transition between the glass and the main body of stable microcrystalline rhyolite. A few spherulites also occur within the glass, possibly the result of spontaneous devitrification.

Spherulites in the Razorback rhyolite vary in diameter from 0.1 to 200.0 mm but usually are 10 mm or less. They differ from the spherulites just described in that they lack radial internal structures, but are so heavily stained that details cannot be determined. Flow lineation of feldspar laths is unaffected by spherulites, which, again, developed after flowage had virtually ceased. The spherulites, however, commonly are flattened vertically, and spherulitic zones may be offset slightly by cleavages formed during flow. The lava must have retained slight mobility after the spherulites had formed (pl. 6B, C).

Partial replacement by a network of cryptocrystalline silica(?) vein-lets is common in black perlite basal to Mimbres Peak rhyolite flows (pl. 7A). Heavy staining makes microscopic identification of fine-grained veinlet minerals impossible. This type of replacement is distinct from the progressive hydrothermal alteration described later in this section.

Plates 7B and 7C illustrate the formation of perlitic glass by fusion of a tuff. Plate 7B shows the tuff, a member of the Mimbres Peak formation collected in NE¼SW¼ sec. 34, T. 18 S., R. 10 W. It is bedded and has abundant foreign inclusions, mostly concentrated in distinct conglomeratic zones. The rest of the rock consists of about 5 percent quartz, oligoclase, and sanidine phenocrysts in a cryptocrystalline groundmass so stained with hematite that its minerals are unidentifiable. However, the groundmass is fragmental in structure. Many fragments, as long as 1 inch, are lighter colored than the hematitic matrix. They show flow banding parallel to the bedding and are irregular in shape, as if they had been viscous at the time of deposition and had flowed slightly. In other fragments, small spherulites and perlitic cracks indicate that they passed through a glassy phase.

Plate 7C shows a glassy fades of the same tuff (pl. 7B). The glass forms lenses as much as 30 feet thick and one-half mile long, not necessarily at the base of the tuff. It contains the same bedding, fragmental structure, and foreign inclusions as the normal rock. The fragments are now perlitic glass, clear under the microscope and black in hand specimens. The matrix also is glassy but is so full of minute cavities as to be opaque under the microscope and brown in hand specimens.

All gradations exist as between tuffs (pl. 7B) and glasses (pl. 7C). In a few places vitrification is more advanced than is shown in Plate 7C, and the entire rock becomes a homogeneous perlitic glass, clear in thin-sections and black in hand specimens. Only relics of fragmental structure remain, but phenocrysts and foreign inclusions are unchanged.

Perlitic glasses formed by vitrification of tuffs characteristically undergo alteration, presumably hydrothermal, along quartz veinlets.

In NW¼SE¼ sec. 34, T. 18 S., R. 10 W., black perlitic glass is cut by fine-grained quartz veinlets, 1-6 inches wide, trending northwest. Black perlite is altered to a massive red rock for 5 feet or less on both sides of quartz veinlets. Alteration is probably hydrothermal. To the northeast the perlite borders on a large area of similar red rock. Most minerals of the hydrothermally altered rock are too fine grained for optical identification. Quartz and feldspar were identified by X-ray methods, in contrast with cristobalite and feldspar, characteristic of the transitional zone between glasses and crystalline flow rock. Changes in bulk composition are unknown.

Plates 7D, 7E, and 7F show progressive hydrothermal alteration of black perlite near a quartz veinlet 6 inches wide. The three specimens illustrated were collected 5, 4, and 2 feet, respectively, from the same veinlet. They show alteration from perlitic glass to a yellowish- or reddish-stained fine-grained crystalline material, fibrous in appearance under the high-power objective, and identified as quartz and feldspar by X-ray diffraction.

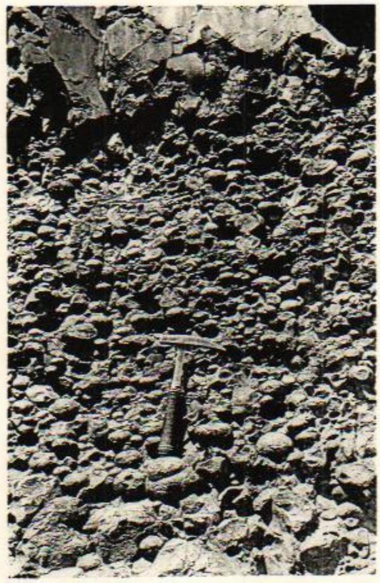
Similar alteration along quartz veinlets occurs in NW¼ sec. 12, T. 19 S., R. 10 W. Plate 4 is a planetable map of this area. Black perlite, which here overlies cream-colored bedded crystal tuffs, is a vitrified fragmental tuff (pl. 8A) and contains abundant rhyolitic inclusions. A rhyolite dike and a small rhyolite plug intrude perlite and crystal tuffs. The hydrothermally altered perlite in Plate 4 is identical with that shown in Plate 7F. A more advanced stage in alteration occurs adjacent to quartz veinlets, where the altered zone is particularly wide. In hand specimens it resembles gray rhyolite flow rock but lacks flow banding. In thinsection it is a completely recrystallized fine-grained growth of irregular quartz and feldspar, showing only remnants of perlitic and fragmental structures (pl. 8C). Also shown in Plate 4 are xenoliths of rhyolite flow rock as much as 14 feet in diameter. Their flow structures are oriented randomly relative to the structures of the fresh and altered perlite, showing that the xenoliths actually are foreign bodies and not another form of alteration. They are surrounded by rims of red altered tuff, a recrystallized form of the perlite. In some outcrops the tuff fragments are parallel to the contact with the xenolith. Similar xenoliths and altered rims have been described in detail by Kuellmer (1954). They occur in a tuffaceous rhyolite (probably equivalent to the Kneeling Nun rhyolite), a few miles north of Dwyer quadrangle.

Glasses can form also as the result of fusion of rhyolite by basic dikes. In the center of sec. 25, T. 18 S., R. 10 W., just north of Donahue Canyon, an andesitic or basaltic dike about 500 feet long and 15-30 feet wide cuts tuffs of the Mimbres Peak and Caballo Blanco formations. Some 2-5 feet of rhyolite was fused. Pumiceous tuff of the Mimbres Peak formation fused into gray perlite; Caballo Blanco rhyolite, into light-gray glass without megascopic perlitic fractures, but with abundant phenocrysts. Locally 2 feet of silicified and recrystallized rhyolite with marked vertical cleavage developed between the dike and the glass. Glass grades into unaltered tuff over 1-3 feet of red indurated rock. The dike is decomposed by weathering or deuteric alteration. Plagioclase is on the andesine-labradorite boundary, and femic minerals have been altered to chlorite and iron oxides.

Similar features appear in NE¼ sec. 34, T. 18 S., R. 11 W., and SE¼ sec. 27, T. 18 S., R. 11 W., where olivine basalt dikes as much as 40 feet wide cut Caballo Blanco and Kneeling Nun rhyolite. Here also phenocrysts were affected by alteration. Biotite is replaced by magnetite for about 17 feet from the contact. Within 5 feet of the dike, sanidine is

Plate 5. Photomicrographs of volcanic rocks.

A



B

C

D

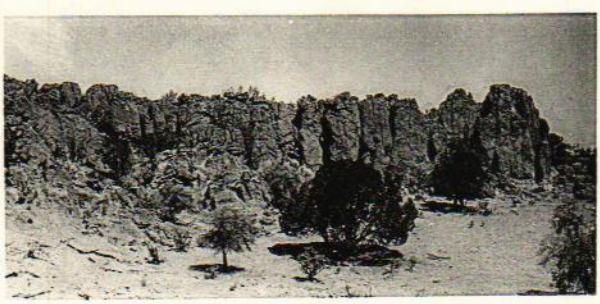


Plate 6. Special features of volcanic rocks.

A B C D E F

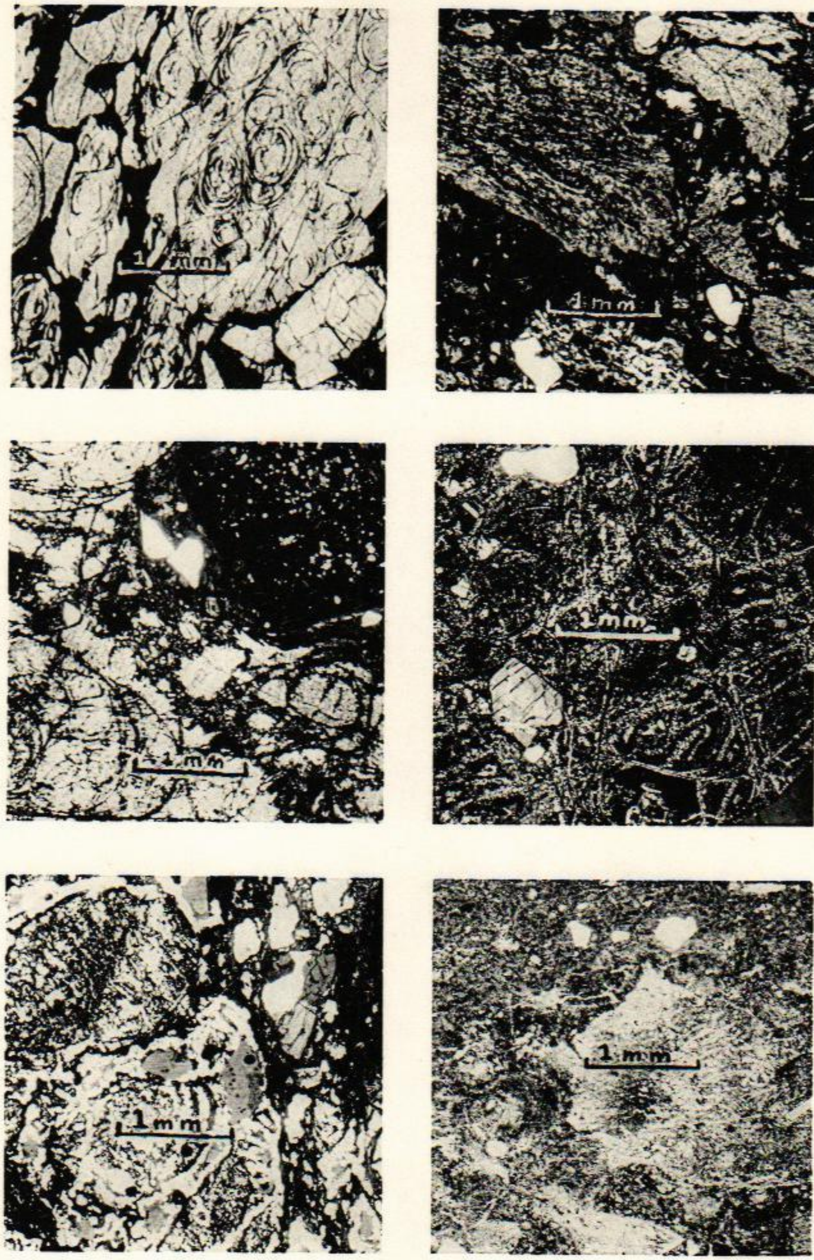
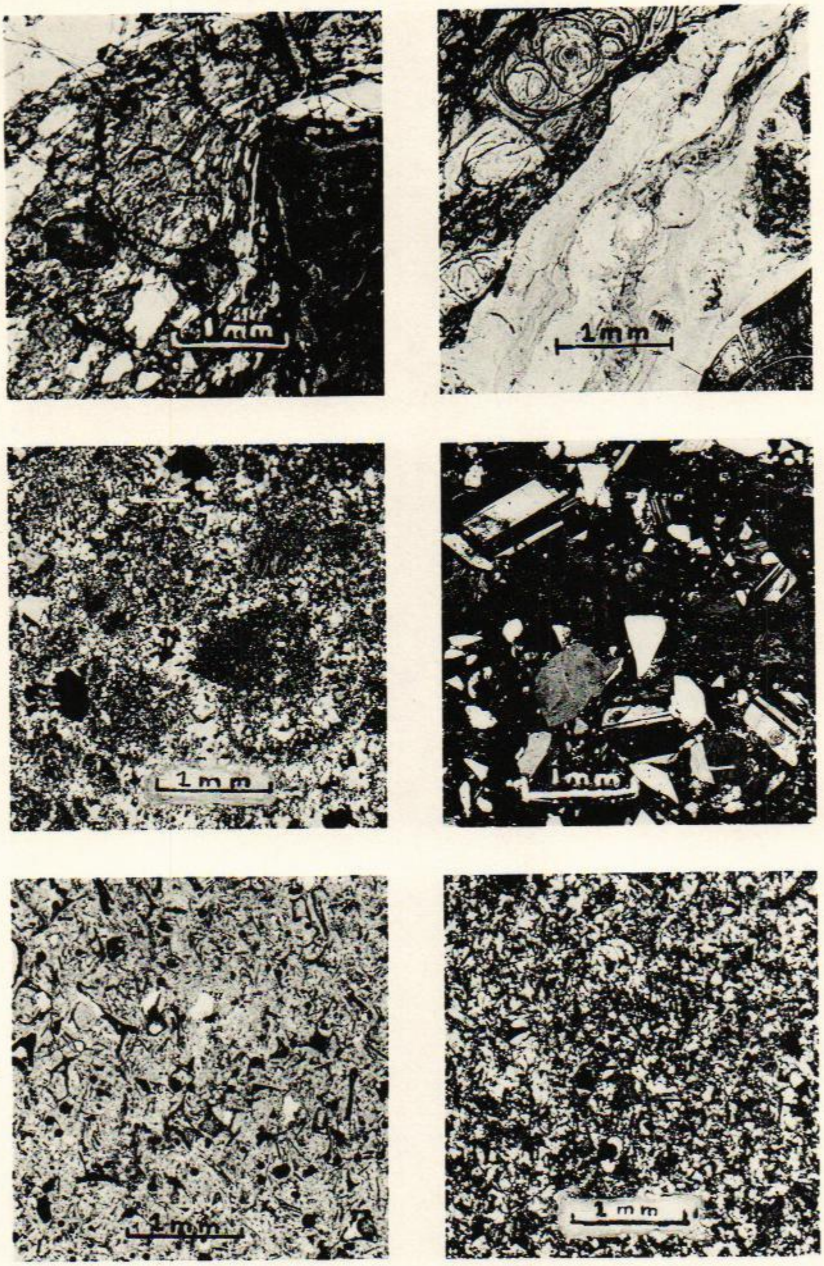


Plate 7. Photomicrographs of perlitic volcanic rocks.



A B C D E F

Plate 8. Photomicrographs of perlitic and fragmental volcanic rocks.

replaced marginally and along fractures by brownish cloudy zones, 0.1 mm wide, with indices of refraction greater than sanidine.

IGNIMBRITES

The upper part of the Lower Volcanic series is characterized by zones of rocks interpreted as ignimbrites (welded tuffs). They resemble ignimbrites in Alaska, Idaho, California, Oregon, the Lesser Antilles, Peru, New Zealand, Queensland, and elsewhere.

Ignimbrites are defined as silicic tuffs formed by incandescent pumice particles, shards, and phenocrysts suspended in clouds of hot gases, the "nuées ardentes" of Lacroix (1904). In Dwyer quadrangle and surrounding areas, the ignimbrites are sheetlike bodies of low primary dip (usually about 1 degree), 10-200 feet thick, and covering areas ranging from a few outcrops to tens or even hundreds of square miles.

Ignimbrites are characterized by abundant phenocrysts, banding ("cutaxitic" structure), lithic inclusions, columnar joints, and lack of sorting. The groundmass may consist of almost uncompressed shards or pumice fragments, more or less indurated and recrystallized (Fenner, 1937, 1948), of shards drawn out and welded together, or of glass showing only relics of welded shards. All gradations exist among these types; the degree and type of welding appear to depend on temperature, pressure, and the presence of volatile materials. The welding tends to be more intense near the bottom of individual deposits. Devitrification structures are common. Structures and textures of ignimbrites are discussed by Marshall (1935). Since not all these rocks are welded, the writer prefers the term ignimbrite ("fiery cloud rock"), coined by Marshall (1935), to the term welded tuff.

The Kneeling Nun, Box Canyon, and Caballo Blanco rhyolites, and several members of the Sugarlump formation, are interpreted as ignimbrites. In the previous section it was shown that bedded tuffs of the Mimbres Peak formation may also be fused or welded into perlitic glass, but these glasses are local and have textures very different from the more widespread ignimbrites. They may represent a type of rock intermediate between true ignimbrites and true windblown tuffs.

Ignimbrites showing a high degree of welding and crystallization are resistant to erosion and form cliffs, such as Rocky Ridge. Spheroidal weathering along vertical joints results in the formation of isolated columns of rock, such as the Kneeling Nun, at Santa Rita. A group of columns, known as the "City of Rocks," is a well-known tourist attraction, located around NW¼ sec. 10, T. 20 S., R. 11 W. The rock is an ignimbrite of the Sugarlump formation, the same that also forms the base of Tabletop and the cliff on both sides of the Mimbres River in SE½ sec. 6, T. 20 S., R.10 W.

When first mapped in adjacent areas, rocks such as the Kneeling Nun rhyolite were described as lava flows (Paige, 1916). The properties of these rocks are incompatible, however, with those of flows or ash falls. Rhyolitic lava is viscous; yet these deposits spread over tens of miles, with an original slope estimated at only 100 feet per mile (Paige, 1933). High fluidity cannot be ascribed to volatile materials dissolved in lava, since there is no evidence of vesicular structures. The structure is fragmental, but size sorting is less than in ordinary windblown tuffs. Windblown tuffs are not welded. The alinement of fragments in ignimbrites suggests some form of flowage.

Petrographically the matrix of most ignimbrites consists of glass shards and pumice fragments more or less compressed, fused, and devitrified. In the Caballo Blanco and Box Canyon rhyolites, the shards can be distinguished plainly and appear as narrow, drawnout, curved, branching, and imperfectly alined bands as much as 0.02 mm long and 0.002 mm wide. The Caballo Blanco rhyolite also contains lenses of less compressed pumice. Devitrification begins with the development of double rows of fine fibrous crystals growing inward from opposite margins of drawnout shards. This texture is termed "pectinate" by Marshall (1935). In more advanced stages, the fibres gain in length and width, entirely replacing the original glass. The shards now become axiolites; that is, strongly elongated spherulites. In tuffs showing the most advanced stages of devitrification (Kneeling Nun rhyolite and some Sugarlump ignimbrite members), fibres transgress fragment boundaries and develop into radiolites (i.e., bundles of radiating fibres) or spherulites (pl. 8D). Fibrous minerals are colorless to brown. They have low birefringence and indices of refraction below balsam. In the Kneeling Nun rhyolite, cristobalite and a feldspar were detected by X-ray diffraction. According to Fenner (1937, 1948), tridymite and alkali feldspars, particularly sanidine, are typical.

An unusual ignimbrite of the Sugarlump formation is located in secs. 29 and 32, T. 19 S., R. 10 W. It is a single bed of exceptionally tough rock, about 25 feet thick and reddish brown. Columnar joints and randomly distributed foreign inclusions are present, as in most ignimbrites. Under the microscope, the groundmass consists of sharply angular and uncompressed shards (pl. 8E). Examination with crossed nicols shows that the shards are recrystallized into irregular equidimensional grains of alkali feldspar and quartz (p1. 8F), identified by X-ray diffraction. This tuff resembles those described by Fenner (1937, 1948) as having been indurated by the action of hot residual gases. Phenocrysts (plagioclase, biotite, and augite) make up less than 2 percent of the rock. Other welded tuffs of the Kneeling Nun or Caballo Blanco type belong to the category of crystal vitric tuffs (phenocrysts, 25-50 percent).

The occurrence of quartz in the matrix of hydrothermally indurated tuffs contrasts with that of cristobalite in welded tuffs of the Kneeling Nun type. It is analogous to the occurrence of quartz in hydrothermally altered black perlite, and of cristobalite in transition zones between flow rhyolite and black perlite. Apparently the metastable mineral cristobalite typically occurs wherever there is transition from the unstable glassy state to the stable crystalline state.

PETROGENESIS

GENERAL STATEMENT

Dwyer quadrangle appears to offer a more complete record of volcanism in southwestern New Mexico than any other known area. About two-thirds to three-quarters of its volcanic rocks belong to the Rubio Peak and Razorback formations, both of intermediate composition. These two formations pinch out toward the northwest and are absent in the well-known Santa Rita area. Intermediate rocks thus occupy a subordinate position at Santa Rita, so that petrogenic theories based on Santa Rita alone would give an unbalanced view. On the other hand, the hypabyssal rocks that characterize the Santa Rita area are not exposed in Dwyer quadrangle. This quadrangle, therefore, is an excellent area for investigating the volcanic phases of magmatic activity, but not for studying the earlier intrusive phases.

Since Dwyer quadrangle is only a small part of an incompletely known volcanic province, and since the entire subject of petrogenesis is controversial, this section admittedly is largely speculative. Nevertheless, some tentative conclusions may be of help in understanding the volcanic history of this and surrounding quadrangles.

A Harker variation diagram of volcanic rocks of Dwyer quadrangle (fig. 3) shows a lime-alkali index of about 56. The suite falls on the border of the calcic and calc-alkaline classes of Peacock (1931). Actually, there may be two unrelated suites, the older being calc-alkaline and the younger more calcic. Regarded by itself, the Lower Volcanic series is typically cart-alkaline. It shows continuous progression from clinopyroxene-orthopyroxene-lamprobolite andesites (with andesine labradorite, or both) to clinopyroxene-lamprobolite-andesine andesites to lamprobolite-andesine latites to sanidine-quartz-oligoclase-biotite rhyolites. The trend of the calcic Upper Volcanic series is less constant and not obviously related to that of the Lower Volcanic series (fig. 5). There is good evidence of a stratigraphic break corresponding to the petrologic discontinuity.

LOWER VOLCANIC SERIES

Peacock (1931), among many other writers, pointed out the correlation between orogeny and eruption of talc-alkaline magmas. The Lower Volcanic series of Dwyer quadrangle is unusual in that a thick and typically orogenic volcanic suite developed in an area where geosynclinal subsidence was slight and deformation mostly by high-angle faulting. Synorogenic magmatism was less than batholithic, but the difference in age between intrusive and effusive rocks (late-Cretaceous

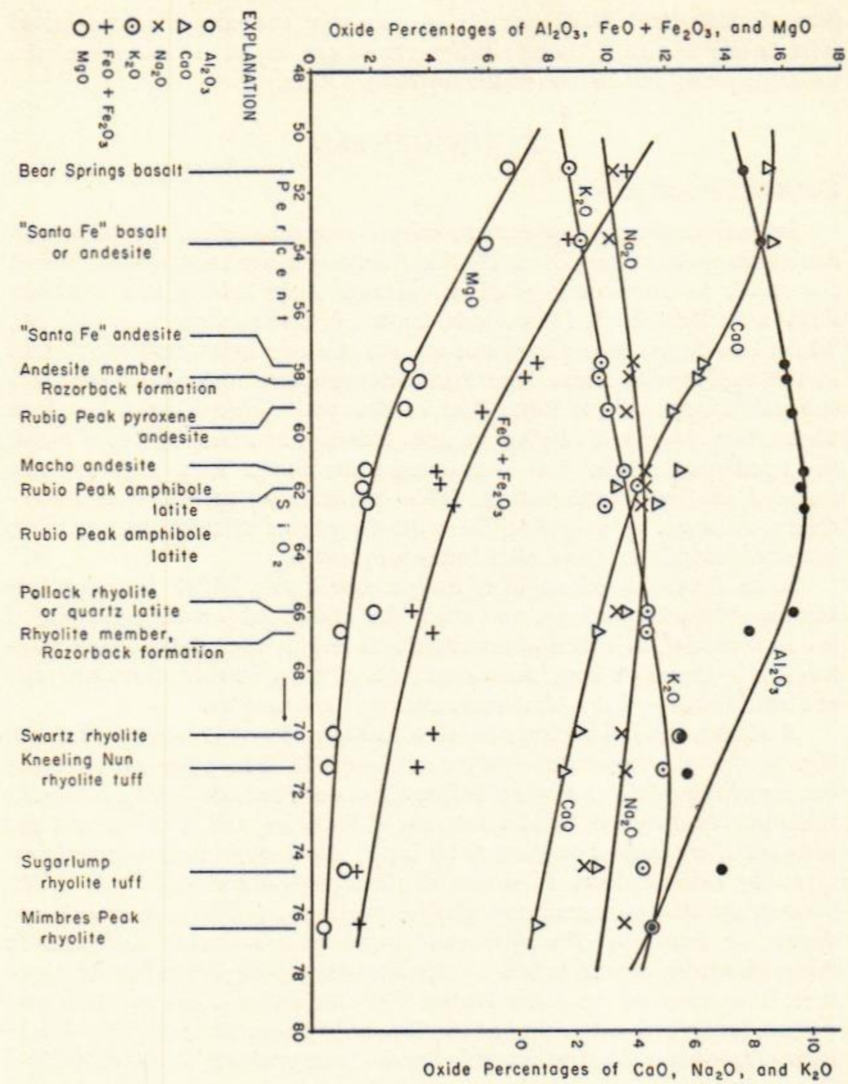


Figure 3

CHEMICAL-VARIATION DIAGRAM OF VOLCANIC ROCKS OF DWYER QUADRANGLE

or early-Tertiary, as against late-Tertiary) may reflect the usual lag between plutonic and volcanic activity (Kennedy, 1938).

An outstanding feature of Dwyer and Lake Valley quadrangles is the chemical resemblance between the earliest effusive rocks (Rubio Peak and Macho andesites) and Laramide intrusive rocks, such as the Cooks Peak granodiorite porphyry (table 7; fig. 5). The course of mineralogical variation (fig. 4) follows a trend predictable from the reaction series of Bowen (1928), starting with a magma of granodioritic type. Basalts are absent in the Lower Volcanic series, and there is no evidence that the andesite-latite-rhyolite suite is derived directly from a hypothetical basalt. Southwestern New Mexico forms an excellent example of a petrographic province in which "granodioritic" characteristics (such as relatively high CaO and K_20) were maintained consistently.

The derivation of the granodioritic province from a primary magma (basaltic or otherwise) will be considered again in connection with the Upper Volcanic series. Theories involving melting and assimilation of a downbuckled crustal segment (Kennedy, 1938) may not provide a solution in the absence of evidence for deep and prolonged subsidence. Strong deformation took place in Precambrian time, but Precambrian potassic (granitic) magmatism differs decidedly from that of later periods, as noted by Lindgren et al. (1910, p. 46):

> The products of the Pre-Cambrian igneous period differ so greatly from those of Tertiary time that both could not reasonably have been derived from the same magma basin. On the other hand, there is striking similarity in composition between the generally uniform Tertiary monzonite intrusive rocks and latites and latite-andesites of the effusive epoch. The suggestion is justified that they were derived from essentially the same source.

If the Lower Volcanic series were derived from a granodioritic magma by fractional crystallization, the order in which minerals appear should follow the reaction series of Bowen (1928). Figure 4 shows this, indeed, to be the case. Consequently, chemical-variation curves should be reasonably smooth and should show progressive increases in the ratios of total iron to magnesium, of alkalis to calcium, and of sodium to potassium. There should be an absolute increase in silicon and absolute decreases in iron, magnesium, calcium, and aluminum. The increase in total alkalis should be slight, since the concentration of sodium should decrease, and that of potassium should increase. Figure 5 shows that these conditions are all met.

Under plutonic conditions, fractional crystallization is believed to result in pegmatitic end products. The writer believes, but cannot prove, that ignimbrites and pumiceous rhyolite tuffs are extrusive equivalents of pegmatites. The chemical discontinuity between intermediate rocks ($Si0_2$, 59-62 percent) and rhyolites ($Si0_2$, 71-77 percent) may reflect the interruption of continuous fractional crystallization, and the separation of a pegmatitic phase. The Pollack and Swartz rhyolites ($Si0_2$, 66-71 percent) are later than the explosive rhyolite tuffs and may be a continuation of the andesite-latite trend.

It may be argued that the writer has not demonstrated any process of fractional crystallization, but rather some unspecified form of magmatic differentiation. In volcanic rocks, however, a silicate melt was undoubtedly present, and crystallization should follow the course established experimentally for such melts. In simplest terms, the writer

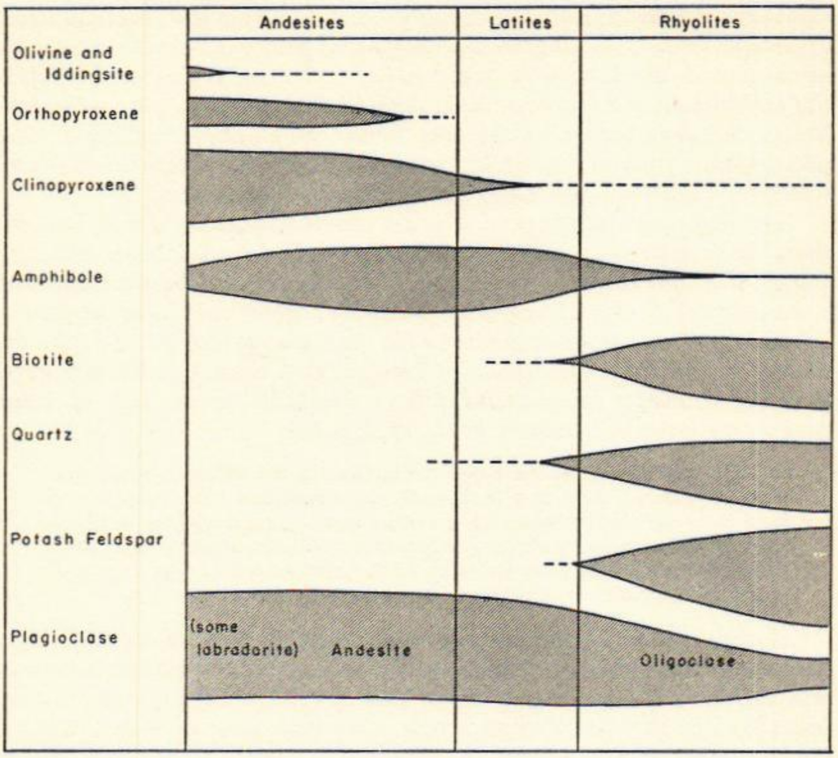


Figure 4

DISTRIBUTION OF PHENOCRYST MINERALS IN THE LOWER VOLCANIC SERIES

visualizes a magma reservoir at moderate to shallow depths, in which crystals settled by gravity. The walls of the reservoir were fractured, and representative samples of magma and suspended crystals at times broke through to the surface. The proportion of lava extruded was probably small in comparison to the volume remaining in the reservoir. This picture is, of course, much too simple. Mineralogical anomalies, such as the presence of two plagioclases in one rock, indicate the existence of complicating factors; for instance, magma may have been modified by assimilation. Convection currents may have led to the mixing of crystals from different parts of the reservoir, where different conditions of pressure, concentration, and temperature prevailed. Eruption to the surface caused changes in environment. Proof of the prevalence of any one process will be lacking as long as the magma reservoir remains buried.

The differentiation process was probably simpler in Dwyer quadrangle than in the generally similar San Juan province. Some mineralogical complications described by Larsen et al. (1936 et seq.) were not

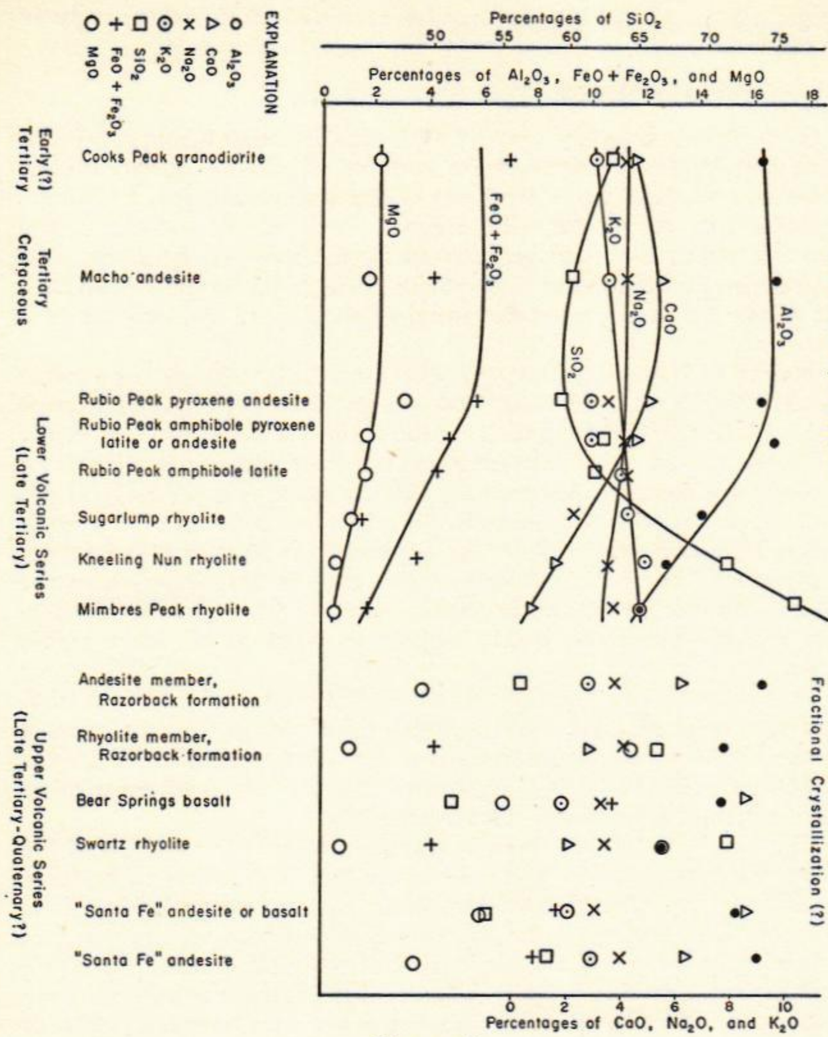


Figure 5

CHEMICAL VARIATION OF THE VOLCANIC ROCKS PLOTTED AGAINST AN ARBITRARY TIME SCALE

found, possibly because the rocks were not studied as thoroughly as were those of the San Juan province. The San Juan volcanic rocks range from Upper Cretaceous to Quaternary. Basalts occur at all stratigraphic levels, and rhyolites commonly are interbedded with rocks of intermediate composition. Further study of volcanism in southwestern New Mexico probably will show that Dwyer quadrangle has an incomplete stratigraphic section. In southwestern New Mexico several contemporary magma reservoirs may have existed in different stages of fractionation.

UPPER VOLCANIC SERIES

If the Swartz rhyolite, a purely local unit, is omitted from consideration, the Upper Volcanic series consists of olivine basalt, olivine andesite, and rhyolite (or trachyte) of the Razorback type. Fractional crystallization of granodioritic magma may account for the Lower Volcanic series, but it cannot account for the rocks of the Upper Volcanic series. Figure 5 shows that systematic chemical variations end with the Lower Volcanic series; the trend of the Upper Volcanic series is inconstant.

Basalts of Dwyer quadrangle (table 5, no. 2, 3) resemble the average basalts (table 5, no. 1) in Daly (1933), except that they are slightly more silicic. If the worldwide basaltic crustal layer postulated by Daly really exists, these rocks could have been derived therefrom, either directly or by slight modification. They would, then, be more deep seated in origin than the earlier calc-alkaline rocks. An origin independent of the Lower Volcanic series would explain their presence as Rustler basalt in the upper part of the Lower Volcanic series, as Bear Springs basalt in the Upper Volcanic series, and in Santa Fe sediments. In many calc-alkaline volcanic provinces, basalts appear to occur at all stratigraphic levels.

It has been shown already (table 6, and accompanying text) that fractional crystallization could have played a part in the development of the basalts and olivine andesites, but that irregularities in the $FeO+Fe_20_3$: $FeO+Fe_20_{3+}MgO$ ratio are the effects of some other process, such as assimilation of felsic material.

The basal unit of the Upper Volcanic series (andesite member of the Razorback formation) is believed to have been contaminated by felsic zenoliths (pl. 5C, D). The original basic magma was probably of the recurrent Bear Springs type. Quartz and oligoclase, the only minerals remaining in the xenoliths, are typical of rhyolites of the Lower Volcanic series. A residual portion of calc-alkaline magma may still have been mobile when basaltic invasions began and may have mingled with basaltic magma.

Figure 3 shows that Razorback olivine andesite contaminated with felsic material is chemically close to the oldest volcanic rocks (pyroxene andesites) of the Lower Volcanic series. This similarity could be cited as evidence that the source magma of the calc-alkaline Lower Volcanic series likewise formed from basaltic magma by sialic contamination. Unfortunately, there is no field evidence that could support or refute this possibility.

The chemical differences between the Upper and Lower Volcanic series are illustrated by the composition of the rhyolite member of the Razorback formation. In Figure 3 this rock falls between the latites and rhyolites of the Lower Volcanic series but disrupts otherwise smooth variation curves. Compared with rhyolites or latites of the Lower Volcanic series, the Razorback rhyolite is notably lower in CaO, $A1_{2}0_{2}$, and $K_{2}0$, and higher in $Na_{2}0$. The ratio of total iron to magnesium also is markedly higher. The rock has trachytic affinities. Kennedy (1938) considered the olivine basalt-trachyte association typical of nonorogenic volcanic suites. A similar significance might be ascribed to the Upper Volcanic series of Dwyer quadrangle, but the data are insufficient.

CONCLUSIONS

The writer believes that the Tertiary volcanic rocks of Dwyer quadrangle consist of two separate suites. The earlier was an orogenic calcalkaline suite, differentiated from a granodioritic magma by fractional crystallization. The granodioritic source magma also formed Laramide intrusive stocks. The later was a calcic suite, possibly nonorogenic and derived from deep-seated basaltic magmas, in part directly or by fractional crystallization, in part by assimilation of silicic rocks, and possibly also by differentiation of a trachytic magma. Andesites formed by felsic contamination of basaltic magma chemically resemble the earlier granodioritic magma.

Structural Geology

SUMMARY OF TECTONIC HISTORY

Between Precambrian and Cretaceous times Dwyer quadrangle and surrounding areas were relatively stable, despite possible disturbances in the late-Paleozoic time. Geosynclinal conditions may have prevailed during the Upper Cretaceous, but the relatively small volume of Upper Cretaceous sediments (Colorado shale) and the short time span they represent indicate that subsidence was neither deep nor long. In this respect southwestern New Mexico differs from many other orogenic provinces.

Laramide deformation appears to have been considerable, though less than in the central and northern Rocky Mountains. It was marked by normal faulting and by intrusion of stocks, laccoliths(?), dikes, and sills of granodioritic adamellitic affinities. Metallic mineralization was widespread. Tight folds and thrust faults developed incidentally to the intrusion of igneous bodies but not otherwise. The disturbance can be dated only as younger than Colorado shale and older than the Rubio Peak volcanic rocks.

The surface over which the earliest Tertiary lavas flowed has low relief, showing that Laramide uplifts had been beveled. In the Santa Rita area, volcanic rocks lie on Laramide intrusive rocks. Faulting concurrent with, and subsequent to, volcanic activity followed the Laramide pattern and is well exemplified in Dwyer quadrangle.

Although the Tertiary rocks of Dwyer quadrangle were not folded by compression, they generally are not horizontal. This results from flow folding of viscous lavas, subsidence of volcanic basins, doming around intrusive bodies, crossbedding of fanglomeratic sediments, and faulting.

REGIONAL STRUCTURE

A profile through Dwyer quadrangle shows fault blocks of the Basin and Range type with northwestward trending faults. Throughout the quadrangle the rocks dip to the southwest. The steepness of dip increases toward the northwest, in the direction of the Black Range. In the northeast corner of the quadrangle, prevailing dips are as high as 70° SW.; near the Mimbres Hot Springs fault they are about 30° SW., and near the Mimbres and Cooks Range faults about 15° SW. The dips are steepest on the upthrown side of faults and decrease with distance from the fault. In the southwest corner of the quadrangle, where there are no northwestward trending faults, the beds are horizontal, and the landscape is of the Colorado Plateau type.

The fault blocks are cut into segments by northeastward trending faults, but these do not affect the regional dip.

This simple picture is complicated by the uneven shapes of some volcanic units. For example, the Rubio Peak and Sugarlump formations fill a deep basin on which the regional southwesterly dip was superimposed. Their thicknesses increase greatly between the northwest and central parts of the quadrangle and thin again toward the southeast.

At Santa Rita about 200 feet of Sugarlump tuffs lies between Kneeling Nun rhyolite and pre-Tertiary basement. At Mimbres Peak 1,300 feet of Sugarlump tuffs and an estimated 5,000 feet of Rubio Peak volcanic rocks lie below Kneeling Nun rhyolite. Since Sugarlump tuffs are conformable with Kneeling Nun rhyolite, which was essentially horizontal at the time of deposition (Paige, 1933), subsidence of about 6,000 feet must have taken place during eruption of the Rubio Peak formation. Sugarlump tuffs probably filled a topographic depression of about 1,000 feet. Since the prevolcanic surface exposed along the northern boundary of Dwyer quadrangle, west of the Mimbres fault, has negligible relief, volcanic rocks could not have accumulated in a preexisting basin. On the contrary, the volcanic basin is here superimposed on a beveled structural high, the northeast limb of the Silver City-Santa Rita syncline described by Ordonez et al. (1955). In the same direction that thicknesses of the Rubio Peak formation increase from 400 to 3,100 feet, the underlying rocks increase in age from Cretaceous to Silurian.

The southern limit of the Rubio Peak basin is near Faywood Hot Springs; its southeastern limit is defined by the Cooks Range horst, and its western rim corresponds roughly to the western boundary of Dwyer quadrangle. The eastern limit is unknown, because exposures in that direction end against the Mimbres fault. The gradual collapse of an emptying magma chamber may be the cause of subsidence.

The rhyolite tuffs of the Lower Volcanic series are more or less platelike in shape. The members of the Upper Volcanic series have variable thicknesses. In contrast to the basin formed by the Rubio Peak volcanic rocks, the Bear Springs basalts seem to have piled up, with steep primary dips, around a vent in or near secs. 21 and 22, T. 18 S., R. 10 W.

In several parts of Dwyer quadrangle, the regional structure is modified by intrusive bodies which have domed surrounding rocks. The two Faywood rhyolite bodies are good examples of plugs not related to known faults. They arch intruded rocks into domes more than 3 miles in diameter, in which dips increase to a maximum of 35 degrees or, locally, even to 75 degrees. They cease to be regular in direction where intruded rocks have been shattered by minor faults.

The domes bring to the surface stratigraphic sequences otherwise inaccessible. At Mimbres Mountain (secs. 7, 8, 17, 18, 19, 20, T. 20 S., R. 10 W.) the interbedding of Rubio Peak flows and Sugarlump tuffs is shown. The structure near Faywood Hot Springs (secs. 9, 10, 14, 15, 16, 21, 22, 23, T. 20 S., R. 11 W.) proves that the Rubio Peak formation thins markedly between the central and southern parts of Dwyer quadrangle. Paleozoic basement is exposed underneath Rubio Peak flows.

Doming by Swartz rhyolite appears to have taken place in sec. 28, T. 18 S., R. 10 W. Without doming, the thickness of Bear Springs basalt would be unreasonably great, and the presence of Razorback andesite west of the Mimbres River (SW¼ sec. 26, T. 18 S., R. 10 W.) would not be explained. Minor faulting is much in evidence near intrusive contacts of Swartz rhyolite.

The Cooks Peak granodiorite porphyry intrusive was described as a laccolith by Lindgren et al. (1910) and Darton (1928), but the writer found no evidence of a floor to the intrusion. The Lobo and Sarten formations are arched steeply above it and may once have formed a continuous roof over the entire igneous body.

Effects of the Cooks Peak intrusion are not confined to arching. In SW1/4 sec. 34, T. 20 S., R. 9 W., the Sarten quartzite roof buckled downward. Opposite walls of a deep canyon consist of quartzite beds dipping toward each other at angles as high as 39 degrees. Minor faults are common near the intrusive; for example, a low-angle fault between Sarten and Lobo sediments can be seen in SE¼SW¼ sec. 34, T. 20 S., R. 9 W.

Locally the granodiorite porphry cuts across older rocks. It cuts Sarten quartzite in sec. 34, T. 20 S., R. 9 W., and Upper Paleozoic limestone in NE¼ sec. 34, T. 20 S., R. 9 W., and SE% sec. 27, T. 20 S., R. 9 W.

FAULTING

Although several periods of faulting have been recognized in Dwyer quadrangle, movement seems to have recurred mostly on the same fault lines.

Pre-Tertiary tectonic history has been obscured by later deformation, but the Laramide orogeny probably set the pattern that persisted through the Tertiary (Lasky, 1936). The Rubio Peak-Sugarlump contact suggests that faulting locally intervened between deposition of the Rubio Peak and Sugarlump volcanic rocks. Intrusion of Mimbres Peak rhyolite along fault lines and accumulation of Piloncillo fanglomerates suggest recurrent faulting during the eruption of the upper part of the Lower Volcanic series. According to Hernon (personal communication, 1952), faulting occurred at Santa Rita during the break between the Lower and Upper Volcanic series. Minor faulting is associated with the eruption of Swartz rhyolite.

The greatest period of faulting tilted all pre-Santa Fe rocks into mountains, which are still dominant topographic features. Santa Fe fanglomerates, derived from these mountains, were affected by still later minor faulting. Figure 6 shows all known and inferred faults.

The Cooks Range horst lies in the southeast corner of the quad-

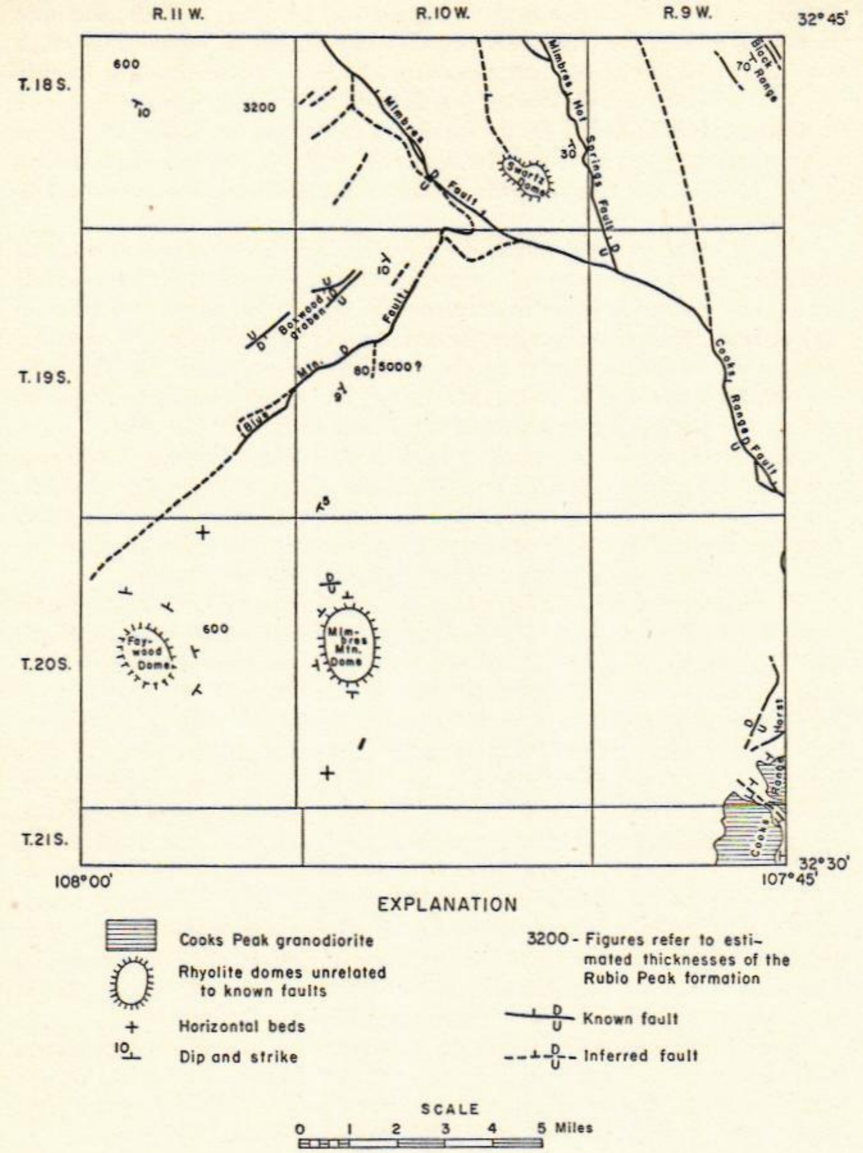


Figure 6

TECTONIC MAP OF DWYER QUADRANGLE, NEW MEXICO rangle. A western border fault is exposed in sec. 22, T. 20 S., R. 9 W. This fault brings the basal Sarten quartzite next to the top of the Fusselman limestone; its offset must be about 850 feet. On the eastern margin of the horst, the Cooks Range (or Sarten) fault has a northerly trend in Deming and Lake Valley quadrangles but turns to N. 20° W. before entering Dwyer quadrangle. Its offset is about 2,000 feet and it dips 60°-70° NNE. The central part of Cooks Range is cut by several trans-current faults.

Beneath the gravels north of Cooks Range, the Cooks Range fault probably splits into several branches. A hypothetical fault entirely covered by gravels appears to continue the N. 20° W. trend of the Cooks Range fault. Its existence must be inferred from repetition of beds between the northeast corner of the quadrangle and sec. 19, T. 18 S., R. 9 W. It is paralleled by the Mimbres Hot Springs fault, to the west, and by the complex structures of the Black Range, to the east.

Another hypothetical fault is indicated in the Mimbres Valley between Hot Springs Canyon and Donahue Canyon by steep eastward dips of Santa Fe fanglomerates and by displacement of the Razorback-Bear Springs contact. The apparent displacement, however, may be due to irregularities in the contact. The offset, in any case, is small.

The Mimbres and Mimbres Hot Springs faults, two probable northward continuations of the Cooks Range fault, are well exposed. North of SW¼ sec. 17, T. 18 S., R. 10 W., the Mimbres fault is a simple fracture or narrow zone of fractures, but to the south it is a complex of branching normal faults. The main faults dip 60°-90° NE.; a subsidiary fault in W½ sec. 20 and NW¼ sec. 28, T. 18 S., R. 10 W., dips 30° NE. Brecciation, gouge development, and slickensiding are widespread. Slickensides pitch close to 90 degrees. Elongate rhyolite plugs may widen the fault zone to 1 mile. On the northern boundary of the quadrangle, the base of the Rubio Peak formation is displaced against the base of the Razorback formation, an offset of about 4,000 feet. This figure represents a maximum, because the Rubio Peak formation probably never developed full thickness near the northern boundary of the quadrangle. The Mimbres fault continues into the Silver City quadrangle, where it branches into several westward faults and dies out (Paige, 1916).

The Mimbres Hot Springs fault is almost as complex as the Mimbres fault. Its trend is N. 20° W., its dip 42°-60° NE. It brings the lower part of the Mimbres Peak formation into contact with the upper part of the Razorback formation, a displacement of about 2,000 feet.

Another set of normal faults trends northeastward, at right angles to the Mimbres fault. Of these, the Blue Mountain fault is the largest. It has been traced from E1/2 sec. 26, T. 19 S., R. 11 W., to San Jose Canyon (W1/2 sec. 9, T. 19 S., R. 10 W.), where it is lost among Rubio Peak latites. South of Mimbres Peak the upward displacement of the southeastern block is about 1,000 feet. The Blue Mountain fault is not so intricately branched as the Mimbres fault. In San Jose Canyon it dips 62° NW. Slickensides pitch 80° NE. in the plane of the fault. Near Piloncillo, the fault zone widens to 100 feet; southwest of Blue Mountain, it widens farther, but directions become inconstant and exposures are poor. South of Juan Alvina Canyon, two parallel faults are 100-200 feet apart.

The Box Well graben is parallel to the Blue Mountain fault, as are several dikes in San Jose Canyon and a set of mineralized faults in the Central mining area to the northwest.

STRUCTURAL CONTROL OF VOLCANISM

The discussion of the structural control of volcanism in Dwyer quadrangle is largely speculative, because little is known about the sources of the volcanic rocks.

Within the quadrangle no sources are known for the ignimbrites and other rhyolite tuffs of the Lower Volcanic series. To the north, however, Kuellmer (1954) has mapped the probable source of the Kneeling Nun rhyolite ignimbrite. It is a vent agglomerate zone with definite northerly trend. This is noteworthy, because the sources of flow rhyolites, confined to the Mimbres Peak formation, are definitely alined along faults trending north to northwest. It would be interesting to know whether eruptions of ignimbrites and other tuffs took place during periods of compression from the southwest or northeast, which closed these fault channels and caused gas pressures to build up to the point where eruptions were violently explosive. The flow rhyolites then would be the result of relaxed compression. Even within the Mimbres Peak formation, flows invariably are underlain by a great volume of pumiceous tuff, as though relaxation of compression had resulted first in eruption of an explosive pumiceous "foam."

The two plugs of Faywood rhyolite are not controlled by known faults. Structurally they seem to resemble salt domes in their complex internal flow structures, more or less circular plan, and doming effect on surrounding rocks. Small amounts of pumiceous tuffs occur near these plugs but are not related to them necessarily.

Only a few dikes are known that could be feeders for the basic and intermediate volcanic rocks. They all trend to the northeast, at right angles to the faults controlling Mimbres Peak rhyolite plugs. There seems to have been little or no displacement along the fractures controlling these dikes, even though they are parallel to the northeastward trending fault system. Basaltic dikes are located in sec. 34, T. 18 S., R. 11 W., and sec. 25, T. 18 S., R. 10 W. Pyroxene andesite dikes occur in sec. 19, T. 18 S., R. 10 W., and secs. 29 and 31, T. 18 S., R. 10 W. A single dike lithologically identical with Razorback andesite crops out in sec. 19, T. 18 S., R. 10 W.

The Razorback andesite dike and one of the pyroxene andesite dikes are a mile long; the rest are much smaller. It must be assumed that the vents that brought the bulk of volcanic material to the surface remain hidden. Volcanic cones may have existed once, but they have been made unrecognizable by faulting and erosion. Only in or near secs. 21 and 22, T. 18 S., R. 10 W., do the presence of volcanic bombs and steep primary dips in Bear Springs basalts suggest the former existence of a cone.

The relation of structure to volcanism thus remains largely unknown. On a regional scale there seems to be no correlation between the amount of faulting and the volume of volcanic rock.

Economic Geology

METALLIC MINERALS

No metallic minerals are being mined at present in Dwyer quadrangle. Known deposits are confined to a small area in the Cooks Range fault zone, accessible by road from the Y-Bar ranch, at Dwyer. In N½ sec. 34, T. 19 S., R. 9 W., the Cooks Range fault branches, and a mineralized slice of Paleozoic sedimentary rock, one-half mile long and 1,000 feet wide, is wedged between Precambrian granite, to the west, and Tertiary volcanic rocks, to the east. The Paleozoic rocks include Fusselman limestone, Percha shale, and Lake Valley limestone. They are much shattered, but mineralization seems to be confined to the top of the Fusselman limestone. The Percha shale may have acted as a barrier to rising mineralizing solutions.

Silver, probably as cerargyrite, was the metal mined. Sulfides are absent or rare; only oxidized minerals, such as cerussite, smithsonite, hemimorphite, and iron and manganese oxides and hydroxides, were found in the old workings.

The ore is largely in veins, less than 2 feet wide, controlled by small faults and breccia zones parallel in strike to the Cooks Range fault and dipping either into the main fault or away from it. The shapes of certain stopes suggest that some of the veins widened locally into replacement deposits.

The mineralized area is honeycombed with small pits, adits, and stopes, many of them caved. The largest stope is only 15 feet high and 25 by 15 feet in plan; the tonnage removed must have been small. According to local reports, some ore was of high grade, but the workings have been abandoned for many years. Since mineralization is confined to a narrow stratigraphic zone in a small fault block, the outlook for future discoveries is poor.

WHITE EAGLE FLUORSPAR MINE

LOCATION AND ACCESS

The White Eagle mine lies in E½ sec. 34, T. 19 S., R. 9 W., 32 miles by road from its railroad shipping point at Deming, New Mexico. It is the largest of several fluorspar properties in the northern part of Cooks Range.

PREVIOUS DESCRIPTION

Johnston (1928) described the geology, structure, and paragenesis of the deposit and quoted eight assays. The deposit was mentioned briefly by Talmage and Wootton (1937). Rothrock et al. (1946) gave a full description, including a geological map on the scale of 1:1,200. Soule (1946) described exploratory diamond drilling by the U. S. Bureau of Mines in 1945. Since 1946 workings have been deepened from 175 feet to 550 feet, so that all existing reports are now incomplete. This report describes the mine as it appeared in 1952.

HISTORY

The White Eagle mine was worked before 1918. In 1946 it was owned by W. D. Howard, L. H. Duriez, and A. White, who leased it early in 1944 to D. F. McCabe. In 1947 it was purchased by Finlay Dunegan and Hiram Harrison, of Deming, who operated the deposit during 1947-49. In the summer of 1950 it was leased, on a long-term basis, to its present operators, the Ozark-Mahoning Co., of Tulsa, Oklahoma.

Production to 1952 totaled about 50,000 tons. Rothrock et al. (1946) estimated that 17,000 tons of ore was shipped prior to 1945; Soule (1946) stated that approximately 25,000 tons, averaging 65 percent CaF_2, had been shipped by 1946. Production from 1947 through 1949 totaled between 20,000 and 25,000 tons (Finlay Dunegan, personal communication, 1952). Production, almost entirely of milling-grade ore, was sold largely as acid spar to the Purisima mill, of the General Chemical Co., at Deming. Smaller shipments were made to Los Lunas, New Mexico. From November 1951 to January 1952 the present operators shipped 1,500 tons of ore, containing 70 percent CaF_2, to Jamestown, Colorado, and Los Lunas, as samples in flotation tests.

DEVELOPMENT AND OPERATIONS

The White Eagle deposit consists of a single system of steeply dipping fissure veins. Prior to 1946 it had been mined in branching and overlapping stopes to a depth of 175 feet below the highest outcrop, and a distance of 700 feet along the strike. Open cuts extend about 500 feet along the outcrop and go to a depth of over 100 feet.

Since its lease by the Ozark-Mahoning Co., the mine has been developed extensively. Of two shafts, only the no. 1 shaft is now in use. It was sunk almost entirely in ore to a depth of 550 feet. Above the 200-foot level, it is inclined 86° NE.; below the 200-foot level, it is inclined 86° SW. Drifts have been driven on the 221-, 318-, and 419-foot levels, and another is planned on the 519-foot level. They extend as far as 200 feet southeast and 575 feet northwest of the shaft.

Access to the mine is by means of an 0.8-ton bucket. No timbering for roof support is needed. The water level remains constant about 10 feet below the 419-foot level. When the shaft was dewatered during drifting on the 519-foot level, 30 gallons of water per minute was pumped out.

About 20 men are employed at the mine. Some of these live on the property, others around Deming. Electricity and gas for household purposes are available at the mine, but drinking water must be transported by truck from the Bryant tank, on the Y-Bar ranch, about 1½ miles to the south.

Indicated reserves of ore total about 150,000 tons. When the present operation was being planned in 1952, it was hoped that production eventually would reach 80 tons a day, with two shifts working. A method of shrinkage stoping was planned. On the surface, ore was to be dumped through a grizzly and sorted by hand. Since gangue is generally in large fragments, sorting raises the grade 10 percent to an average of over 60 percent CaF_2. The operators were considering construction of a concentrator at Deming. Concentrate was to be used in the manufacture of hydrofluoric acid.

GEOLOGY OF THE DEPOSIT

The northern part of Cooks Range consists largely of pink or gray Precambrian granite gneiss. The range is terminated to the east by the Cooks Range fault, which here brings Precambrian granites into contact with Tertiary Rubio Peak lathes. About 800 feet north of the no. 1 shaft, the main fault splits, causing a sliver of Fusselman limestone, a little over one-half mile long and about 1,000 feet wide, to be wedged between the granite and the latites.

Precambrian granite has been intruded by preore dikes that cannot be correlated with volcanic rocks of Dwyer quadrangle, including two types of altered andesite and White Eagle porphyritic rhyolite. In hand specimens the andesites are fine grained. One is light bluish gray and is known to the miners as "blue andesite"; the other, deep olive green, is known as "green andesite." Pyrite is disseminated through green andesite but apparently is not related to fluorite mineralization. The shapes and mutual relations of the andesite bodies are unknown. They do not crop out but have been cut in many places by mine workings. Under the microscope the rocks appear highly altered. Chlorite replaces femic minerals. A large dike of White Eagle rhyolite crops out south of the mine, and smaller dikes follow the fault separating granite from Fusselman limestone. The relationship of the White Eagle rhyolite to the andesites is unknown.

The first period of faulting, along a trend of N. 55° W., was followed by intrusion of an irregular wedge-shaped body of fine-grained black andesite, distinct from the earlier green and blue andesites. The wedge is as much as 60 feet wide at the 419-foot level, but dies out below the surface. At the northwestern end of the open cut, an outcrop of what may be decomposed black andesite has weathered to a yellowish green and cannot be identified. Black andesite cuts all earlier rocks, but White Eagle rhyolite seems to be unfavorable for its emplacement.

In renewed faulting, black andesite was brecciated and fissured. Fissures were mineralized with coarsely crystalline pale-green or colorless fluorite, and lenses and crosscutting veinlets of cryptocrystalline

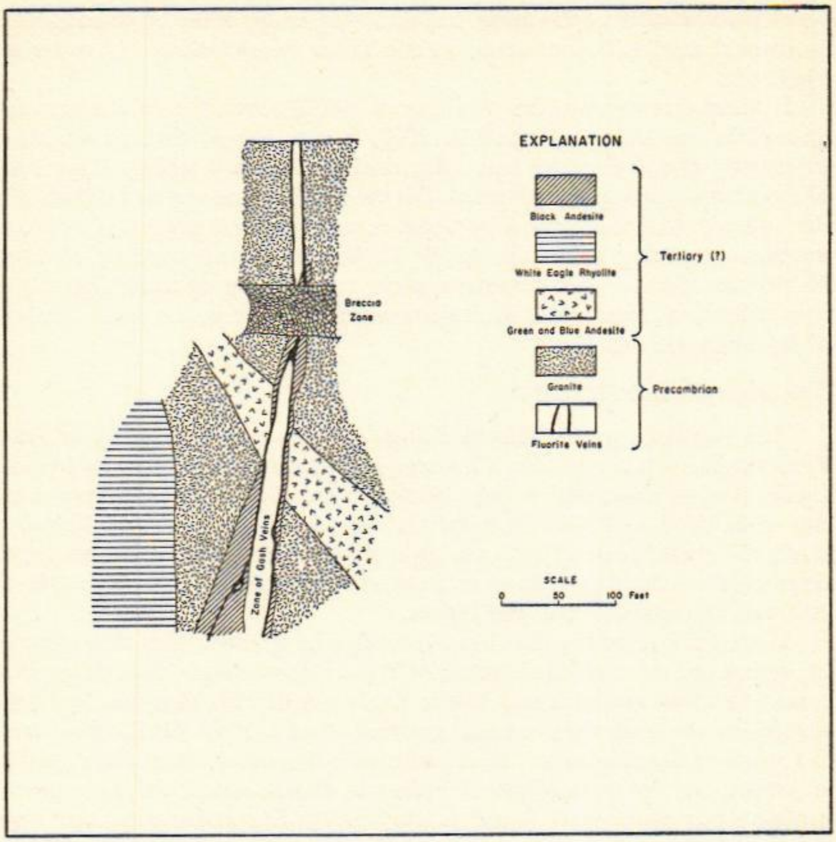


Figure 7

Diagrammatic section through the White Eagle ore body southeast of the no. 1 shaft

gray chertlike silica. Later a few vugs were partly filled by crystals of purple fluorite and amethystine quartz. Thin crosscutting veinlets of quartz crystals, some with comb structure, probably belong to this second phase of mineralization. Fluorite, silica, quartz, and minor calcite appear to have been the only minerals introduced. Less than 0.81 percent of barite is present. A sample of ore and black andesite, tested in a Geiger counter by E. L. Woolard, of Columbia University, showed no anomalous radioactivity. The assays in Table 9 were taken from Rothrock et al. (1946).

Lenticular fragments of wall rock are common in fissure veins. Elongate in the plane of the fissure, they may be several feet long but are rarely more than a few inches wide. They represent fault breccia, as

TABLE 9. ASSAYS OF ORE FROM THE WHITE EAGLE MINE

ASSAY No.*	DESCRIPTION OF SAMPLE	CHIEF CONSTITUENTS (Percent)		
		CaF_2	SiO_2	$CaCO_3$
1.	Average analysis of a few carloads of ore shipped in 1918..................	82.0	12.0	2.0
2.	Average of seven samples taken in various parts of old workings in 1924..........	87.2	6.8	—
3.	Grab sample from stockpile, 1927	88.3	8.6	—
4.	Shipments totaling 1,254 tons made in 1941			
	Range	62.0-84.0	—	—
	Weighted average	72.8	—	—
5.	Sample sent to Alloy Metals mill for analysis, 1943	77.5	—	—

* 1. From Ira L. Wright.
2. From Johnston (1928).
3. From Johnston (1928).
4. From W. D. Howard.
5. From H. W. Lust, manager, Alloy Metals Division, Continental Machines, Inc.

well as wall rock that remained in place but was surrounded by stringers and branching veinlets of ore.

Economic mineralization is controlled by two parallel fissures. The larger of these runs close to the northeast wall of the black andesite wedge; the smaller runs within a few feet of its southwest wall. Workings are entirely within the larger fissure. In addition to these veins, there are smaller subsidiary gash veins. The width of the main veins is variable. The larger of the two ranges from 0 to 6 feet and averages 4-5 feet; the smaller generally is less than 3 feet wide. Mineralization is controlled closely by black andesite; White Eagle rhyolite is an unfavorable host.

Gash veins are present on the southwest side of both veins but are much better developed on the larger vein. They are interpreted as pinnate tension gashes (Hills, 1953, p. 133). Their shapes and relations to major fractures are shown in Figure 8.

The two main veins are separate at the surface but join near the 221-foot level. Below the 221-foot level they are separate but close. The space between them is largely occupied by gash veins. At the 318-foot level the system, including gash veins, is 27 feet wide and consists entirely of minable ore. This is the richest part of the mine. At the 419-foot level the veins are again 40 feet apart.

This relatively simple pattern is complicated by several faults, preore and postore, that offset mineralized fissures. Below the 130-foot level the shaft passes through a brecciated zone about 50 feet thick, dipping less than 5° NW. Sparse fragments of fluorite have been reported in the breccia, which suggests that movement was postore. This relatively bar-

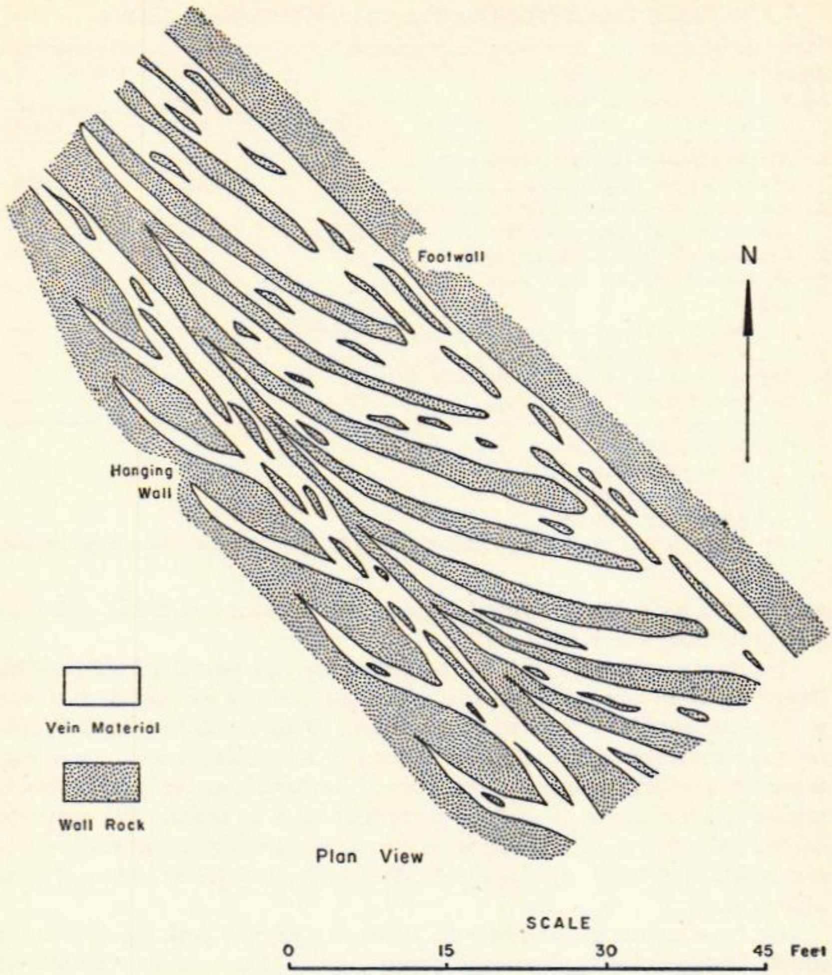


Figure 8

DIAGRAMMATIC SKETCH (WHITE EAGLE MINE) SHOWING THE RELATION OF GASH VEINS TO THE MAIN FISSURE VEINS ON THE 318-FOOT LEVEL

ren zone formed the bottom of mine workings prior to 1950; only recent development has shown the richest ore to be below it. Because of movement along the crushed zone, the larger vein dips 86° NE. above the 200-foot level and 86° SW. below it. This explains the kink in the shaft.

On the 318-foot level, 230 feet northwest of the shaft, the ore body is offset by a fault that strikes N. 4° E. and dips 70° W. Horizontal movement is 30 feet to the north. Minor mineralization follows this fault, showing that it is preore but later than fissures controlling mineralization. On the 221-foot level this fault was cut 260 feet northwest of the shaft. This distance was greater than anticipated, indicating that the fault either changes dip or is itself offset by another fault.

On the 318-foot level, 440 feet northwest of the shaft, the veins are cut by a fault striking N. 18° W. and dipping about 40° SW. Horizontal movement is about 15 feet to the south. Breccia contains fragments of fluorite, indicating that movement was postore. Drifts on other levels do not extend far enough to meet this fault. It approximately parallels two low-angle faults described by Rothrock et al. (1946), in an adit at the northwest end of the deposit and on the 130-foot level of the abandoned no. 2 shaft. Movement was slight.

Southwest of the black andesite body, granite is sericitized and chloritized. In the few places where workings cut its northeast side, the granite is bluish gray and fresh. Mineralized White Eagle rhyolite seems unaltered, except for minor sericitization.

The age of mineralization is unknown. Johnston (1928) states that the deposit formed as the final crystallization product of White Eagle rhyolite, but the evidence is insufficient. In the northern Cooks Range as a whole, there seems to be little correlation between occurrences of rhyolite and fluorite.

POSSIBLE EXTENSIONS OF THE ORE BODY

In 1952, exploration did not extend beyond the fault contact of Precambrian granite and Fusselman limestone, to the northwest, nor into the large dike of White Eagle rhyolite, to the southeast. It is not known whether fluorspar in limestone, attributed by Johnston (1928) to replacement, is continuous with fissure veins in granite, or whether the veins can be found again south of the rhyolite dike. Mineralization continues below present workings, but it seems unlikely that the favorable conditions of the 318-foot level will be repeated.

ACKNOWLEDGMENTS

Mr. Edward Powell, superintendent of the White Eagle mine, and Mr. Jack Hale, foreman, gave the writer full access to the mine in the summer of 1952. Except where specifically credited to other sources, all data in this part of the report were supplied by Mr. Powell. Permission to publish this material was granted by the Ozark-Mahoning Co., of Tulsa, Oklahoma.

OTHER FLUORSPAR MINES

Fluorspar is distributed widely at the northern end of Cooks Range. Aside from the White Eagle mine, no deposit was being worked in August 1952. In N½ sec. 28, and S½ sec. 21, T. 19 S., R. 9 W., there are many prospect pits, open cuts as much as 40 feet deep, and shafts. The ore is in siliceous veins ranging in width from a few inches to 3 feet and trending N. 75° E. or N. 15° W., plus or minus 25 degrees. These veins have been described by Rothrock et al. (1946). They include the Vista, Wagon Tire, and Defense group of claims. The first two are in Vista diorite, the last in Precambrian granite. The Vista mine was being worked in early 1952 but had been abandoned by June. Other deposits are mined sporadically by prospectors.

A prospect not mentioned by Rothrock et al. (1946) is located in NW¼SW¼ sec. 27, T. 20 S., R. 9 W. It is an open cut 50 feet long and 30 feet deep, in the side of a hill of Precambrian granite. The vein is 42 inches wide. It consists of stringers of fluorite as much as 12 inches wide, lenses of altered granite, and vein quartz. Fluorite is either saccharoidal, with crystals 1-2 mm long, or coarsely crystalline, with crystals 10-20 mm long. It is colorless or light green. The deposit was worked either in 1950 or early 1951. Production was about 350 tons.

PERLITE

The term perlite is used for siliceous volcanic glasses with perlitic fractures, containing 2-10 percent water. When heated, perlite decrepitates, forming artificial pumice. The market for perlite is growing rapidly. Its main use is as a light-weight aggregate and insulator in construction work. The processing plant closest to Dwyer quadrangle is at Socorro, New Mexico. It is doubtful whether any deposit in Dwyer quadrangle is of commercial grade. Some aspects of perlite genesis and petrology are described on p. 46-49.

Perlitic glasses occur in the Mimbres Peak, Pollack, Razorback, and Swartz rhyolites, but only the Mimbres Peak formation merits consideration. Its glassy phases are found at the base of flows and margins of intrusives, in small dikes, in breccias, and as lenses in tuffs. Flows with glassy bases generally lie on bedded pumiceous tuffs, which may be naturally decrepitated perlite.

Glasses of the Mimbres Peak formation are of two types, here called "gray" and "black" perlite. Gray perlite breaks readily along perlitic fractures. It contains few impurities, except for a few flow-folded bands of spherulitic chalcedony, and is of acceptable commercial grade. The deposits, however, seem too small for exploitation. The black perlite deposits are large, but the grade is low. Its megascopic fractures are rectangular, but perlitic cracks can be seen under the microscope. Impurities include phenocrysts of quartz, sanidine, oligoclase, biotite, minor hornblende, and sphene, inclusions of silicified rhyolite and foreign material, and various devitrification and alteration products. Both types of perlite grade into fine-grained crystalline rhyolite by way of a cryptocrystalline zone with spherulitic and radiolitic textures.

Gray perlite forms deposits on Mimbres Peak and in the Box Well graben. Flow perlite as much as 15 feet thick grades above into devitrified rhyolite and lies on 100 feet of perlite breccia. The Box Well graben, in NW¼ sec. 8, T. 18 S., R. 10 W., is the most accessible part of the deposit and has been prospected. If flow perlite is the only rock of commercial grade, the tonnage in the deposit would be small. Should the breccia prove workable as well, the available amount would be about 500,000 tons. A large part, however, lies on Mimbres Peak and is difficult to reach. The overburden is slight. The deposit lies 6 miles by road from the Eby ranch, at Faywood Post Office (Dwyer). The road is poor, and transportation costs would be high.

Small deposits of gray perlite are scattered along the Mimbres and Mimbres Hot Springs faults, but they do not warrant development.

Large tonnages of black perlite exist at several places along the Mimbres fault zone. A hill in SW½ sec. 34, T. 18 S., R. 10 W., and NI/2 sec. 3, T. 19 S., R. 10 W., is capped by flow rhyolite grading downward into 50 feet of black perlite resting on pumiceous tuffs. On the northern side of the hill, exposures are continuous for about three-quarters of a mile. The average width of outcrop is 100 feet. On the southern and southwestern side of the hill, exposures are scattered. Perlite pinches out toward the southeast; in other directions it is cut off by the Mimbres fault. A deposit of identical geological setting was found in W½ sec. 20, T. 18 S., R. 10 W., but the exposures are narrow because of steep slopes. In both these occurrences the rock is impure. The overburden is generally heavy and consists of unusually tough rock.

Another large deposit of black perlite crops out in W½SE¼ sec. 34, T. 18 S., R. 10 W. It appears to be a vitrified tuff. Because of conglomeratic zones and hydrothermal alteration, it is not of commercial grade. Small deposits of black perlite occur in many other places in the Mimbres and Mimbres Hot Springs fault zones.

BUILDING MATERIALS

Adobe has been prepared locally from Quaternary and Recent alluvium. Bedded green, white, and pink tuffs of the Sugarlump formation make attractive and easily worked building stones. They have been used locally, especially as flagstones. A small quarry in white bedded tuffs is located on the Bell ranch, in NE¼SE¼ sec. 30, T. 20 S., R. 10 W., but was idle in July 1952.

POSSIBILITIES FOR FUTURE MINERAL DISCOVERIES

Dwyer quadrangle is part of a large area of intense metallic mineralization in pre-Tertiary rocks. Most of this area is covered by unproductive Cenozoic volcanics and valley-fill sediments, but almost all pre-Tertiary "windows" show commercial mineralization. The Kingston-Hillsboro, Lake Valley, and Cooks Peak districts to the east are largely inactive, but the Santa Rita-Silver City-Bayard-Central area to the northwest is a major producer of copper, zinc, lead, silver, gold, and minor manganese and iron. The Chino mine, at Santa Rita, only 6 miles from the northwest corner of Dwyer quadrangle, has been among the five largest copper mines in the United States for the last 13 years (Ordonez et al., 1955).

It is perhaps probable that mineral deposits exist in Dwyer quadrangle, hidden beneath younger rocks. Structurally the quadrangle appears favorable. The northeastward trending fault system is parallel to mineralized faults in the Bayard-Central area, including the Groundhog and Barringer faults. Regionally, structural complexities seem to favor mineralization, and certain areas within the Mimbres, Mimbres Hot Springs, and Blue Mountain fault zones are highly complex, more so than could be shown on the scale of the geologic map.

Unfortunately, almost 95 percent of Dwyer quadrangle is covered by barren Cenozoic rocks, largely of unknown thickness. The entire area east of the Mimbres fault must be regarded as unfavorable for economic mineralization, because it is covered by unknown thicknesses of volcanic rocks and fanglomerates.

West of the Mimbres fault, the volcanic rocks reach thicknesses of 7,000 to 8,000 feet, which makes most of this area unfavorable. However, the base of the volcanic rocks is exposed along the northern boundary of Dwyer quadrangle, and their thickness in this area is relatively small on the west side of the Mimbres fault. This is due to subsidence of the Rubio Peak volcanics, tilting of the entire volcanic sequence to the southwest by the Mimbres fault, and subsequent erosion.

The Mimbres fault raised the base of the volcanic rocks about 4,000 feet; the transverse Blue Mountain fault raised it an additional 1,000 feet. The two faults intersect in a complex area covering parts of sec. 34, T. 18 S., R. 10 W., and sec. 3, T. 19 S., R. 10 W. This area seems more favorable for prospecting than any other in the quadrangle. The structures are complex, the Blue Mountain fault parallels the mineralized northeastward trending faults of the Central-Bayard area, and volcanic cover is at a minimum. The exact thickness of the volcanic rocks is unknown; it is perhaps 200-1,000 feet in the area lifted up by both faults.

The southwest part of the quadrangle is covered largely by gravels and horizontal volcanic rocks. In domes around Faywood rhyolite intrusions, the thickness of the volcanic rocks is 600 feet or more. This area must be regarded, therefore, as unfavorable for mineralization. The narrow belt of Paleozoic limestone around the intrusion northeast of Faywood Hot Springs is unmineralized.

The thicknesses of alluvium and volcanic rocks west of Cooks Range are unknown; this area also must be regarded as unfavorable.

Many small fluorite and lead-zinc-silver deposits are known in the pre-Tertiary rocks of Cooks Range. The outstanding structural feature of the range is the Cooks Peak granodiorite porphyry laccolith or stock, which domed surrounding and overlying sediments. Intrusions in the

Santa Rita-Silver City area that deformed surrounding sediments have zinc ore bodies in their periphery, whereas the Santa Rita intrusive rock, which shattered internally but did not affect surrounding sediments, has disseminated copper deposits as well as zinc deposits (Ordonez et al., 1955). The Cooks Peak intrusion seems to follow the same behavior; it shows no evidence of copper mineralization, and none is likely to be found.

Large extensions of known lead-zinc-silver deposits in Dwyer quadrangle are not likely to be found, since such deposits are confined to a narrow fault block in sec. 34, T. 19 S., R. 9 W. The parts of Cooks Range which lie in Lake Valley and Deming quadrangles (Jicha, 1954; Darton, 1917) may be more favorable, however.

Fluorite mineralization in Cooks Range seems to be younger than the lead-zinc-silver mineralization. In the White Eagle mine it is younger than the White Eagle rhyolite, which is probably a member of the late-Tertiary Lower Volcanic series. Traces of fluorite occur in the Mimbres Peak rhyolite, and there is a slight possibility that workable deposits may exist in volcanic rocks. It is reported that some years ago a fluorite vein was discovered in volcanic rocks on the Eby ranch, west of Dwyer; verification of this report is lacking. Waters from active hot springs, at Faywood Hot Springs and Mimbres Hot Springs, have a fluorine content far higher than ordinary ground water (table 10).

The small exposures of Paleozoic rocks in the northwest part of Dwyer quadrangle show some silicification, but no economic mineralization has been found.

Hot Springs

Two hot springs are known in Dwyer quadrangle. Faywood Hot Springs, in SE¼NW¼ sec. 20, T. 20 S., R. 11 W., was the site of a resort hotel, now demolished. Mimbres Hot Springs, in NWIA sec. 13, T. 18 S., R. 10 W., also was formerly the site of a hotel, but the buildings were converted into a private residence some years ago. Table 10 shows partial chemical analyses of the waters of these springs.

TABLE 10. PARTIAL CHEMICAL ANALYSES OF HOT-SPRING WATERS *
(In parts per million)

	MIMBRES HOT SPRINGS' (137°F)	FAYWOOD HOT SPRINGS (129.2°F)
SiO,	53	n.d.
Ca	12	n.d.
Mg	2.6	n.d.
Na and K	86	41
HCO,	113	282
SO,	65	50
Cl	17	18
F	16	7
NO,	0	0.1

*Analyst: U. S. Geological Survey, Quality of Water Laboratory, Albuquerque, New Mexico. Data furnished by F. X. Bushman. Springs supplying water for domestic use.

Faywood Hot Springs is a single spring, although other hot springs are known in the vicinity, outside Dwyer quadrangle. The surrounding country is covered by gravels; hence the structural setting is unknown. The spring lies within a mile of the Blue Mountain fault and the Fay-wood rhyolite dome. The volcanic rocks beneath the gravels are believed to be relatively thin and probably lie on Paleozoic limestone.

Mimbres Hot Springs is a group of about 30 springs, with a combined flow considerably in excess of 100 gallons per minute. The springs lie in the Mimbres Hot Springs fault zone. At the surface the country rock is Rubio Peak latite and Kneeling Nun(?) rhyolite. According to the owner of the springs, neither the temperature nor the volume of the water undergoes seasonal fluctuations.

Compared to ordinary meteoric ground water from wells in Dwyer quadrangle, the hot-spring waters are rich in fluorine. Analyses of water from 24 ground-water wells show an average fluorine content of 0.7 parts per million, compared to 16 ppm for Mimbres Hot Springs and 7 ppm for Faywood Hot Springs. The average proportion of sulfate ion is about twice as high in hot-spring waters as in ground water. Water from Mimbres Hot Springs has 86 ppm of combined alkalis, compared to an average of 37 ppm for ground water; Faywood Hot Springs has only 41 ppm. Faywood Hot Springs water shows more than twice the bicarbonate concentration of water from Mimbres Hot Springs, which probably accounts for the deposit of calcareous tuff 25 feet high at Faywood Hot Springs. No such deposit is found at Mimbres Hot Springs.

The only consistent characteristic of these hot-spring waters is the high concentration of fluorine. A cold surface spring in Carisa Canyon (Carisa Tubs in SE¼SW¼ sec. 31, T. 18 S., R. 9 W.) also shows a fluorine content of 5.2 ppm. The spring lies on the projected southward continuation of the Mimbres Hot Springs fault, which disappears under younger gravels about three-quarters of a mile to the north. This fault is, of course, the same that seems to control the location of Mimbres Hot Springs.

High concentration of fluorine in an area of widespread fluorite mineralization, and alinement along faults, indicate that at least part of the hot-spring waters is telluric rather than meteoric. If so, the temperatures of the water in these springs may represent the residual phase of volcanism in Dwyer quadrangle.

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