General Geology of Santa Rita Quadrangle Grant County, New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 555

General Geology of Santa Rita Quadrangle Grant County, New Mexico

By WILLIAM R. JONES, ROBERT M. HERNON, *and* SAMUEL L. MOORE

GEOLOGICAL SURVEY PROFESSIONAL PAPER 555

A study of the physical and chemical characteristics of the sedimentary and igneous rocks and of the structural framework of a major base-metal mining district

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 67-151

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

CONTENTS

ILLUSTRATIONS

TABLES

GENERAL GEOLOGY OF SANTA RITA QUADRANGLE GRANT COUNTY, NEW MEXICO

By William R. Jones, Robert M. Hernon, and Samuel L. Moore

ABSTRACT

The Santa Rita quadrangle, an area of about 62 square miles, is bounded by the meridians 108°00′ and 108°07′30″ W. and the parallels 32°45′ and 32°52′30″ N. It is in Grant County, N. Mex., about 115 miles northwest of El Paso, Tex., the closest large city. It lies within the Mexican Highland section of the Basin and Range physiographic province and is near the south margin of the Datil section of the Colorado Plateaus.

Exposed rocks of the quadrangle range in age from Precambrian to Recent. Strata of Paleozoic and Cretaceous age, which are much broken by faults, locally domed and folded by forcefully injected magma, and traversed by dike swarms of northeasterly trend, are exposed in the central part of the quadrangle. These rocks are surrounded by flat-lying volcanic rocks of Miocene(?) age, which underlie dissected plateaus to the north and south and once blanketed the region for tens of miles in all directions. Rocks of Precambrian age are exposed only in a lens-shaped area of metamorphic rocks adjacent to the east margin of the Hanover-Fierro pluton. Rocks of Cambrian through Mississippian age are exposed on the east and west sides of that pluton, adjacent to a sill on its west side, and in the northeast quarter of the quadrangle. Gently inclined resistant limestone beds of the Pennsylvanian Magdalena Group largely underlie the west-central and northeastern parts of the quadrangle. The Beartooth Quartzite and the Colorado Formation of Cretaceous age, thick sills of Late Cretaceous(?) and early Tertiary age, and tuffs and flows of Miocene(?) age largely underlie the southern part of the quadrangle; the Colorado Formation, laccolithic bodies of syenodiorite, andesite breccia, swarms of mafic dikes, all of Late Cretaceous(?) or early Tertiary age, and basaltic andesites of Miocene(?) age largely underlie the northern part of the quadrangle.

Precambrian basement complex, which in this region is composed mainly of granite, quartzite, and greenstone, is covered by a relatively thin section of strata of Paleozoic and Mesozoic age comprising about 2,800 feet of Paleozoic rocks and 1,000–2,000 feet of Mesozoic rocks. An additional 4,000 feet of sedimentary and volcanic rocks was deposited in late Mesozoic or early Tertiary time but was eroded from most of the area by Miocene(?) time.

There are nine formations of Paleozoic age. These are (1) the Bliss Formation (Upper Cambrian and Lower Ordovician), consisting of 140–188 feet of sandy and shaly magnesian limestone, shale, and glauconitic and hematitic sandstone; (2) the El Paso Limestone (Lower Ordovician), consisting of about 520 feet of thin- and thick-bedded limestone and dolomite; (3) the Montoya Dolomite (Middle and Upper Ordovician), consisting of about 325 feet of sandstone, sandy and cherty dolomite, and pure dolomite; (4) the Fusselman Dolomite (Silurian), consisting of approximately 100 feet of gray massive cherty dolomite; (5) the Percha Shale (Upper Devonian), consisting of 230–315 feet of black fissile shale and gray limy shale which contains limestone nodules; (6) the Lake Valley Limestone (Lower Mississippian), consisting of 300–400 feet of limestone and marly limestone; (7) the Oswaldo Formation (Middle and Upper Pennsylvanian), consisting of 330–420 feet of cherty limestone, thin beds of shale, and lenses of sandstone: (8) the Syrena Formation (Upper Pennsylvanian), consisting of 170–390 feet of limy shale and argillaceous limestone; and (9) the Abo Formation (Lower Permian), consisting of 0–265 feet of mudstone and limestone conglomerate.

Strata of Triassic, Jurassic, and Early Cretaceous age are absent. Strata of Late Cretaceous age rest disconformably on the Abo and Syrena Formations and include the Beartooth Quartzite and the overlying Colorado Formation. The Beartooth is 50–140 feet thick and is predominantly a fine-grained crossbedded quartzite with some thin black shale and conglomerate beds; the Colorado Formation ranges from 0 to about 1,000 feet in thickness and is divided into a lower, black shale member (220 ft) and an upper, sandstone member.

Rocks of Laramide age are made up largely of purple and dark- and light-green indurated andesite breccia and conglomerate that are intruded by great swarms of mafic porphyry dikes. Little is known about the exact age of the andesite breccia in the quadrangle, but it was probably deposited in early Tertiary time. The andesite breccia and the related plugs and dikes are older than the main epoch of mineralization and metalization; hence, they are potential hosts for ore deposits throughout the region.

About 25 types of intrusive rocks occur as sills, laccoliths, stocks, dikes, and plugs of Late Cretaceous(?) and early Tertiary age. The various intrusive bodies were emplaced in a definite chronological order—the sills first, the stocks next, and the dikes and small plugs last. Seven types of rocks occurring as sills are distinguished and separately described: syenodiorite porphyry, augite-hornblende andesite, rhyolite porphyry, alaskite porphyry, quartz diorite porphyry (two facies), hornblende quartz diorite, and trachyte porphyry. Three compound plutons were intruded in the area. In order of decreasing size, these are the Hanover-Fierro pluton, the Santa Rita stock, and the small Copper Flat stock. Three types of granodiorite porphyry dikes were intruded next, and were followed in turn by quartz monzonite porphyry dikes, quartz latite porphyry dikes and plugs, and, finally, by a rhyodacite plug and a swarm of dikes of similar composition.

Volcanic rocks of Miocene(?) age include flows of rhyodacite; flows, dikes, and plugs of basaltic andesite; welded tuff ranging in composition from rhyolite to quartz latite; soft pumiceous and crystal tuff; red and black obsidian; plugs of

rhyolite; and interlayered sandstones and semiconsolidated gravels. In order of deposition, these rocks are (1) the Rubio Peak Formation; (2) the Sugarlump Tuff; (3) the Kneeling Nun Rhyolite Tuff; (4) pitchstone, sandstone, and rhyolite tuff; (5) rhyolite tuff (in the northern part of the quadrangle); (6) felsitic rhyolite plugs and dikes of Miocene(?) age; (7) gravel and boulder deposits (in the northwestern part of the quadrangle); (8) rhyolite tuff intercalated between flows of basaltic andesite; (9) basaltic andesite flows; and (10) basaltic andesite plugs and dikes. Minor disconformities between the formations indicate several short-lived erosion intervals; the most conspicuous separates the middle group of dominantly felsic tuffs from the top series of basaltic andesite flows.

Sedimentary rocks of probable early Tertiary age are found within a craterlike structure south of Hanover; semiconsolidated gravels, conglomerates, and sandstones of late Miocene(?) and Pliocene age are found in the Mimbres River valley; and small remnants of alluvium of Pleistocene age cemented with caliche and iron oxides, and alluvium and talus of Recent age, are found locally within the quadrangle.

The Santa Rita quadrangle lies on the northeast side of a regional horst bounded by northwest-striking faults of the Basin and Range system. The strata within the horst form a broad, shallow syncline that is locally modified by domes, arches, and tight superficial folds peripheral to several funnel-shaped stocks. The principal structural features formed early in the Cenozoic Era. Extending southwestward across the area is the Fort Bayard arch, formed by the emplacement of sills and modified by three transverse folds formed during the emplacement of the main mass of the Hanover-Fierro pluton. Normal faulting that occurred earlier than the intrusion of the stocks produced the Santa Rita horst, a crudely triangular block bounded on the northeast by an 8-mile-long segment of the Mimbres fault, on the northwest by the Barringer fault, and on the south by a zone of discontinuous faults trending N. 75° E. Narrow subsidiary grabens and horsts are located along the south margin of the Santa Rita horst.

Peripheral folds produced by the forceful injection of magma surround the south lobe of the Hanover-Fierro pluton and the stock at Copper Flat, but not the Santa Rita stock. These folds, the arching of beds over swollen sills, and drag folds along the major faults are the only evidence of folding in the area.

Faults and fractures, some of which are filled by dikes, are arranged in numerous patterns: northwest of Hermosa Mountain the fractures and dikes have a radial pattern; north of Hanover Mountain the dikes form a rectangular grid pattern; northwest of Santa Rita both the dikes and the faults have a pronounced networklike pattern; and in the southwestern part of the quadrangle the faults and dikes form a braided pattern.

The fault and fracture pattern includes east-northeast-trending, northeast-trending, and northwest-trending sets; but the northwest-trending set, except for the Mimbres fault, is largely restricted to a mile-wide belt that includes the Santa Rita stock.

Of those faults which strike between north and east, about 40 percent dip west or north and about 60 percent dip east or south. The major faults are (1) the Mimbres fault, which strikes N. 40° W., dips steeply northeast, and brought rocks of Pliocene age down against rocks of Ordovician age, thus indicating a stratigraphic throw of 1,300 feet or more; (2) the Barringer fault, which strikes N. 30°–75° E., dips steeply northwest, and brought rocks of Late Cretaceous age down against rocks ranging in age from Cambrian to Late Cretaceous, thus indicating a stratigraphic throw of 1,400–1,600 feet; (3) the Hobo-Bayard fault, which strikes N. 30°–60° E., dips steeply southeast, and has a stratigraphic throw ranging from 400 feet to at least 1,000 feet; (4) the Groundhog–Ivanhoe–Lovers Lane fault zone, which strikes N. 25°–60° E., dips 20°–70° SE., and brought the "upper sill" in the Colorado Formation down against the Syrena Formation in the footwall, thus indicating a stratigraphic throw ranging from 500 feet to at least 1,700 feet; and (5) the Carbonate fault, which strikes N. 55°–65° E., dips 50°–70° SE., and has a stratigraphic throw of about 600 feet. The total stratigraphic throw on the major faults is the result of intermittent movement during the Cenozoic; initial movement preceded the injection of stocks, and movement recurred both after the injection of granodiorite porphyry dikes and after Miocene(?) volcanism.

The elliptical area near Hanover that is underlain by alluvium and sedimentary rock of early Tertiary age marks the location of a steep-walled mile-long craterlike depression (called the Hanover Hole) that formed in postore time. The rocks of Mesozoic and Paleozoic age that existed where this calderalike basin formed were either blown out and scattered over the region or sank more than 1,000 feet when magma was withdrawn from beneath the elliptical area. Adjoining the Hanover Hole are two small areas and one large area in which the rocks are brecciated, presumably by the explosive release of magmatic gases.

The principal structural features were formed between Late Cretaceous and Miocene(?) time and are related to the intrusive activity. They can be assigned to four episodes within this interval: (1) doming and some faulting accompanying the intrusion of sills and laccoliths; (2) extensive normal faulting between the intrusion of sills and the intrusion of stocks; (3) folding and some faulting related to the intrusion of the funnel-shaped stocks; and (4) faulting and fracturing during dike emplacement. The Mimbres, Groundhog, and San Jose faults were reactivated both during and after the episode of Miocene(?) volcanism and after the deposition of Pleistocene valley fill, as part of the regional formation of basin-and-range fault blocks.

Two old erosion surfaces are recognized: a youthful to mature surface at the base of the Miocene(?) volcanic rocks, and a pediment, called the Bayard surface, cut in Pliocene or early Pleistocene time in part contemporaneously with deposition of the valley-fill gravel. Only remnants of the older surface are found in the Santa Rita quadrangle, and the Bayard surface has been partly destroyed during the present cycle of erosion.

INTRODUCTION

William R. Jones and Robert M. Hernon, the two senior authors of this report, were killed in line of duty on June 29, 1965, in a tragic automobile accident in New Mexico. We of the United States Geological Survey are proud to present this report as an eminently fitting memorial to the scientific devotion of two of our finest colleagues.

LOCATION AND ACCESSIBILITY

The Santa Rita quadrangle, in Grant County, N. Mex., is bounded by the meridians 108°00′ and 108°07′30″ W. and the parallels 32°45′ and 32°52′30″ N. At this latitude, 7½-minute quadrangles cover about 62 square miles and measure 7¼ miles between bounding meridians and 8½ miles between bounding parallels. The location of the quadrangle within the State and within the Silver City 30-minute quadrangle is shown in figure 1.

All parts of the Santa Rita quadrangle are readily accessible via a network of dirt roads stemming from paved roads. U.S. Highway 180, connecting Silver City and Deming, N. Mex., passes through Bayard, N. Mex., a mile west of the southwest corner of the quadrangle. State Highway 90, connecting Silver City with Lordsburg and Hillsboro, passes through the central part of the quadrangle, generally in an easterly direction. These two highways intersect at Central, N. Mex., just west of the quadrangle's west boundary, and are further connected by a paved secondary road which extends from Bayard northeastward through the settlement of Vanadium to intersect Highway 90 at Hanover, N. Mex. A spur of the Atchison, Topeka, and Santa Fe Railroad extends from Bayard northeastward to Fierro, following Whitewater and Hanover Creeks. From Hanover Junction, at the confluence of these creeks, a second spur extends eastward up Santa Rita Creek to the Chino copper mine.

SURFACE FEATURES AND DRAINAGE

Relief in the quadrangle is moderate, ranging from 100 to 200 feet in the central part to 1,600 feet in the dissected lava fields. The highest elevation, 8,054 feet, is in the Pinos Altos Range near the northwest corner of the quadrangle. The highest point in the southern part of the quadrangle, 7,712 feet (sec. 2, T. 18 S., R. 12 W.), is about 1 mile southeast of the Chino mine, or about half a mile south of the landmark known as Kneeling Nun. The lowest point, 5,790 feet, is in a sand wash in the extreme southeast corner; a comparable point, about 5,795 feet, is in a creek bottom at the southwest corner, just south of the town of Bayard.

The major drainage divide swings southward in a broad irregular arc from near the 108°05′ mark on the north edge of the quadrangle map. It passes successively through Fierro Hill and the highlands south of Willow Springs Canyon and crosses State Highway 90, 1¾ miles west of the east margin of the quadrangle. From the highway the divide extends southwestward through Kneeling Nun to intersect the south margin of the quadrangle at about the same longitude as at the north margin. Thus the divide makes a jagged-line arc concave to the west. The area west of the divide is drained by Santa Rita, Hanover, Beartooth, and Ansones Creeks, and by Gold and Yellowdog Gulches. These intermittent streams empty into Whitewater and Cameron Creeks, which in turn lead southward to the Deming Basin. The area east of the divide and north of the Georgetown cemetery drains into Shingle, Myers, and Willow Springs Canyons, and eventually into Deming Basin via the Mimbres River. South of the cemetery and east of the divide, the drainage flows via numerous unnamed creeks through Lampbright Draw (Paige, 1916, topog. sheet) and into Deming Basin.

The landforms in the quadrangle reflect an erosional stage of late youth to late maturity and are modified by streams entrenched during Quaternary rejuvenation. The northwestern and southern parts of the area, underlain by volcanic rocks and interbedded gravel, are characterized by precipitous slopes bordering deeply entrenched canyons. The northeast corner is a dissected bench underlain by thick conglomerate deposits of late Cenozoic age. Many ridges in that sector are topped by narrow remnants of a flat surface which slopes gently southward. The landforms in the central part of the quadrangle are cut in older rocks—intrusive igneous rocks and sedimentary rocks ranging in age from early Tertiary to Precambrian. The long somewhat arcuate topographic basin drained by Hanover Creek coincides with the extent of the Hanover-Fierro pluton, which is less resistant than the Paleozoic limestones and Cretaceous quartzites that underlie the surrounding hills and benches. The topographic basin which extends from Wimsattville to Hanover coincides with an elliptical craterlike hole that formed and was filled by clastic sediments in pre-Miocene time. The plugs and sediments within the basin are eroded more easily than the limestone and quartzites that form its rim.

Several hills rise prominently above the general surface in the central part of the quadrangle. These landmarks include Humbolt Mountain and Topknot Hill, both capped by Beartooth Quartzite; Fierro Hill and Hermosa Mountain, capped by sill rock; and Hanover Mountain, capped by metamorphosed sandstone and shale and ribbed by a few dikes.

The prominent surface features of the central part of the area are inherited from an earlier prevolcanism erosional epoch. Before Miocene(?) time the northern and southernmost parts of the quadrangle were deeply excavated, but the central part was left as a topographic high which includes several prominent hills, among them the Hanover and Hermosa Mountains. The upper Tertiary volcanic rocks covered the entire area and preserved the earlier topography. The cover in the central part was relatively thin and was removed by erosion during the Quaternary.

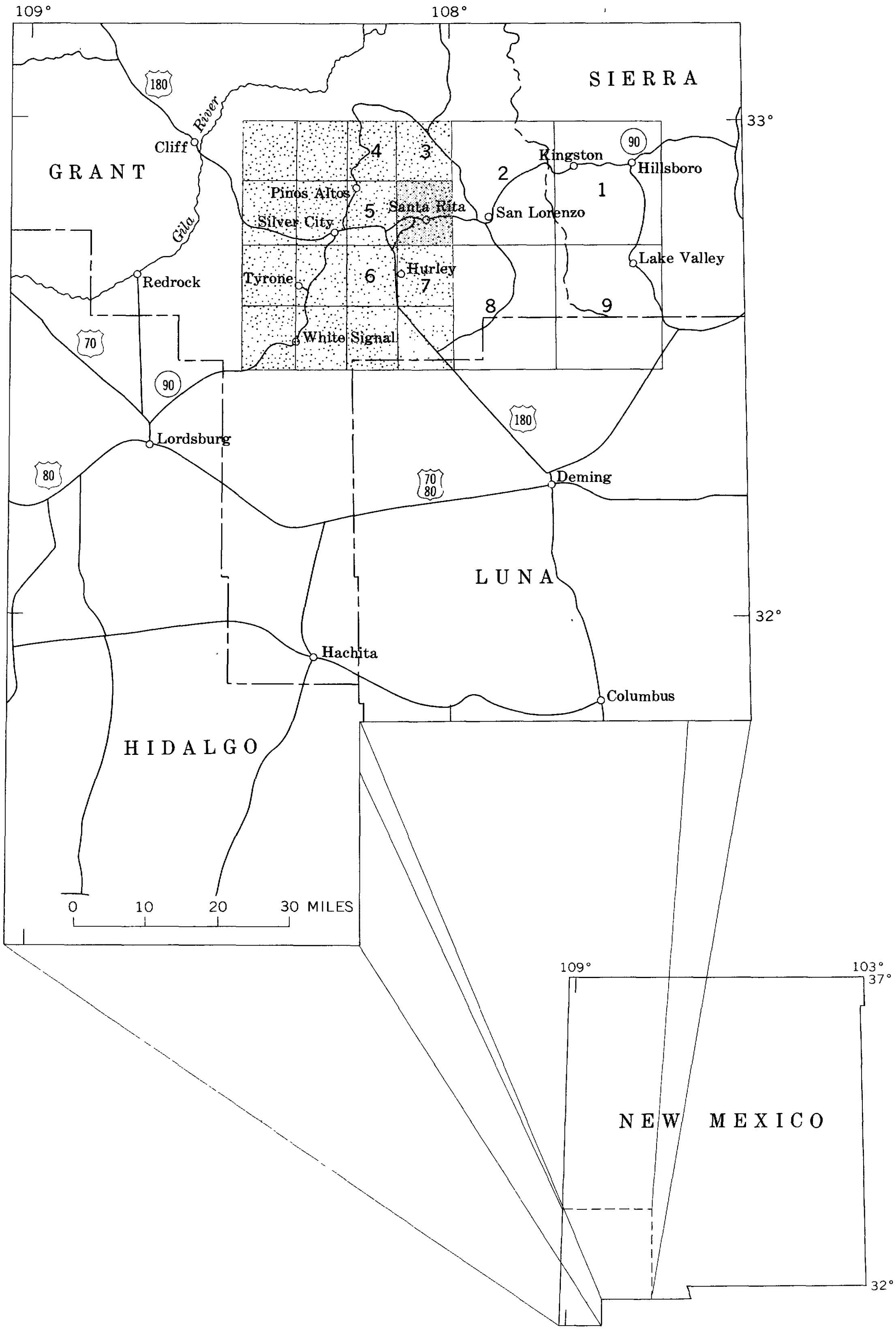


FIGURE 1.—Index map of New Mexico, showing area of plate 1 (shaded), and area of Silver City 30-minute quadrangle (stippled). Names of numbered quadrangles are: 1, Hillsboro; 2, San Lorenzo; 3, Allie Canyon; 4, Twin Sisters; 5, Fort Bayard; 6, Hurley West; 7, Hurley East; 8, Dwyer; and 9, Lake Valley.

The less prominent surface features, related to present-day intermittent streams, were formed subsequent to the uncovering of the pre-Miocene(?) surface. One, or in some places two bench levels are found along some stream valleys. These benches indicate that erosion was accelerated, presumably either by spasmodic uplifts of the area or by abrupt lowering of the base level of the streams.

PREVIOUS WORK

The geology of the Santa Rita area has been investigated almost continuously for the past 80 years. L. C. Graton (in Lindgren and others, 1910), Sidney Paige (1909, 1912, 1916, 1935), A. C. Spencer and Paige (1935), and S. G. Lasky (1930, 1936), geologists of the U.S. Geological Survey, can be credited with working out the basic geology of the area. Mining company geologists, E. H. Wells, J. M. Sully, H. A. Schmitt (1933a, b; 1939a, b; 1942; 1948), P. F. Kerr (in Kerr and others, 1950), G. J. Ballmer (1953), P. G. Leroy (1954), and Georges Ordóñez, W. W. Baltosser, and Keith Martin (1955), to mention a few, have made substantial contributions to the geologic knowledge of the area. Schmitt's contribution, based on careful large-scale mapping, is outstanding, especially his work on pyrometasomatic deposits (1939a, 1948).

In keeping with trends in geologic interest, the subject of rock alteration in the Santa Rita region has attracted considerable attention in recent years. The earliest work emphasizing metamorphism in this region was by R. E. Landon (1929). His report was followed by Lasky's (1936) observations of wallrock alteration associated with vein deposits in the Bayard area, and by Schmitt's (1939a) definitive study of pyrometasomatism at the Pewabic mine. More recently, graduate students from Columbia University, under the direction of P. F. Kerr, have made significant contributions to the understanding of rock alteration (Kerr and others, 1950; Leroy, 1954).

Soon after completing their field investigations of the Santa Rita quadrangle, the authors published a brief report on some of the more interesting geologic features of the area (Hernon and others, 1953). In 1956 the authors placed in open file a geologic map of the Central mining district, at a scale of 1:10,000, and tabular summaries of the igneous and sedimentary rocks (Jones, 1956). In 1961, findings on the geologic events which culminated in primary metalization in the district were published (Jones and others, 1961). An aeromagnetic and geologic map of part of the Silver City mining region, including the area of the Santa Rita quadrangle, was recently published (Jones and others, 1964). In the text that accompanies that map, major magnetic anomalies are interpreted and evaluated. A summary report on the ore deposits of the Central mining district has been prepared by R. M. Hernon and W. R. Jones and will soon be published.

Naturally, much of the geologic interest and work has been centered around the ore deposits. Paige (1909) and Kniffin (1930) described the iron-ore deposits surrounding the Hanover-Fierro pluton; more recently, Kelley (1949), in a comprehensive review, described the geology and economics of the iron-ore deposits of the Central district. The zinc and zinc-lead deposits around the south margin of the Hanover-Fierro pluton were described by Schmitt (1939a, b) and by Lasky and Hoagland (1948). Zinc-lead deposits in the Bayard area were described by Lasky (1936), and briefly by Duriez and Neuman (1948). Publication of a geologic report by Paul Leroy and Keith Martin, formerly geologists of the Kennecott Copper Corp., on the Oswaldo zinc mines, located between the Hanover and Santa Rita mineral centers, has been delayed by the untimely death of Leroy.

The copper deposits of the area have been described by many writers. One of the earliest reports was by John M. Sully (1909),[1] who is credited with recognizing the possibility of developing a large tonnage of low-grade copper ore in the Santa Rita area. L. C. Graton examined the copper deposits in 1905, and Lindgren, Graton, and Gordon (1910) and Paige (1912) reported on them. Spencer and Paige (1935) described the deposits briefly, following examination of them in 1927 and 1932. Since then G. J. Ballmer, W. W. Baltosser, P. G. Leroy, Georges Ordóñez, R. A. Metz, and A. W. Tipton, Jr., employees of the Kennecott Copper Corp., have done large-scale mapping of the mineralized area.

To understand the relation between alteration and hypogene metalization, one must have a complete knowledge of the sequence of igneous intrusions. Considerable progress has been made on this complex problem since Gilbert (1875), after riding through the area, stated that a vast flood of porphyry had risen through the beds of the region and that most of the area was underlain by a "single porphyry."

Graton (in Lindgren and others, 1910) distinguished two porphyries that in general correspond to present-day preore and postore igneous groups. Paige (1909) noted textural variations in the Hanover-Fierro pluton and distinguished early quartz diorite porphyry sills and laccoliths from granodiorite and quartz monzonite stocks and accompanying dikes. Paige also

[1] Sully, John M., 1909, Report on the property of the Santa Rita Mining Co.: Boston, privately printed.

recognized an early preore epoch of intrusion and volcanism that resulted in emplacement of thousands of dikes and thick deposits of andesite breccia. Landon (1929), concentrating on igneous rocks within the productive part of the area and concerned chiefly with preore intrusions, distinguished three groups of granodiorite rocks on the basis of form and texture: (1) granodiorite porphyry sills, (2) coarse- to medium-grained stocklike or laccolithlike granodiorite intrusives, and (3) granodiorite porphyry dikes. He recognized the plug underlying Bull Hill, just east of Hanover, as a postore intrusive, but apparently he was not aware of the multiplicity of postore dikes and plugs or, for that matter, of the multiplicity of preore sills, stocks, plugs, and dikes which are known today. Schmitt (1933b; 1939a) and Spencer and Paige (1935) advanced the knowledge of igneous history when they distinguished postore dacite, quartz latite, and latite porphyry dikes and stocks of Tertiary age from preore dikes and stocks. No attempt was made by Spencer and Paige (1935, p. 33–35) to map individual dikes; hence, they showed only a small percentage of the dikes, and these only schematically. Lasky (1936) first differentiated earlier quartz diorite sills from later quartz diorite sills, although Spencer and Paige (1935, p. 33–35) had previously recognized and accurately described mineralogical and textural variations in the various sills and laccoliths. Spencer and Paige in their mapping did not separate what are now known as the quartz monzonite porphyry dikes and the earlier granodiorite porphyry dikes. They (p. 39) admitted that some granodiorite dikes might have been injected earlier than others, "for in some places they cut mineralized veins, and in others they are cut by such veins." Lasky (1936, p. 35) at first preferred the idea of two ages of veins rather than two ages of granodiorite dikes. Later, however, after more detailed work, he (in Lasky and Hoagland, 1948, p. 14) recognized at least two, and possibly three, ages of granodiorite dikes. Aside from the aplite dikes which as early as 1908 were known to cut the principal stocks, Paige (1909) and Kerr (in Kerr and others, 1950, p. 292) recognized, and in places mapped separately, two groups of granodiorite porphyry dikes and a later series of Tertiary latite dikes. They reported one group of granodiorite dikes as quartz granodiorite porphyry and the other as an older hornblende granodiorite porphyry. Kerr and his coworkers recognized postore quartz porphyry dikes as well as latite dikes, but they probably did not realize the complexity of the postore series. They (p. 299) suspected that the hornblende granodiorite porphyry dikes were older than the principal stocks, but this hypothesis seems unlikely now.

This somewhat lengthy summary of previous work will give the reader some conception of what had been done up to the time work for this report was begun in 1948. Many previous studies would have been more meaningful had the sequence of igneous intrusions been better known. It was largely with this goal in mind that the present work was undertaken, for epochs and stages of intrusion provide the only means of determining the timing of metamorphism and metalization.

SCOPE AND NATURE OF THIS REPORT

RELATION TO REGIONAL STUDY

This geologic investigation of the Santa Rita quadrangle is an integral part of a program intended to appraise the mineral possibilities of the Silver City region—that is, the area within the limits of the old 30-minute Silver City quadrangle (Paige, 1916). A large part of the task involves assembling, integrating, and interpreting information from several operating companies. Four 7½-minute quadrangles have been mapped. The Santa Rita quadrangle, which includes most of the Central mining district, was mapped first, and this report contains the results of that mapping. Reports on the Allie Canyon quadrangle adjoining on the north, the Fort Bayard quadrangle on the west, and the Hurley West quadrangle to the southwest are being prepared. This report covers the general mapping phase of the proposed district study, which should eventually include special investigations of stratigraphy, igneous petrology, rock alteration, and individual ore deposits.

FIELDWORK

Remapping of the Santa Rita quadrangle began in 1945 and continued, with some interruption, until July 1952. Mapping of approximately 3 square miles in the southwestern corner of the area was adapted from Lasky's revision of his earlier (1936) map, at a scale of 1:12,000. His field revision was accomplished at intervals from 1945 to 1948. The following individuals, listed in order of decreasing time spent on the project, took part in the geologic mapping: R. M. Hernon, S. G. Lasky, W. R. Jones, S. L. Moore, A. F. Shride, T. G. Lovering, J. K. Grunig, M. W. Cox, and G. S. Koch, Jr. From 1953 to 1965 Jones revisited the area on numerous occasions, modifying and adding to the geologic map. Efforts to date have been expended largely in providing a basic geologic map of the district, with special attention to determining the sequence of igneous intrusions. It has been necessary to identify the rocks in many areas through the veil of alteration, with only cursory attention to the nature of the alteration.

MAPPING METHODS

Parts of the geologic map (pl. 1) were adapted from large-scale geologic maps made available to the authors by numerous individuals associated with mining companies. The surface geologic map of the Pewabic mine, made under the direction of Schmitt (1939a), has been reduced more than twentyfold and otherwise adapted to the scale and nomenclature of the quadrangle map. Similarly, the map of a ½-square-mile part of the Hanover region was adapted from large-scale surface maps. (See Kerr and others, 1950, fig. 19 and pl. 10.) Large-scale maps of small areas made by company geologists were accessible to the authors. These were valuable not only as guides in mapping of complex areas, but also as assurance that in the smaller scale mapping no areas of geologic importance would be overlooked.

The complex geology in the heart of the mining district and in a few square miles along the east margin of the quadrangle was mapped at a scale of 1:12,000 with planetable and open-sight alidade. The north and south Chino pits were mapped, bench by bench, at scales ranging from 1:2,400 to 1:6,000. The rest of the quadrangle was mapped at a scale of 1:10,000, principally on enlargements of the undistorted parts of aerial photographs.

ACKNOWLEDGMENTS

We are indebted to several companies and to many individuals—particularly the managements of the local divisions and operating subsidiaries of the American Smelting and Refining Co., the Empire Zinc Co., the Kennecott Copper Corp., the Peru Mining Co., and the U.S. Smelting, Refining and Mining Co.—for their assistance in compilation of a comprehensive and up-to-date report on the area. Courtesies extended by the companies included access to information and mines, and availability of their technical and operating staffs for discussion of certain geologic problems. The following individuals aided our work in the district: James P. Pollock and Byron Hardie, of the American Smelting and Refining Co.; John Faick, Joseph Horton, Walter E. Granlund, and Jerry F. Parker, of the New Jersey Zinc Co.; Will W. Baltosser, Robert A. Metz, and Arthur W. Tipton, Jr., of the Kennecott Copper Corp.; Jerry W. Faust, L. J. Conley, and J. W. Burgess, of the American Zinc, Lead and Smelting Co.; and James V. Neuman, Jr., and Stearns Cook, of the U.S. Smelting, Refining and Mining Co. Special acknowledgment is made to the late G. J. Ballmer, former superintendent of mines, Kennecott Copper Corp., and to H. A. Schmitt, consulting geologist, for their many helpful discussions and specific aids. Ira Wright, mining engineer of Silver City, N. Mex., gave information also regarding earlier operations at certain properties.

GEOLOGIC SETTING

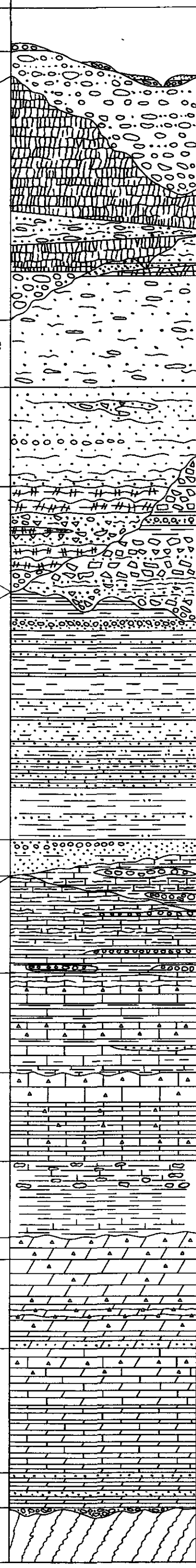
The Santa Rita quadrangle is near the southeastern tip of the Colorado Plateau and on the north rim of the Sonoran geosyncline, where sedimentary rocks are relatively thin (McKee, 1951, pl. 3*D*). The "Tectonic Map of the United States" (King and others, 1944) shows that the Santa Rita area lies near the confluence of a southeast-trending and a south-trending tectonic belt. In the Santa Rita–Silver City–Tyrone region, the prominent structures of the southeast-trending belt include faults of northwest and northeast trend. The fault of the south-trending tectonic belt closest to the map area is about 12 miles to the east, in the Black Range. The geologic setting of the Santa Rita quadrangle is well illustrated on the new geologic map of the southwestern part of New Mexico (Dane and Bachman, 1961).

Although Fenneman (1931) considered the quadrangle to be within the Mexican Highland section of the Basin and Range province, actually the Santa Rita quadrangle is within the broad transitional zone between the Colorado Plateaus and the Basin and Range province.

Many types of rocks ranging in age from Precambrian to Recent occur in the Santa Rita quadrangle: (1) gneiss of Precambrian age; (2) quartzite, shale, dolomite, and limestone of Paleozoic age; (3) andesite breccia of Late Cretaceous(?) and early Tertiary age; (4) syenodiorite to granodiorite sills, laccoliths, and dikes, and granodiorite, quartz monzonite, quartz latite, and rhyodacite stocks, plugs, and dikes, of early Tertiary age; (5) a sequence that includes rhyolite to quartz latite crystal and lithic tuffs, and andesite and basalt flows interbedded with water-laid deposits of sand, tuff, and conglomerate, of Miocene(?) age; and (6) valley-fill deposits of Miocene(?) to Pleistocene age.

The distribution of the various rocks is shown on plate 1, and the succession and thickness of layered rocks are shown in figure 2 and on plate 2.

Exposures of the Precambrian metamorphic rocks are restricted to a small lens-shaped area along the east-central margin of the Hanover-Fierro pluton (pl. 1), where the Precambrian and Paleozoic rocks were bent sharply upward by the forceful intrusion of magma. Paleozoic rocks of pre-Mississippian age are exposed on the east and west sides of the Hanover-Fierro pluton. They crop out also along the escarpment southwest of the Mimbres fault, in the northeastern part of the quadrangle.



SYSTEM OR SERIES	FORMATION	APPROXIMATE RANGE IN THICKNESS (FEET)	LITHOLOGY
Recent and Pleistocene	Younger alluvium Older alluvium		Unconsolidated alluvium and colluvium in valley floors, flat uplands, and on slopes. Includes sand, silt, and gravel.
Pliocene and Miocene(?)	Gravel deposits in Mimbres River system	0-800	Somewhat consolidated poorly sorted bolson deposits ranging from silt to boulder deposits. Similar and in part equivalent to Gila Conglomerate and Santa Fe Formation.
Miocene(?)	Basaltic andesite flows and underlying gravel and boulder deposits	0-850	Dark-gray finely crystalline porphyritic flows; weather reddish brown; contain phenocrysts of pyroxene, magnetite, and olivine in matrix of labradorite.
Miocene(?)	Pitchstone, sandstone, and indurated rhyolite tuff underlain by Kneeling Nun Tuff	0-600	Crystal fragments of quartz, sanidine, biotite, and oligoclase, and rock fragments imbedded in compacted glass shards, in part devitrified and in part replaced by chalcedony. Black pitchstone contains rock fragments and is locally vesicular.
Miocene(?)	Sugarlump Tuff	0-600	Pumiceous tuff, gravel, and sandstone locally replaced by clinoptilolite. Generally well stratified.
			Andesite breccia.(See below.)
Miocene(?)	Rubio Peak Formation	0-600	Conglomerate containing intercalated indurated tuffs and rhyodacite and andesite flows. (Rubio Peak Formation)
Lower Tertiary and Upper Cretaceous(?)	Andesite breccia	0-500	Andesite breccia and fine-grained crystal tuff, volcanic sandstone, and some nonvolcanic sandstone and mudstone.
Upper Cretaceous	Colorado Formation	0-1000	Upper 800 feet consists of tan, greenish-brown, and white sandstone interbedded with dark-green, brown, and black shale. Lower 225 feet is black limy shale except for 20 feet of quartzite about 80 feet above base. Thin beds of fossiliferous impure limestone conspicuous in lower part above the lower beds of black shale.
Upper(?) Cretaceous	Beartooth Quartzite	66-142	Fine-grained quartzite containing thin black-shale partings locally. Conglomerate beds near top.
Lower Permian	Abo Formation	0-265	Red shale, mudstone, and limy mudstone containing lenses of algal conglomerate locally.
Upper Pennsylvanian	Syrena Formation	170-390	Impure limestone and limestone interbedded with irregular lenses of red calcareous shale and with shale beds particularly in lower 140 feet.
Upper and Middle Pennsylvanian	Oswaldo Formation	330-420	Blue-gray limestone, fairly pure except in upper part, interbedded with thin shale beds; gray to red siliceous shale or grit about 20 feet thick occurs at base; known locally as "Parting shale."
Lower Mississippian	Lake Valley Limestone	300-400	Limestone, pure crinoidal and massive in upper part, argillaceous and thin bedded in central part. Much nodular chert throughout.
Upper Devonian	Percha Shale	230-315	Upper member, or Box Member, is gray calcareous shale containing abundant limestone nodules; lower member, or Ready Pay Member, is black fissile shale, calcareous at base.
Silurian	Fusselman Dolomite	100-300	Gray cherty finely crystalline vuggy massive dolomite.
Upper and Middle Ordovician	Montoya Dolomite	300-350	Light-gray to gray very finely crystalline massive dolomite containing interbedded dolomite and dark chert in central part and concentrations of opalescent quartz sandstone at base.
Lower Ordovician	El Paso Limestone	500-519	Thin- to thick-bedded light-gray limestone and dolomite. Chert nodules in upper part; abundant fucoidal markings in lower part.
Upper Cambrian	Bliss Formation	140-188	Predominantly dark-brown massive quartzite, locally hematitic and glauconitic. Grayish-brown shaly dolomite and basal coarse conglomerate locally.
Precambrian			Granite, granite gneiss, and greenstone.

FIGURE 2.—Columnar section of layered rocks Santa Rita quadrangle, Grant County, N. Mex.

The west-central and northeastern parts of the quadrangle are underlain by gently inclined resistant limestone beds of Carboniferous age, predominantly the Pennsylvanian limestones. The southern part of the district is underlain by the Beartooth Quartzite and the Colorado Formation of Late Cretaceous age, by thick sills of quartz diorite, and by tuffs and flows of Miocene(?) age. The northwestern part of the area, north of the Barringer fault, is underlain by clastic beds of Late Cretaceous age; large laccolithic bodies of syenodiorite of Laramide age; andesite breccia, tuffs, and thousands of basic dikes of Late Cretaceous(?) and early Tertiary age; and tuffs and flows of Miocene(?) age. Granodiorite or quartz monzonite porphyry stocks and dikes and a somewhat younger suite of more salic porphyries predominate in the central part of the quadrangle. These rocks are probably all of early Tertiary age and are older than the Miocene(?) volcanic suite.

PRECAMBRIAN ROCKS

In the Santa Rita quadrangle, Precambrian rocks crop out in only one place and have been penetrated in only one deep drill hole.

About 2,000 feet east of Fierro and just west of the Humbolt shaft (sec. 10, R. 12 W., T. 17 S.), light-gray finely crystalline gneiss, containing abundant black lenticular clots and streaks of finely crystalline biotite, underlies a narrow lenticular area measuring 1,600 feet in a northerly direction and about 150 feet in an easterly direction. The lenticular area is bordered on the east by the Bliss Formation and on the west by the Hanover-Fierro pluton. The streaks of biotite in the lens give the rock a speckled appearance and a vertical gneissic structure (fig. 3.) Thin-section examination reveals that the material between the biotite streaks consists primarily of potassic feldspar and quartz, commonly forming an aplitic (allotriomorphic granular) texture but also arranged in parallel streaks conformable to the orientation of the lenticular clots of biotite. Stubby grains of zoisite make up 5–10 percent of one specimen; in some places numerous well-separated grains of zoisite have the same optical orientation. Brown biotite flakes are disseminated throughout the rock as well as the clots. The amount of biotite ranges from 5 to 20 percent; a few grains are bleached and altered to muscovite or chlorite. Muscovite is irregularly disseminated, and in one thin section it appears to replace the potassium feldspar almost completely. Magnetite and zircon are common accessory constituents but make up less than 1 percent of the rock. A few grains of tourmaline and kaolinite are present.

FIGURE 3.—Precambrian gneiss, containing black lenticular clots and streaks of finely crystalline biotite.

Near the center of sec. 23, T. 17 S., R. 12 W., about 1 mile north of Santa Rita, gray and pink Precambrian granite was penetrated by drill at a depth of 2,000 feet (elev 4,546 ft). Between depths of 1,925 and 2,000 feet, just below the Bliss Formation, the material recovered was classified as probably igneous.

In the surrounding region, Precambrian rocks crop out west of the Mimbres River along State Highway 90, along the west flanks of the Silver City Range and Lone Mountain, and, farther west, in the Little and Big Burro Mountains. The rocks include many varieties of granitic rock, and also micaceous schists, gneisses, greenstone, and quartzite. Brief descriptions of these occurrences were given by Entwistle (1944), Paige (1916), and Gillerman and Whitebread (1956). Kuellmer (1954, p. 6) stated that Precambrian rocks in the Black Range consist of graywacke and granite cut by diabase dikes.

PALEOZOIC ROCKS

The succession of Paleozoic strata exposed in the Santa Rita and adjoining quadrangles ranges from Cambrian to Permian in age. Although epochs of each period in the Paleozoic Era are represented, the thickness of the Paleozoic section aggregates only about 3,100 feet. Comparable thickness characterizes sections in adjoining areas within a radius of about 50 miles; for example, the section is about 2,400 feet thick in the Black Range (Kuellmer, 1954, p. 11), about 2,300 feet thick in the Cooks Range

(Jicha, 1954, p. 32–34), and about 2,000 feet thick in the Silver City Range. Epochs within the Paleozoic Era for which no sedimentary record exists, owing either to nondeposition or to erosion, are Early and Middle Cambrian, Late Silurian, Early and Middle Devonian, Late Mississippian, and Late Permian.

Except for the continental red beds of Early Permian age (the Abo Formation), all the sedimentary rocks of this era were deposited in shallow seas, evidently on an intermittently submerged foreland shelf. Nine principal formations of Paleozoic age have been distinguished in the Santa Rita quadrangle: the Bliss Formation, of Late Cambrian and Early Ordovician age; the El Paso Limestone, of Early Ordovician age; the Montoya Dolomite, of Middle and Late Ordovician age; the Fusselman Dolomite, of Silurian age; the Percha Shale, of Late Devonian age; the Lake Valley Limestone, of Early Mississippian age; the Oswaldo and Syrena Formations of the Magdalena Group, of Middle and Late Pennsylvanian age; and the Abo Formation, of Early Permian age.

Data on the chemical composition of carbonate rocks of all ages in New Mexico were compiled by Kottlowski (1957, 1962). Additional chemical analyses of the El Paso Limestone, the Montoya Dolomite, the Lake Valley Limestone, and the Oswaldo Formation were reported by Schmitt (1939a, tables 8, 9, p. 801).

CAMBRIAN AND ORDOVICIAN SYSTEMS—BLISS FORMATION

The sandstone, quartzite, and carbonate beds that lie unconformably upon Precambrian rocks throughout most of southern New Mexico are correlated with the lithologically similar Bliss Sandstone in the Franklin Mountains, north of El Paso, Tex. In agreement with usage by Kelley and Silver (1952, p. 33), these basal beds of the Paleozoic section, in recognition of their diverse lithology, are called the Bliss Formation. In this region the upper contact of the Bliss is commonly obscure. Although an erosional surface may locally separate the Bliss Formation from the overlying El Paso Limestone, in many places the contact is gradational, and beds typical of each formation alternate and intertongue (Kelley, 1951, p. 2201). The contact of the Bliss with the Precambrian is generally more easily located.

The Bliss Formation is not extensively exposed in the Santa Rita quadrangle, occurring only at places along the sides of the north-trending Hanover-Fierro pluton. These exposures are severely sheared and metamorphosed. Where exposed in the creek bed north of Snowflake Canyon (sec. 10, T. 17 S., R. 12 W.), considerable magnetite has been introduced, so that the rocks have a black to greenish-black cast; and soft, presumably sheared, beds of green earthy material intervene between hard ill-defined layers of quartzite. The formation at this place is 140 feet thick, but this can hardly be the true thickness. Spencer and Paige (1935, p. 13) assigned the base of the Bliss Formation 95 feet lower than do the authors; the 95 feet of "schistose quartzite" at the base of their section is assigned in this report to the Precambrian.

On the west flank of the Hanover-Fierro pluton, the only material definitely recognizable as belonging to the Bliss Formation is on the south side of a trail which crosses the north end of Union Hill. At that place, reddish-brown quartzite lies against the pluton and is overlain by green earthy layers of sheared and altered rock. Elsewhere along the western contact of the stock, lenses of highly metamorphosed quartzite and green material occur below beds of El Paso Limestone.

Measured sections.—The original character of the Bliss Formation was probably intermediate between its character in exposures 8 miles east and 8 miles southwest of Santa Rita; detailed descriptions of these exposures, therefore, are given in the following stratigraphic sections.

Bliss Formation (San Lorenzo quadrangle), 8 miles, by State Highway 90, east of Santa Rita, N. Mex.

	Thickness (feet)
El Paso Limestone.	
Bliss Formation:	
Quartzite, crossbedded, glauconitic, varicolored; lower 4 ft shaly	17
Limestone, thin-bedded, finely to coarsely crystalline, dolomitic; contains shaly partings; weathers massive or to slabs; trilobite fragments	14
Sill rock (18 ft).	
Limestone, dolomitic, thin-bedded, yellow to brown, finely crystalline to dense; many thin layers rich in glauconite in lower half; much of the limestone is conglomeratic	40
Quartzite, brown; weathers to rust color; medium to very coarse grained; crossbedding conspicuous in upper part. Top 12 in. is coarse grit. Fragments of limestone and trilobites in lower part	25
Limestone, dolomitic, medium-bedded, conglomeratic; glauconitic at base	13
Limestone, dolomitic, impure, with shaly partings; glauconitic sandstone beds in lower 3 ft	8
Dolomite, conglomeratic and glauconitic; contains subrounded to angular fragments of Precambrian greenstone which are increasingly abundant toward base; shaly partings and intraformational conglomerate beds common	17
Conglomerate, unsorted; angular to subrounded pebbles and boulders as much as 4 ft long of the underlying Precambrian greenstone; upper 3 ft is conglomerate composed of well-rounded granules and small pebbles of greenstone; grades abruptly into overlying conglomeratic dolomite	12
Total	146
Unconformity.	
Precambrian greenstone.	

Bliss Sandstone (Hurley West quadrangle), southwest side of west peak of Lone Mountain, 8 miles southwest of Santa Rita, N. Mex.

[W. P. Pratt, written commun., 1961]

El Paso Limestone.

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

Precambrian granite.

Fossils, age, and correlation.—No fossils were found in the Bliss Formation within the Santa Rita quadrangle, but well-preserved brachiopods were obtained from glauconitic sandstone 11–47 feet above the base of the formation at Lone Mountain; most abundant were *Billingsella coloradoensis* and *Eoorthis* (R. H. Flower, written commun., 1960). Small trilobite fragments were noted in the Bliss Formation exposed 8 miles east of Santa Rita, but there the brachiopod-bearing units that occur in the Lone Mountain section are missing. Paige (1916, p. 4) reported *Billingsella coloradoensis* and fragments of *Ptychoparia* in glauconitic sandstones near the base of the Bliss in the Silver City Range.

Dr. R. H. Flower, of the New Mexico Bureau of Mines and Mineral Resources, has made considerable progress in the faunal zonation of the Bliss Formation in New Mexico, but at present (1964) this zonation is not complete. In the Franklin Mountains, Tex., the type locality, the entire Bliss Formation was assigned to the Early Ordovician by Cloud and Barnes (1946) because of its similarity to the so-called Bliss at Beach Mountain. J. Bridge, however, regarded the Bliss at its type locality as Late Cambrian (King and Flawn, 1953, p. 98). At some localities in southern New Mexico the lower part is Late Cambrian. According to Flower (1958, p. 63, 66), the lowermost beds of Late Cambrian age seem to be restricted to the Silver City–Lone Mountain area and are considered to be of early Franconian age. Beds of late Franconian age are present in many ranges in southwestern New Mexico and are probably represented in the region surrounding the Santa Rita quadrangle. Beds of the uppermost Cambrian (Trempealeau Stage) are represented by the second quartzite from the top at both Lone Mountain and the locality 8 miles east of Santa Rita (Pratt, 1967). The Cambrian part of the Bliss is about 132 feet thick at Lone Mountain and 75 feet thick at the exposure east of Santa Rita. The remaining units, totaling 56 and 71 feet, respectively, at the two exposures are of Early Ordovician age (early Gasconadian, according to Flower, 1958, p. 63).

The Cambrian part of the Bliss Formation is correlated with the upper part of the Abrigo Limestone of southern Arizona as defined by Ransome (1904), and with the Orr and Notch Peak Formations of the House Range, Utah (Howell and others, 1944). Epis and Gilbert (1957) believed that the Cambrian and Ordovician parts of the Bliss were equivalent in part to the dolomite and sandstone of the uppermost Abrigo which successively underlie the El Paso Limestone in southeastern Arizona (fig. 4). The brachiopod *Billingsella* is found near the base of this dolomite and also near the base of the Copper Queen Limestone Member, the upper member of the Abrigo, near Bisbee, Ariz. (Stoyanow, 1936, p. 470), and near the top of the Abrigo in the Swisshelm Mountains, where it is associated with *Eoorthis* (Gilluly, 1956, p. 24). *Billingsella* has not been found in Cambrian beds older than the Franconian Stage (Conaspis zone), notwithstanding extensive collecting. If *Billingsella* is truly so restricted in occurrence, the correlation of part of the Bliss with upper units of the Abrigo seems reasonable.

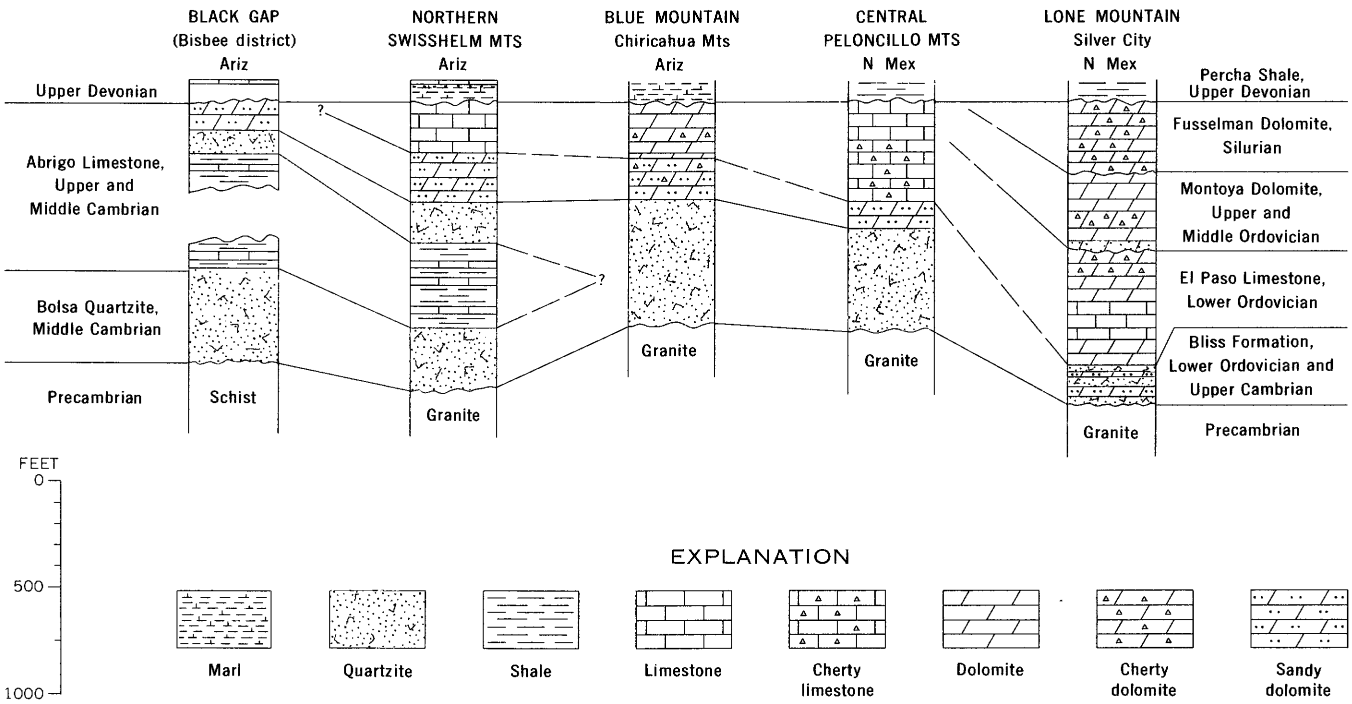


FIGURE 4.—Suggested correlations and relations of lower Paleozoic strata between Bisbee, Ariz., and Silver City, N. Mex. (Modified from Epis and Gilbert, 1957, fig. 4, p. 2238.)

ORDOVICIAN SYSTEM

EL PASO LIMESTONE

The light-gray thin-bedded limestone that has siliceous crenulations and lies above the glauconitic and ferruginous quartzite of the Bliss Formation and below the coarse basal sandstone or sandy dolomite of the Montoya Dolomite of Middle and Late Ordovician age was named the El Paso Limestone by Richardson (1909). The type locality, in the Franklin Mountains north of El Paso, Tex., was redescribed in detail and the formation subdivided into three units and two subunits by Cloud and Barnes (1946). Kelley and Silver (1952, p. 40) suggested that the El Paso Limestone be raised to group status and be subdivided into two formations, the Sierrite Limestone at the base and the Bat Cave Formation at the top. These formations cannot be mapped in the Santa Rita quadrangle nor in the Black Range to the east (Kuellmer, 1954), and they are difficult to map in the Cooks Range to the southeast (Jicha, 1954, p. 8–11). It seems advisable, therefore, to retain the El Paso as of formation rank, and to use the stratigraphic and faunal zones described by Flower (1955, p. 67–69) wherever necessary for locating minor faults. Many of these zones can be distinguished in the essentially unmetamorphosed section of the El Paso at Lone Mountain.

The El Paso Limestone seems to be conformable with the underlying Bliss and the overlying Montoya Formations. The basal contact of the El Paso is somewhat arbitrarily placed at the top of the uppermost quartzite bed of the Bliss. No evidence has been found to indicate a time break between the Bliss and the El Paso. The upper contact is a disconformity that represents part of Middle Ordovician time.

Within the Santa Rita quadrangle the El Paso Limestone is exposed in a small area southeast of Georgetown, where only the uppermost beds are present, and around the Hanover-Fierro pluton, where it is abnormally thin, metamorphosed, and faulted.

Around the pluton, the El Paso and other formations of early Paleozoic age were arched, by the forceful intrusion of the magma, into an elliptical dome, whose long axis trends northwest. The south and north margins of the dome were stoped by the magma, so that only stretched limbs remain on the southwest and northeast flanks. In the ridge south of Snowflake Canyon the El Paso is 323 feet thick, dips 40°–25° E., and is composed of white coarsely crystalline thin-bedded dolomitic marble separated by thin wavy siliceous layers. The dip of the rocks flattens with increasing distance from the pluton. The position of the 323 feet of El Paso with respect to the normal stratigraphic section of El Paso, which measures 519–534 feet thick in adjoining areas, is not known. The section adjacent to the pluton may have been thinned by internal shearing, by faulting along the contact with the Bliss, or by erosion of the topmost beds before deposition of the Montoya Dolomite. A generalized stratigraphic section of the El Paso Limestone exposed in the ridge south of Snowflake Canyon follows.

El Paso Limestone measured along ridge south of Snowflake Canyon, NE¼ sec. 15, T. 17 S., R. 12 W.

Montoya Dolomite.	
El Paso Limestone:	
Limestone, white, dolomitic, coarsely crystalline; contains chert nodules; thicker bedded than underlying unit	97
Limestone, white, dolomitic, coarsely crystalline; about 20 percent chert nodules; thin bedded	123
Limestone (marble), white, dolomitic, tremolitic, thin-bedded, with thin wavy siliceous layers	113
Total	323
Bliss Formation.	

The El Paso is even more highly metamorphosed west of the pluton, along the east flank of Union Hill, where the pluton irregularly penetrated the lower Paleozoic beds. The thickest section of El Paso Limestone on the west side of the Hanover-Fierro pluton is exposed in the hill southeast of the Continental shaft (sec. 9, T. 17 S., R. 12 W.), but the upper and lower limits are very poorly defined, and the formation is strongly folded. Across the gulch to the south the beds swing sharply eastward before turning southward to parallel the margin of the pluton. Several prongs of the pluton penetrate this flexure. Farther south, along the east flank of Union Hill and as far as the Union Hill portal, the El Paso Limestone is very thin or absent between the distinctive chert-rich layers of the Montoya and the pluton. The Hanover-Bessemer iron pits are in the chert-rich layers and the underlying sandy dolomite. The basal sandstone of the Montoya is not recognizable, unless the quartzite above the Union Hill portal is Montoya rather than a sliver of Bliss. In lenticular areas between the pits and the pluton, beds of coarse andradite garnet occur; these units may be metamorphosed beds of the El Paso.

Measured sections.—The original character of the El Paso Limestone was probably intermediate between its character in exposures 8 miles east and 8 miles southwest of Santa Rita. Detailed descriptions of these exposures are given in the following stratigraphic sections.

El Paso Dolomite, southwest side of west peak of Lone Mountain

[W. P. Pratt, written commun., 1961]

	Thickness (feet)
Montoya Group, Second Value Dolomite, Cable Canyon Sandstone Member.	
El Paso Dolomite:	
Dolomite, medium-gray; weathers light brownish gray; fine to medium crystalline; thick bedded, blocky to massive; contains nodules and wavy layers of chert as much as 1 in. thick at many horizons; calcite veins fairly common	233
Dolomite, medium-dark-gray, medium-crystalline, granular, thick-bedded; massive fracture; locally conglomeratic; conglomerate contains slabby ½- to 1-in. fragments of dolomite	9

El Paso Dolomite, southwest side of west peak of Lone Mountain—Continued

	Thickness (feet)
El Paso Dolomite—Continued	
Limestone, light-gray; weathers light bluish gray to medium gray, locally with abundant distinctive light-brown fucoidal markings (irregular amoeboid splotches as much as several inches long, having long dimensions generally parallel to the bedding); both crystalline and clastic; grain size variable but generally very fine to medium; generally very thin bedded; blocky to massive fracture; chert lenses 30 ft above base; contains a few crosscutting masses of limestone conglomerate consisting of limestone fragments less than 1 in. across in a medium-grained clastic limestone matrix; two thin dolomite beds in upper part	177
Dolomite and limestone, interbedded	5
Dolomite, light- to medium-gray; weathers light brownish gray; fine to medium crystalline; very thin bedded, blocky; abundant fucoidal markings in lower 60 ft	95
Total	519
Bliss Sandstone.	

El Paso Limestone, north wall of canyon above State Highway 90, about 6 miles east of Santa Rita, N. Mex.

	Thickness (feet)
Base of Montoya Dolomite:	
Sandstone, fine-grained to very coarse grained	12
El Paso Limestone:	
Limestone, light-gray, thick-bedded, dense but crystalline; contains abundant small to large irregular nodules of chert; forms cliff with overlying sandstone	13
Limestone, light-gray, thick-bedded, dense and crystalline; contains a few wavy siliceous layers and sparse irregular light-colored nodules of chert; forms ledges	92
Limestone, light-gray, dense; contains a few thin fossiliferous crystalline beds and some dark-gray dense limestone with specks of crystalline calcite; forms irregular ledges	44
Largely covered, but probably mostly gray finely crystalline limestone	8
Limestone, medium- to light-gray; weathers buff; moderately massive; contains many thin wavy siliceous bands and nodular chert and dark-gray layers, especially in upper part. Some fossiliferous beds and thin fragmental layers. Forms slopes which have ledges	73
Limestone, dark-gray, thin-bedded, very finely crystalline to dense; contains sparse calcite grains (cystoid fragments?) and many thin wavy siliceous streaks. Conspicuous seaweed(?) markings. Some intraformational conglomerate layers	10
Limestone, medium-gray, finely crystalline and mottled. Partly covered	10
Limestone, gray, thin-bedded, in part slabby, crystalline; contains wavy siliceous bands. Partly covered	20
Limestone, gray, dense, moderately massive and crystalline	23
Shale	4
Limestone, light-colored, crystalline	13

El Paso Limestone, north wall of canyon above State Highway 90, about 6 miles east of Santa Rita, N. Mex.—Con.

	Thicknes (feet)
El Paso Limestone—Continued	
Limestone, light-gray to buff; weathers white; dense; contains thin wavy siliceous partings	55
Limestone, white, crystalline, crinoidal	4
Limestone, light-gray, massive, dense; weathers white	5
Limestone, crystalline; probably crinoidal or cystoid bed	3
Limestone, light-gray to buff, finely crystalline, dense; has wavy thin siliceous partings. Thin flat-coiled gastropods, *Ophileta*	62
Limestone, olive-brown, medium to finely crystalline; lacks wavy siliceous layers	4
Limestone, light-gray and gray-buff, finely crystalline to dense, thin-bedded; contains numerous interbedded wavy siliceous layers	91
Total	534
Bliss Formation.	

Fossils, age, and correlation.—In southwestern New Mexico the El Paso Limestone is locally very fossiliferous, especially in nondolomitized beds; but within the Santa Rita quadrangle the fossils have been obliterated by deformation and metamorphism. The fauna in the El Paso at nearby Lone Mountain includes gastropods, straight and curved cephalopods, and less abundant brachiopods, sponges, and trilobites (Pratt, 1967). The lower 100 feet of the El Paso Limestone at Lone Mountain is dolomitized, and fossils are sparse. However, the gastropod *Ophileta* and the brachiopod *Apheoorthis* are present, indicating an early Canadian (Gasconade) age (R. H. Flower, oral commun., 1960). These beds made up the Sierrite Limestone of Kelley and Silver (1952).

Flower (1953, p. 106), referring to the Sierrite Limestone, the lower formation of the El Paso Group, stated that the fauna was sparse and included *Clarkeoceras*, *Ophileta*, *Symphysurina*, *Hystricurus*, *Kainella*, and *Leiostegium*. This fauna, he stated, "indicates a correlation with the Gasconde" (lower Canadian). The upper formation of the El Paso, the Bat Cave Formation, "contains a succession of faunas ranging in age from Middle Canadian (Gorham and Roubidoux equivalents) to beds of Powell or possibly younger age" (Flower, 1953, p. 107). Siphuncles of endoceroid and piloceroid cephalopods, as well as abundant sponges and a variety of gastropods, brachiopods, and trilobites, are conspicuous except in dolomitized beds. Further details will be presented in a forthcoming report on the Hurley West quadrangle by Pratt (1967).

Kelley and Silver (1952, p. 56) stated that the El Paso was originally either entirely or partly continuous with the Abrigo (restricted), Copper Queen, Longfellow, and Muav Formations of Arizona. Together these units supposedly form a "homotaxic carbonate blanket," which accumulated as the seas transgressed eastward. Epis and Gilbert (1957, p. 2223), however, stated that the El Paso Limestone should no longer be considered as the age equivalent of the Abrigo Formation, for the El Paso overlies the Abrigo in several places. The Abrigo, except for the topmost sandstone and dolomite units, which are probably equivalent to part of the Bliss Formation, pinches out to the east before reaching the Chiricahua or Dos Cabezas Mountains of eastern Arizona. (See fig. 4.)

The El Paso Limestone is correlated with parts of several formations of the Western United States—for example, the Manitou Formation of Colorado, the Garden City Formation of Utah, the Ellenburger Group of Texas, and the Goodwin Limestone and Ninemile Formation of the Pogonip Group of Nevada, Utah, and California. (Twenhofel, 1954, p. 247–298; Reuben J. Ross, Jr., written commun., 1963.)

MONTOYA DOLOMITE

The Montoya Dolomite was described by Richardson (1908) and named by him for a railroad station 10 miles north of El Paso, Tex. Richardson regarded the upper limit of the formation to be at the top of a chert-rich sequence of beds bearing fossils of Late Ordovician age, but Entwistle (1944) raised the upper limit to include light-gray fine-grained dolomite beds containing stratigraphically higher Late Ordovician fossils. At most places the contact between the Montoya and the overlying Fusselman Dolomite is well defined by an abrupt change in color (from light gray to brownish gray), in grain size (from sublithographic to finely crystalline), in fossil content (from meager to relatively abundant), and in texture (from dense to decidedly vuggy) (fig. 5). Because these contrasting features cannot be recognized in the aureole of metamorphism surrounding the Hanover-Fierro pluton, the Montoya and Fusselman Dolomites cannot be mapped separately in that area. East and southeast of Georgetown, however, the contact is clearly defined, and the formations are shown separately on the geologic map. Toward the east margin of the quadrangle the contact is only approximately located, however, because the combination of dip slope, poor exposure, faults, and widespread silicification makes the contact difficult to follow. The base of the Montoya is defined as the base of a sandstone unit, where that unit is present, or as the base of massive sandy dolomite beds where the sandstone unit is missing.

Four lithologic units are recognizable in the Montoya Dolomite: the Cable Canyon Sandstone Member at the base, overlain in succession by the Upham Dolomite Member, the Aleman Cherty Member, and the

Cutter Dolomite Member. These members were named by Kelley and Silver (1952), who gave them formation rank in the Montoya Group. The present authors rank the units as members for two reasons: first, the lower two units are not mappable in many places at a scale of 1:24,000, and second, the rank as members is consistent with the rank given units of similar thickness and extent in other formations—for example, those in the Percha Shale and those in the Lake Valley Limestone. The type sections of the four units of the Montoya are in the Caballo Mountains, about 50 miles east of the Santa Rita quadrangle. The rather involved evolution of the nomenclature of Upper Ordovician and Silurian rocks was summarized by Pratt and Jones (1961).

Cable Canyon Sandstone Member.—The Cable Canyon Sandstone Member crops out intermittently along the east side of the Hanover-Fierro pluton and in an area about a mile to the east, southeast of Georgetown (sec. 8, T. 17 S., R. 11 W.). In Snowflake Canyon it is about 10 feet thick, but on the next ridge south it is less than 1 foot thick. Elsewhere around the Hanover-Fierro pluton it is absent, or almost so, as a result either of shearing during intrusion of the stock or of nondeposition. East-southeast of Georgetown the Cable Canyon is 28 feet thick and can be followed for several hundred feet.

The contact of the Cable Canyon with the underlying El Paso Limestone is sharp, but its upper contact in many places is poorly defined, owing to the gradual transition from dominant sandstone to sandy dolomite.

In general, the sandstone is coarse grained, thick bedded, and brownish gray. The quartz grains commonly have a milky iridescence, are well rounded, and are cemented by dolomite which is gray on fresh fractures but brownish gray on weathered surfaces. In the sandy dolomite part the quartz grains are disseminated as individual rounded fragments or are segregated in patches and streaks. Parts of the unit are crossbedded, and some massive outcrops upon close inspection are seen to be very thin bedded. The grain size ranges from that of medium sand (0.25 mm) in well-sorted layers to pebbles (2–5 mm) in poorly sorted layers.

Upham Dolomite Member.—The Upham Dolomite Member crops out around the Hanover-Fierro pluton and in a small area south-southeast of Georgetown. On the east side of the pluton it is approximately 54 feet thick, but this may or may not have been its original thickness at this place, because the beds have been deformed and metamorphosed.

Southeast of Georgetown the Upham is nearly twice as thick (91 ft), but the beds are faulted, and repetition may occur in the section.

FIGURE 5.—Contact between Cutter Dolomite Member of Montoya Dolomite and overlying Fusselman Dolomite, Lone Mountain, N. Mex.

The dolomite is light to dark gray, finely to coarsely crystalline, and thick bedded; in places it contains a few large chert nodules. Crinoid plates are abundant locally, but in general, fossils are sparse. The lowermost beds are commonly sandy. All these features are obscure in exposures adjacent to the Hanover-Fierro pluton, where the dolomite has been recrystallized, bleached, and locally metamorphosed to tremolite, serpentine, and other silicates. Correlation of the beds in this area is based solely on their stratigraphic position between the distinctive sandstone below and the chert-rich layers above.

Aleman Cherty Member.—The Aleman Cherty Member of the Montoya is one of the most distinctive lithologic units in the area (fig. 6). The alternation of thin layers of gray dolomite and black chert which characterizes the Aleman is recognizable even in the most severely metamorphosed exposures, where the chert is now serpentine and the dolomite is marble or

FIGURE 6.—Distinctive banded outcrop of the Aleman Cherty Member of the Montoya Dolomite, Lone Mountain, N. Mex.

magnetite. The Aleman, like the other members of the Montoya Dolomite, crops out around the Hanover-Fierro pluton and southeast of Georgetown.

The abundant chert of the Aleman occurs usually as well-defined layers a fraction of an inch to a few inches thick, but also as elongate nodules. The layering is not everywhere as well defined as is shown in figure 6, but chert everywhere constitutes 25–40 percent of the unit. The chert is mottled dark gray and black and is in part reddish. It has replaced brachiopods and trilobites in the section at Lone Mountain. The unmetamorphosed dolomite weathers light gray, is generally very finely crystalline to aphanitic, is barren of fossils, and forms layers 1–6 inches thick.

Cutter Dolomite Member.—The gray aphanitic dolomite beds, 100 feet thick or more, which overlie the Aleman Cherty Member and underlie the Fusselman Dolomite southeast of Georgetown are confidently correlated with the Cutter Formation of Kelley and Silver; but near the Hanover-Fierro pluton, dolomite beds above the Aleman Member and below the Percha Shale are marbleized, and the Cutter is indistinguishable from the Fusselman Dolomite. Excellent exposures of the Cutter occur in creek bottoms in the NE¼ sec. 7, T. 17 S., R. 11 W., where the beds strike parallel to the Mimbres fault and dip about 10° SW. The Cutter here is light to dark gray and dense and aphanitic. In its middle part, weathered surfaces have a pinkish cast, and bedding is thinner. Just below the middle part is a zone about 3 feet thick containing numerous well-preserved brachiopods. The zone of fossils commonly found at the base is not present in this outcrop. The contacts of the Cutter Member with the Aleman below and with the vuggy fossiliferous brownish-gray Fusselman above are sharp and obvious. (See fig. 5.)

Measured sections.—A measured section of the Montoya Dolomite exposed south of Snowflake Canyon is included with the section of the Silurian Fusselman Dolomite on page 20. This section is greatly metamorphosed and poorly exposed. For this reason a section of the Montoya measured at Lone Mountain and two partial sections at other localities are described. (Also see graph, fig. 7.)

Montoya Group, measured on the south side of the south peak of Lone Mountain

[W. P. Pratt, written commun., 1961]

	Thickness (feet)
Fusselman Dolomite.	
Montoya Group:	
Cutter Dolomite:	
Dolomite, medium-brownish-gray; weathers light brownish gray to light gray; very finely crystalline, in places aphanitic; no bedding visible; massive fracture	71
Dolomite, medium-dark-gray; weathers medium brownish gray; very finely crystalline; no bedding visible; massive fracture	8
Dolomite, medium-light-gray; weathers light gray to medium brownish gray; very finely crystalline; laminated to very thin bedded; massive fracture; several limestone conglomerate beds; a few thin chert lenses about 15 ft above base	85
Dolomite, medium-light-gray; weathers light brownish gray with brown streaks (caused by brachiopods); very finely crystalline; very thin bedded; massive fracture; abundant brachiopods	10
Mudstone, calcareous; mottled light olive gray both fresh and weathered; very thin bedded; slabby; contains limestone lenses; very weakly resistant; poor outcrop	8
Dolomite, medium-brownish-gray with reddish streaks; weathers light brownish gray; very finely crystalline; thick bedded; massive fracture; abundant small brachiopods	2
Limestone, muddy, light-pinkish-gray; weathers medium grayish brown to light gray; very finely crystalline; no bedding visible; very weakly resistant; no outcrop	16
Dolomite, medium-gray; weathers light gray to brownish gray; very finely crystalline; thick bedded; massive fracture; a few irregular chert masses in lower part; abundant small pods (filled vugs) of coarsely crystalline dolomite weather to rough surface	7
Total Cutter Dolomite	207

Montoya Group, measured on the south side of the south peak of Lone Mountain—Continued

	Thickness (feet)
Montoya Group—Continued	
Aleman Formation:	
Dolomite, medium-gray; weathers light gray; very finely to finely crystalline; no bedding visible; massive fracture; common irregular veinlets of white coarsely crystalline dolomite; rounded irregular masses of chert like that in unit below, becoming smaller and less abundant toward top; brachiopods, more abundant toward top	10
Dolomite and chert, interbedded. The dolomite is medium gray, very finely crystalline, and laminated and weathers light gray with very smooth surface; it appears massive within but breaks into 1- to 2-in.-thick slabs because of chert. The chert, which makes up about 10–20 percent of unit, is dark gray to brownish gray, with alternating dark and light bands 1/16–1/4 in. thick, and occurs as lenses and discontinuous layers, generally 1/4–1 in. thick; it weathers reddish brown. Chert is somewhat more discontinuous near bottom. Grades into unit above	67
Total Aleman Formation	77
Second Value Dolomite:	
Upham Dolomite Member:	
Dolomite, medium-brownish-gray; weathers light brownish gray; fine to medium crystalline, locally coarsely crystalline; thick bedded; massive fracture; abundant tiny cavities; abundant brachiopods in middle part weather to dark brown and stand out in relief on weathered surfaces	3
Dolomite, medium-dark-gray; weathers medium brownish gray; finely to medium crystalline; thick bedded; massive fracture; abundant crinoid fragments; a few brachiopods at top	10
Dolomite, medium-dark-gray with brownish-red specks; weathers medium brownish gray; finely crystalline; thick bedded; massive fracture; abundant small crinoid fragments; a few chert nodules as much as 1 ft long	6
Dolomite, medium-gray; weathers light brownish gray; finely crystalline; thick bedded; massive fracture; a few large chert lenses	6
Dolomite, medium-dark-gray with small brownish-red streaks; weathers medium brownish gray; medium crystalline, becoming finer upward; thick bedded; massive fracture; small crinoid fragments fairly common; a few brachiopods and cephalopods	22

Montoya Group, measured on the south side of the south peak of Lone Mountain—Continued

	Thickness (feet)
Montoya Group—Continued	
Second Value Dolomite—Continued	
Upham Dolomite Member—Continued	
Dolomite, sandy, medium-dark-brownish-gray; weathers medium brownish gray; finely to medium crystalline; thick bedded; massive fracture; in places essentially a medium-grained dolomitic sandstone; sandy parts contain a few white quartz grains	5
Total Upham Dolomite Member	52
Cable Canyon Sandstone Member:	
Sandstone and sandy dolomite, medium-gray; weathers medium brownish gray; generally coarse grained but ranges from fine to very coarse grained; thick bedded; massive fracture; ranges irregularly from sandstone to sandy dolomite; weathered surface patchy because of greater resistance of sandy parts	7
Quartzite and sandstone, light-gray; weathers dark brown; medium to very coarse grained; scattered pebbles as much as 1/4 in. in diameter; very thin bedded, locally crossbedded; massive fracture; contains characteristic white or "opalescent" quartz grains	5
Dolomite, sandy, medium-gray; weathers light brownish gray; finely crystalline; thick-bedded; massive fracture; contains abundant coarse sand grains concentrated in rounded irregular masses generally 1/4–1/2 in. long but as much as 8 in. long which stand out as knobs on weathered surface, some well enough indurated to be classified as quartzite; common large filled vugs of calcite	4
Total Cable Canyon Sandstone Member	16
Total Montoya Group	352
El Paso Dolomite.	

Partial section of Montoya Dolomite 1½ miles southeast of Georgetown, N. Mex., S½ sec. 8, T. 17 S., R. 11 W.

	Thickness (feet)
Montoya Dolomite:	
Cutter Dolomite Member:	
Dolomite, gray, very fine grained; partial section	57
Aleman Cherty Member:	
Dolomite, brown-gray, crystalline, interbedded with layers of chert 1/4–1/2 in. thick; in places crinkled	74

Partial section of Montoya Dolomite 1½ miles southeast of Georgetown, N. Mex., S½ sec. 8, T. 17 S., R. 11 W.—Continued

	Thickness (feet)
Montoya Dolomite—Continued	
Upham Dolomite Member:	
Dolomite, gray, finely crystalline; sparse chert	57
Dolomite, dark-gray; weathers light gray to brown gray; crystalline; obscurely bedded; irregular layers of chert nodules 6–8 ft above base. Chert nodules are white to smoky and are as much as 18 in. long	34
Total Upham Dolomite Member	91
Cable Canyon Sandstone Member:	
Sandstone; grains of milky-white quartz ranging in diameter from 3 to 5 mm	20
Dolomite, sandy; weathers reddish tan; contains thin beds of coarse sandstone	8
Total Cable Canyon Sandstone Member	28
Total partial section, Montoya Dolomite	250
El Paso Limestone:	
Limestone, gray to buff, finely crystalline; thin-bedded; contains much chert.	

Partial section of Montoya Dolomite 7½ miles east of Santa Rita

	Thickness (feet)
Montoya Dolomite:	
Aleman Cherty member:	
Limestone, dolomitic, thin-bedded; many thin chert bands spaced 1–3 in. apart	45+
Upham Dolomite Member:	
Dolomite, dark-gray, crystalline, very fine grained; irregular chert nodules abundant in lower 15 ft, sparse above	25
Dolomite, dark-gray, finely crystalline, massive; sandy in lower 6 ft	21
Total Upham Dolomite Member	46
Cable Canyon Sandstone Member:	
Sandstone, medium- to very coarse grained	12
Total partial section Montoya Dolomite	103+
El Paso Limestone.	

Fossils, age, and correlation.—Although only a few fossils have been seen in the Montoya Dolomite in the Santa Rita quadrangle, elsewhere, in nearby as well as distant areas, brachiopods, corals, and crinoids are locally abundant. Only a few poorly preserved endoceroids and gastropods have been found in the Cable Canyon Sandstone Member. Jicha (1954, p. 12) found *Receptaculites* and *Maclurites* in the uppermost beds of the sandstone, and a large cephalopod was found by W. P. Pratt in the Cable Canyon at Lone Mountain. The brachiopods *Rafinesquina*, *Sowerbyella*, and *Rhynchotrema* and isotelid trilobites were found in the lower part of the Upham in the Cooks Range (Jicha, 1954, p. 12). Higher beds contain abundant crinoid plates and *Zygospira*, and a large convex *Rafinesquina*. *Zygospira* was questionably identified by Reuben J. Ross, Jr., of the U.S. Geological Survey, in the middle part of the Upham near Bear Mountain, northwest of Silver City (Pratt and Jones, 1961, p. 499). Flower (1953, p. 108) stated that the fauna of the Upham included, in addition, the following fossils: *Maclurites*, *Receptaculites*, *Halysites* (now *Catenipora*), and *Actinoceras*. He considered the fauna indicative of late Trenton rather than Richmond age.

Neither the Upham Dolomite nor the Aleman Cherty Member has yielded many well-preserved fossils in the region of Silver City or Santa Rita, but some brachiopods were noted at the base of the Upham at Lone Mountain, and two trilobites were found in chert layers within the upper half of the Aleman at Lone Mountain. To date the Aleman has yielded, largely from the Cooks Range (Jicha, 1954) and the Caballo Mountains (Kelley and Silver, 1952, p. 61), the following fossils:

Streptelasma sp.
Platystrophia sp.
Hebertella sp.
Rhynchotrema cf. *R. dentatum* Hall
Rhynchotrema sp.
Lepidocyclus cf. *L. capax* (Conrad)
Zygospira recurvirostris
Strophomena sp.
Dalmanella sp.

Fossils are generally sparse in most exposures of the Cutter Member in southwestern New Mexico. The exposures at Bear Mountain and Lone Mountain are exceptional. A variety of brachiopods collected and identified from the Bear Mountain area by Reuben J. Ross, Jr., in 1956 was reported by Pratt and Jones (1961, p. 499). Paleontological reports by Reuben J. Ross, Jr., W. A. Oliver, and Jean M. Berdan on the collections from Lone Mountain will be published shortly by W. P. Pratt (1967).

The Montoya Dolomite is of Middle and Late Ordovician age; the two lower members are considered Red River equivalents, and the two upper members, Richmond equivalents (Flower, 1958, p. 70).

SILURIAN SYSTEM—FUSSELMAN DOLOMITE

The Fusselman Dolomite was first described by Richardson (1908, p. 479–480), who named it after Fusselman Canyon, in the Franklin Mountains, north of El Paso, Tex. As explained by Pratt and Jones (1961), the lower 150 feet of Richardson's Fusselman is now included in the Montoya Dolomite. Pray (1958, p. 40) selected and described a new type section

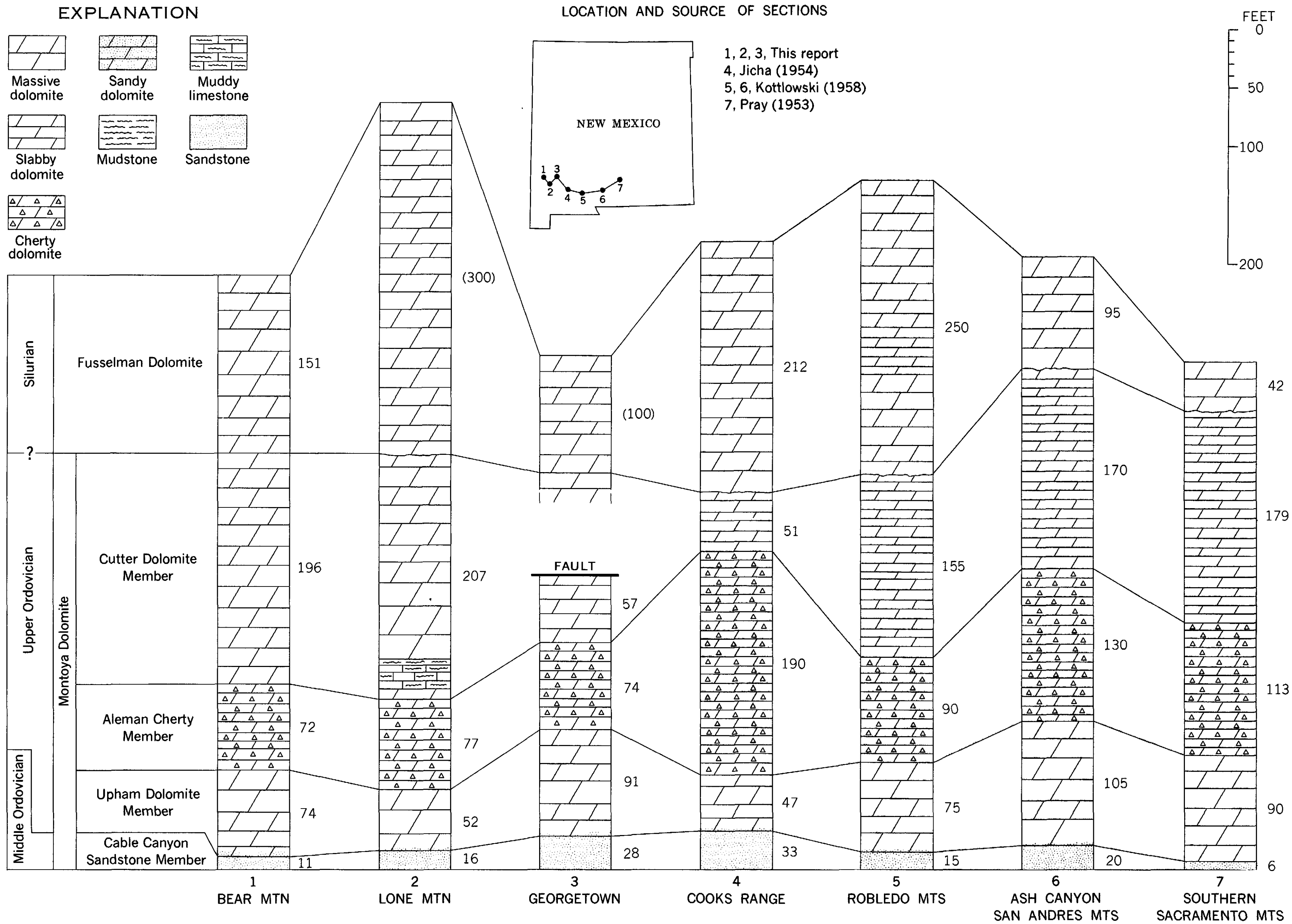


FIGURE 7.—Generalized columnar sections of Montoya and Fusselman Dolomites in southern New Mexico. Thicknesses in parentheses are approximate. From Pratt and Jones (1961, fig. 7).

in the Franklin Mountains 6 miles north of Fusselman Canyon, where an uninterrupted sequence of beds is well exposed. In New Mexico the upper contact of the Fusselman Dolomite is clearly defined by the lithologic change from carbonate rock to shale of Devonian age. The disconformity at the contact represents the interval from Middle Silurian through Middle Devonian.

The Fusselman Dolomite crops out around part of the Hanover-Fierro pluton in the central part of the Santa Rita quadrangle, and east and southeast of Georgetown, just west of the Mimbres fault. Because metamorphism has made it impossible to distinguish the Cutter Member of the Montoya Dolomite from the Fusselman Dolomite near the pluton, the Montoya and Fusselman in that area are shown as one unit on the geologic map. Only at the Georgetown exposures are the formations shown separately on the map. In both areas the upper contact of the Fusselman is clearly defined by the base of the Percha Shale of Late Devonian age.

The Fusselman Dolomite in the canyon walls east of the Georgetown mines is dark brownish gray, very finely to medium crystalline, and thick bedded and has massive fracture. It weathers to a rough, pitted surface and contains many silicified fossils—principally corals in the lower part and gastropods in the upper. At the Georgetown locality the Fusselman Dolomite forms a cliff below the weakly resistant Percha Shale. It is cut off to the north by the Mimbres fault but continues to the southeast into the adjoining quadrangle. The thickness of the Fusselman near Georgetown is estimated to be 100–125 feet; it is doubtful that a more exact thickness can be measured, because the top is nearly a dip slope and the bedding in the upper part is obscure owing to widespread silicification beneath the Percha Shale.

Probably at least the upper 88 feet of a series of metamorphosed carbonate beds exposed beneath the Percha Shale in the ridge south of Snowflake Canyon is the Fusselman Dolomite. (See the following measured section.) The limestone or dolomite there is white on fresh fracture but weathers tan, and it contains abundant irregular chert nodules, some of which are altered to tremolite. This marble has been quarried in recent years and used as roofing gravel.

Measured sections.—The following generalized stratigraphic section was measured along the ridge south of Snowflake Canyon. Owing to extensive recrystallization and silication of the dolomite beds in the upper part of the section, the authors did not recognize the contact between the Cutter Dolomite Member of the Montoya and the Fusselman Dolomite.

Montoya and Fusselman Dolomites south of Snowflake Canyon, NE¼ sec. 15, T. 17 S., R. 12 W.

	Thickness (feet)
Percha Shale: tan hornfels.	
Fusselman Dolomite and Cutter Dolomite Member of Montoya Dolomite:	
Dolomitic marble, white; weathers tan; coarsely crystalline; many irregular chert nodules, locally altered to tremolite	88
Limestone and dolomite, white to light-gray with pepperlike spots, crystalline; contains some chert and local concentrations of tremolite	123
Dolomite, gray, fine-grained	75
Dolomite, light-gray, coarsely crystalline; contains irregular vuggy chert nodules	76
Total Fusselman Dolomite and Cutter Dolomite Member of Montoya Dolomite	362
Montoya Dolomite:	
Aleman Cherty Member:	
Dolomite and chert; dolomite is coarsely crystalline and interbedded with thin layers of dark-red chert	42
Upham Dolomite Member:	
Dolomite, light-gray, coarsely crystalline; contains some small irregular chert nodules	54
Cable Canyon Sandstone Member:	
Sandstone and sandy dolomite. (Thickens to 10 ft in Snowflake Canyon.)	1
Total Aleman, Upham, and Cable Canyon Members of Montoya Dolomite	97
El Paso Limestone.	

By far the best exposures of the Fusselman Dolomite in the region were described and measured at Lone Mountain and at Bear Mountain (Pratt and Jones, 1961, p. 495, 498). In these locations the Fusselman is at least 270 feet and 150 feet thick, respectively, and consists of a monotonous succession of fossiliferous brownish-gray aphanitic to finely crystalline massive dolomites.

Fossils, age, and correlation.—Exposures of the Fusselman Dolomite east of Georgetown are exceptionally fossiliferous. The following forms from the lower 75 feet were identified by W. A. Oliver, Jr. (written commun., 1959, 1960):

1. *Palaeophyllum* sp.
2. Phacelloid rugose coral, unident.
3. *Paleofavosites* sp.
4. Halysitoid coral, indet.
5. *Halysites* sp.
6. *Favosites*? sp.
7. Rugose coral, indet.

Forms 1–4 were found 40–50 feet above the base of the Fusselman and were associated with the brachiopod *Barrandella* sp., identified by C. W. Merriam (written commun., 1962). Forms 5–7 were found at its base, just above the Cutter.

Streptelasma sp. (identified by W. A. Oliver, Jr., written commun., 1959) was among many unidentifiable gastropods collected from a block of the Fusselman exposed southeast of the Georgetown Cemetery, in the SW cor. sec. 8, T. 17 S., R. 11 W.

South of Bear Mountain (center of sec. 14, T. 17 S., R. 15 W.), Reuben J. Ross, Jr., W. R. Jones, and C. G. Bowles measured a well-exposed section of the Fusselman and collected fossils from three zones (Pratt and Jones, 1961, p. 498). The fossils were identified and assigned ages by Ross, Jean M. Berdan, and Richard S. Boardman, geologists of the U.S. Geological Survey.

1. Zone in topmost 13 ft (USGS colln. 4854–SD):
   - *Virgiana decussata* (Whiteaves)—Middle Silurian (Berdan)
   - Many small horn corals
   - Some tabulate corals
   - Gastropods, one of which is trochiform
   - Cephalopod fragment
   - Leperditiid ostracode
2. Zone at 10 ft above base (USGS colln. 4853–SD):
   - *Catenipora* sp. aff. *C. micropora* (Whitfield), *Halysites* (*Halysites*) sp., Phaceloid coral, possibly *Fletcherina*? sp. — Silurian (Berdan)
   - Ramose, branching stromatoporoid
3. Zone at 5 ft above base (USGS colln. 4852–SD):
   - *Catenipora* sp. aff. *C. micropora* (Whitfield), *Pycnactis*? sp. — probably Silurian (Berdan)
   - Ramose, branching stromatoporoid

According to Jean M. Berdan (written commun., 1963), "The presence of *Barrandella* near the middle of the formation, and *Virgiana* near the top, indicates that the Fusselman in the Santa Rita quadrangle is not younger than Llandovery, the oldest of the three divisions of the Silurian in England." In other areas of southern New Mexico, Pray (1953) reported Lower Silurian fossils; and in the thickest section, in the Franklin Mountains, he reported halysitoid corals of Middle Silurian age (Pray, 1958, p. 37).

DEVONIAN SYSTEM—PERCHA SHALE

The shale and limy shale beds lying between the Fusselman Dolomite and the Lake Valley Limestone in southwestern New Mexico were named the Percha Shale by Gordon and Graton (1906) for Percha Creek, near Kingston, N. Mex. Subsequently, Stevenson (1945, p. 241) selected a new section 2½ miles southeast of Hillsboro, N. Mex., and divided it into a lower member, the Ready Pay Member, and an upper member, the Box Member. The Percha Shale seems to be accordant in attitude with both the underlying Fusselman and the overlying Lake Valley. The nature of the upper contact is shown in figure 8.

In the Santa Rita quadrangle the best exposures of the Percha Shale are east of the Hanover-Fierro pluton. The formation occurs in a thin crescent-shaped outcrop concave to the west and extends for about 2 miles from the Barringer fault to near the Pewabic mine, where it is truncated by the pluton. It is intruded by sills in the northern and southern parts of this exposure, and is cut by several dikes in the central part. Good exposures of the Percha Shale are also present in the escarpment that extends northwestward and southeastward through Georgetown and across State Highway 90 just east of the quadrangle boundary. Sills of various compositions intrude the shale all along this escarpment. A triangular patch of Percha Shale intruded by a sill is exposed on a hill northwest of Fierro. There the Percha is truncated by tongues of the Hanover-Fierro pluton, which intrude branches of the Barringer fault. The beds dip 40° NE. and are overlain by the Lake Valley Limestone. Although the Percha Shale is locally well exposed west of Union Hill, it is intruded by a thick sill of syenodiorite and is intensely metamorphosed in the southern part of the exposure, so that neither its true thickness nor its original nature is preserved.

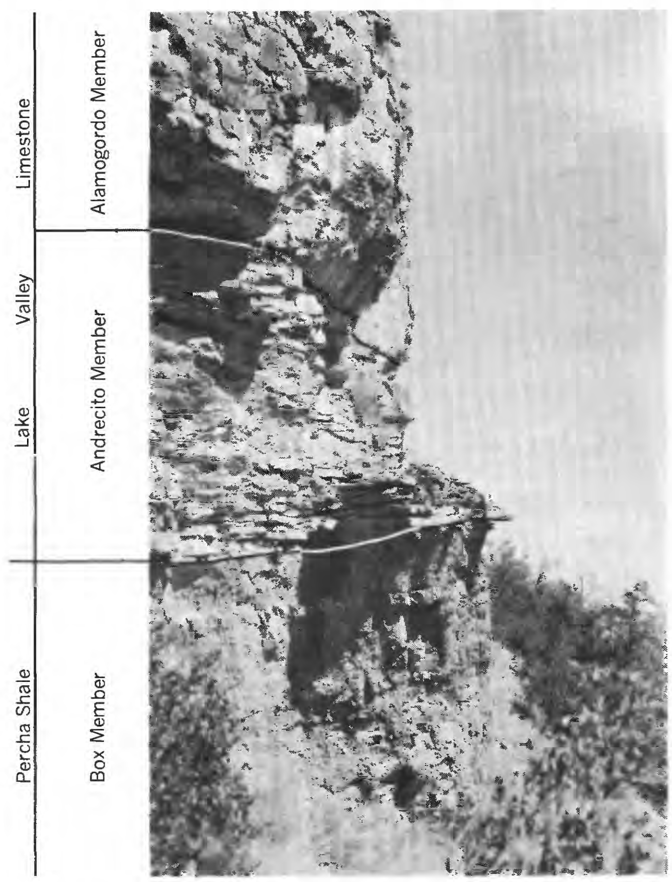


FIGURE 8.—Upper contact of Percha Shale, half a mile north of Georgetown, N. Mex.

In the Santa Rita quadrangle the Percha Shale ranges in thickness from 100 feet at the Continental shaft to 315 feet near Georgetown. West of Union Hill, Spencer and Paige (1935) measured 220 feet of shale above a syenodiorite sill and about 20 feet of shale below the sill, for a total of 240 feet. East of the Hanover-Fierro pluton, in the middle part of the exposure, measured sections range in thickness from 140 to 175 feet (Spencer and Paige, 1935, p. 19). The shale is only 190 feet thick in the Seven Hundred well, north of Santa Rita, and 230 feet thick in drill holes east of Hanover. Some of this variation is probably original variation, but most of it may safely be related to thinning along the flanks of folds.

The Percha is predominantly shale, although it includes several other kinds of rocks. In the Santa Rita quadrangle, as in the Lake Valley district of New Mexico, beds of tan calcareous shale 5–12 feet thick occur at its base. These beds, and the overlying dominantly gray, brown, and black fissile shale, constitute the Ready Pay Member. This member is overlain by the Box Member, which is characterized by grayish-green calcareous shale containing a profusion of gray limestone nodules and a few thin beds of limestone (fig. 9).

Measured section.—The following stratigraphic section, exposed in a gulch about 1,400 feet north of Georgetown, is typical of the Percha Shale in the quadrangle.

Percha Shale in gulch about 1,400 feet north of Georgetown

	Thickness (feet)
Lake Valley Limestone.	
Percha Shale:	
Box Member:	
Limestone, gray, thin-bedded; interbedded with thin beds of mudstone which contain nodules of blue limestone	10
Shale, gray, thin-bedded; contains many nodules of limestone 1–4 in. in diameter; interbedded with calcareous shale near top	85
Total Box Member	95
Ready Pay Member:	
Shale, black, fissile. (15-ft sill 75 ft above base excluded.)	195
Shale, gray to brown; contains laminae of blue argillaceous limestone a fraction of an inch thick	20
Shale, tan, limy; contains laminae of white calcite in bedding planes	5
Total Ready Pay Member	220
Total Percha Shale	315
Fusselman Dolomite.	

About 1,000 feet east of Buckhorn Gulch, on the north slope of the hill, the Box Member contains a thin lens of a hard compact dark-purple to black claystone that has not been recognized elsewhere in the quadrangle.

Unmetamorphosed Percha Shale is the least resistant of the Paleozoic formations and erodes to gentle slopes, commonly with deep gullies. Where metamorphosed to hornfels, the limy parts of the formation are resistant and form ridges, such as those in the west-central part of sec. 16, T. 17 S., R. 12 W., half a mile southwest of Union Hill.

Fossils, age, and correlation.—Flower (1953, p. 110) reported that fragmentary fish plates and teeth were found in the basal beds of the Percha Shale, but generally the black fissile shale of the Ready Pay Member is unfossiliferous. Faunas from the Box Member, consisting largely of brachiopods, bryozoa, corals, and crinoid remains, were listed and described by Kelley and Silver (1952), Stainbrook (1947), Entwistle (1944), Darton (1928), and Kindle (1909). The following fossils were collected from the Box Member about 1 mile north of the Georgetown ruins (USGS loc. 5612–SD, Santa Rita quadrangle, Grant County, N. Mex.), and were identified by J. T. Dutro and W. A. Oliver, Jr.:

Echinoderm debris, indet.
Tabulophyllum sp.
Rugose coral, indet.
Fenestrate bryozoan, indet.
Petrocrania? sp.
Schizophoria australis Kindle
Schuchertella? sp.
Acanthatia nupera Stainbrook
Leioproductus coloradensis (Kindle)
Planoproductus hillsboroensis (Kindle)
Bispinoproductus? sp.
Sentosia praecedens Stainbrook
"*Echinoconchus*" *laminatus* (Kindle)
Camarotoechia sobrina Stainbrook
Paurorhyncha cooperi Stainbrook
"*Nudirostra*" cf. "*N.*" *perchaensis* (Stainbrook)
"*Nudirostra*"? sp.
Yunnanellina? sp.
Cyrtospirifer cf. *C. animasensis* (Girty)
Cyrtospirifer kindlei Stainbrook
Syringospira prima Kindle
Strophopleura? sp.
Torynifer spinosus (Kindle)
Composita bellula Stainbrook
Cleiothyridina? cf. *C.*? *coloradensis* (Girty)
Nautiloid cephalopod, undet.

According to Dutro, this assemblage is of Late Devonian (Famennian) age. Flower (1953, p. 110) cited the presence of a clymenid ammonite in the Percha near Lake Valley as strong evidence of a Late Devonian age. Some of the fossils identified by Kindle from the Silver City region are found also in the

Devonian part of the Ouray Limestone of southwestern Colorado, the Three Forks Limestone of Montana, and the Pinyon Peak Limestone of central Utah.

The Ready Pay Member of the Percha Shale was correlated by Epis, Gilbert, and Langenheim (1957, p. 2255) with the Sly Gap Formation of central New Mexico and with the Swisshelm Formation of southeastern Arizona. The Box Member may be younger than either formation.

LOWER MISSISSIPPIAN SERIES—LAKE VALLEY LIMESTONE

Rocks of Mississippian, Pennsylvanian, and Permian ages in the Silver City–Santa Rita region were called by Paige (1916) the Fierro Limestone, a name now abandoned. The lower part of the Fierro was correctly correlated by Paige with the Lake Valley Limestone. Schmitt (1933b, p. 188) introduced the name Hanover Limestone for the crinoidal limestone which forms a distinct unit at the top of the Lake Valley Limestone in the Central mining district. This unit is now recognized throughout southern New Mexico as the Tierra Blanca Member of the Lake Valley Limestone, one of six members defined by Laudon and Bowsher (1949, p. 10–15). Only the lower four members are recognized in the Santa Rita and adjoining quadrangles; they are, from oldest to youngest, the Andrecito, the Alamogordo, the Nunn, and the Tierra Blanca. Mississippian formations younger than the Lake Valley, if ever present, were eroded prior to deposition of the basal shale of the Oswaldo Formation of the Magdalena Group (Pennsylvanian).

The name Lake Valley Limestone was given by Cope (1882, p. 214) to calcareous beds lying conformably on the Percha Shale at Lake Valley, N. Mex. As originally defined, the formation included beds now referred to as the Caballero Formation of Laudon and Bowsher (1941, p. 2116), which underlie the Lake Valley Formation in Lake Valley and in the San Andres and Sacramento Mountains farther east.

In the Santa Rita quadrangle the Lake Valley Limestone underlies narrow areas close to the west, south, and east sides of the Hanover-Fierro pluton. It is exposed also in a narrow strip that extends southeastward from Shingle Canyon to and beyond the east-central part of the Santa Rita quadrangle.

The Lake Valley Limestone is dominantly light-gray limestone, but some units contain marls and thin limy shale beds. The carbonate beds, unlike carbonate beds in formations of early Paleozoic age, contain little magnesium; indeed, some crinoidal units are essentially pure calcium carbonate (Schmitt, 1939a, tables 8, 9, p. 801).

In the Santa Rita quadrangle the Lake Valley Limestone ranges in thickness from 335 to 450 feet (Spencer

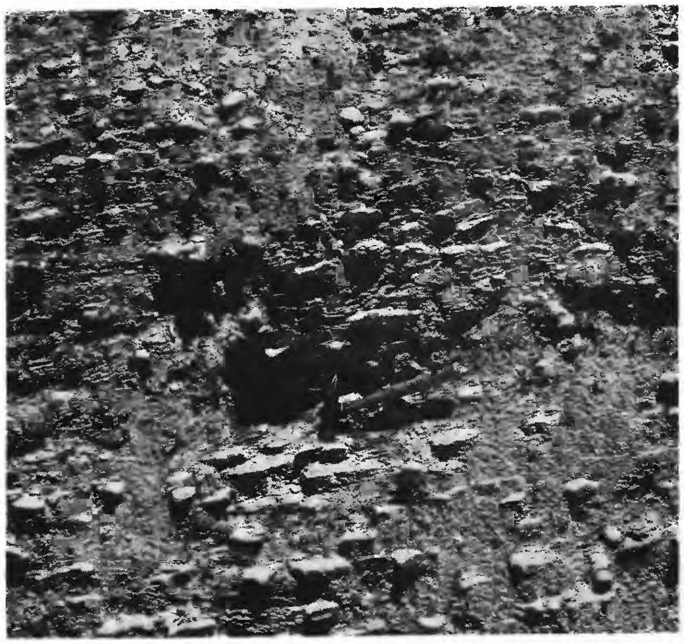


FIGURE 9.—Close-up of Box Member of Percha Shale, showing limestone nodules.

and Paige, 1935, p. 21). In an unaltered and undeformed exposure at the east margin of the quadrangle the authors found it to be 356 feet thick. The thickness of each member varies, even within a few thousand feet laterally. This variability is characteristic of the formation and of its members throughout southern New Mexico (Laudon and Bowsher, 1949, fig. 39). Nevertheless, some of the differences in thickness in the Santa Rita quadrangle are the result of flowage during local folding in Laramide time.

The alternation of resistant and nonresistant lithologic units within the Lake Valley Limestone makes its outcrop conspicuous. The first and third units above the base erode to gentle slopes, whereas the second and fourth form prominent ledges tens of feet high.

Andrecito Member.—The Andrecito Member was named for exposures in the south wall of Andrecito Canyon, where its type section is in the NW¼ sec. 8, T. 18 S., R. 4 E. (Laudon and Bowsher, 1949, p. 12–13.) In the Santa Rita quadrangle the slabby beds of limestone and shaly limestone that lie above the Box Member of the Percha Shale and below dark-gray thick-bedded cherty limestone are correlated with the Andrecito Member of the Lake Valley Limestone. The Andrecito Member is characterized by thin bedding, slabby fracture, and abundant bryozoan, crinoid, and brachiopod remains (fig. 8). The layers are composed of gray shaly or crinoidal limestone and marl; some beds contain nodules of black chert. Lateral variation in lithology and thickness, even within short distances, is pronounced. For example, a crinoidal limestone bed that is 17 feet thick near State Highway 90 is only 5 feet thick less than 3 miles to the northwest, at Georgetown. Within the quadrangle the Andrecito Member ranges in thickness from about 15 feet to perhaps as much as 60 feet. Near State Highway 90, 3 miles east of Santa Rita, the Andrecito Member has been measured as 29, 39, and 41 feet thick in three closely spaced exposures. North of Georgetown it is only 15 feet thick. A much greater range in thickness occurs in southwestern New Mexico (Laudon and Bowsher, 1949).

Alamogordo Member.—Dark-gray to black thick-bedded (18–24 inches) fine-grained limestone containing abundant large nodules of dark-brownish-gray to black chert arranged in layers parallel to bedding, and commonly showing concentric black and white or red and white layers, is correlated with the Alamogordo Member as defined by Laudon and Bowsher (1949). In the eastern part of the quadrangle this member forms a nearly vertical cliff that ranges in height from 25 to 45 feet, (fig. 8), and in exposures near the Hanover-Fierro pluton it is about 40 feet thick; because internal shearing has made it less resistant in many places, it does not everywhere form a ledge. The Alamogordo is the least fossiliferous of the four members of the Lake Valley.

Nunn Member.—The Nunn Member consists of aphanitic to finely crystalline thin- to medium-bedded slabby light-gray to nearly black marly limestone; it is richly fossiliferous and, in places, crinoidal. In the middle part of the member the limestone is interbedded with shale and contains lenses and nodules of black chert. The Nunn Member is 166 feet thick in an exposure 3 miles east of Santa Rita, and 182 feet thick north of the Pewabic mine. Because it is weakly resistant, this member erodes to gentle slopes on which ribs of limestone protrude slightly through the rubble of the marly beds. North of State Highway 90, abundant well-preserved brachiopods have weathered out and lie in the marly rubble.

Tierra Blanca Member.—Light-gray to gray and nearly white massive crinoidal, in part cherty, coarsely crystalline limestone makes up the Tierra Blanca Member of the Lake Valley Limestone. Except for some large generally light-colored nodules of chert, this member is almost entirely pure calcium carbonate; it contains only 0.19–0.44 percent MgO in analyzed samples (Schmitt, 1939a, p. 801). Because this member is the principal host rock of sphalerite-galena and magnetite-chalcopyrite ores in the area, its thickness is of significance to miners. A range in thickness from 35 to 220 feet is reported in the Oswaldo No. 2 mine, but this variation seems excessive and was undoubtedly caused by internal flowage during folding. Although the folding in the area of this mine was rather gentle, the thinnest sections are along the crests of the folds, and the thickest along the flanks (P. G. Leroy and Keith Martin, written commun., 1953). In the shaft of the Bullfrog mine, near Vanadium, the Tierra Blanca Member is 163 feet thick. East of Santa Rita it is 105 feet thick, and east of the Hanover-Fierro pluton it is 115 feet thick (Spencer and Paige, 1935, p. 22). In the Empire Zinc Co.'s mine, the crinoidal limestone member is 130–140 feet thick along the crest of the curving anticline which encircles the Hanover lobe of the pluton, but on the limbs of this fold it is usually much thinner, and in places is not more than 80 feet thick (Spencer and Paige, 1935, p. 22). These reported thicknesses indicate the thickness variation to be expected in new penetrations.

In an attempt to explain the concentration of ore in the Tierra Blanca Member, Rove (1947, p. 71–72) tested the permeability of the limestone and found it to be 200 times greater than that of the Nunn Member.

The Tierra Blanca Member is overlain conformably by the basal shale unit of the Oswaldo Formation of Pennsylvanian age. In the Oswaldo No. 2 mine, a massive grayish-white chert zone about 10 feet thick occurs intermittently along the contact. This accumulation of chert evidently formed during the erosional interval preceding deposition of the Oswaldo Formation, and it is evidence that the variations in thickness of the Tierra Blanca Member may be partly the result of uneven erosion.

Measured sections.—Details of the lithology of the Tierra Blanca within the Santa Rita quadrangle are given in the following two representative stratigraphic sections, one of which was measured along the east margin of the quadrangle and the other, just east of the central part of the quadrangle.

Lake Valley Limestone 3 miles east of Santa Rita, in canyon just south of State Highway 90, SW¼ sec. 20, T. 17 S., R. 11. W.

	Thickness (feet)
Oswaldo Formation, basal shale unit.	
Lake Valley Limestone:	
Tierra Blanca Member:	
Limestone, white, massive, sugary, crinoidal	15
Limestone, light-gray, very massive, crinoidal; contains gray chert nodules; 6 ft of medium-gray crystalline limestone at base contains dark-gray chert nodules	22
Limestone, nearly white, medium-bedded; massive fracture; crinoidal; contains sparse white chert nodules	68
Total Tierra Blanca Member	105

Lake Valley Limestone 3 miles east of Santa Rita, in canyon just south of State Highway 90, SW¼ sec. 20, T. 17 S., R. 11 W. —Continued

	Thickness (feet)
Lake Valley Limestone:—Continued	
Nunn Member:	
Crinoidal limestone alternating with dense dark-gray bryozoan-rich limestone; a little shale and marl	17
Limestone, medium- to dark-gray, dense to very fine grained, thin- to medium-bedded, marly; many thin layers rich in bryozoans; dark chert in top of bed and in bed 15 ft above base, otherwise chert free	54
Concealed	10
Limestone, gray to nearly black, dense to very fine grained, thin- to medium-bedded, chert-free, marly and slabby. Bryozoan layers sparse in upper 34 ft	85
Total Nunn Member	166
Alamogordo Member:	
Limestone, gray and dark-gray, dense to fine-grained, thin- to thick-bedded; chert common; sparse fossils, thin bryozoan layers; forms cliff	44
Andrecito Member:	
Crinoidal limestone alternating with slabby bryozoan-rich limestone; contains large dark-gray and black chert nodules	17
Limestone, thin-bedded, slabby and shaly, interbedded with many thin bryozoan layers; lower 3 ft concealed. (Basal bed in a nearby section is 4 ft of crinoidal limestone.)	24
Total Andrecito Member	41
Total Lake Valley Limestone	356
Percha Shale.	

Lake Valley Limestone on second ridge south of Humbolt shaft. S½ sec. 10, T. 17 S., R. 12 W.

[Recorded by H. A. Schmitt (Spencer and Paige, 1935, p. 22). Assignment to members by W. R. Jones]

	Thickness (feet)
Oswaldo Formation, basal shale.	
Lake Valley Limestone:	
Tierra Blanca Member:	
Limestone, gray to pink; many crinoid stems	35
Limestone, massive, coarse-grained, crystalline; sparse fossils	40
Limestone, white, coarse-grained, crystalline	40
Total Tierra Blanca Member	115
Nunn Member:	
Limestone, blue, medium- to thin-bedded; contains black chert; where thin bedded, contains crinoid stems. Shaly bed 10 ft below top, and 10 ft of calcareous shale at base	182
Alamogordo Member:	
Limestone and siliceous limestone, irregularly interbedded	41

Lake Valley Limestone on second ridge south of Humbolt shaft, S½ sec. 10, T. 17 S., R. 12 W.—Continued

	Thickness (feet)
Lake Valley Limestone—Continued	
Andrecito Member:	
Limestone, siliceous; contains small lenses of blue limestone	30
Limestone, siliceous; thin layers interbedded with softer material	30
Total Andrecito Member	60
Total Lake Valley Limestone	398
Top of Percha Shale.	

Fossils, age, and correlation.—In the Silver City region, as elsewhere, the Lake Valley Limestone contains a large assemblage of fossils, principally brachiopods, crinoids, corals, and bryozoa. Faunas collected from the Lake Valley Limestone at the type locality and in the Mimbres Mountains (Black Range) near Kingston, N. Mex., were described by Darton (1928, p. 17, 18). More recent collections were listed by Jicha (1954, p. 17, 19, 20), Laudon and Bowsher (1949), and W. P. Pratt (written commun., 1964).

On the basis of abundant fossil evidence, the Lake Valley Limestone is dated as Early Mississippian—probably early Osage equivalent, according to J. T. Dutro, Jr. (written commun., 1960), and Weller and others (1948). The Mississippian Subcommittee has correlated the lower four members of the Lake Valley Formation with the Fern Glen Limestone of southwestern Missouri (Weller and others, 1948). Part of the Lake Valley can undoubtedly be correlated with the Escabrosa Limestone of southeastern Arizona, although part of the Escabrosa may be slightly older (Kinderhook) and part is younger than Osage.

PENNSYLVANIAN SYSTEM—MAGDALENA GROUP

Gordon (1907) proposed the name Magdalena Group for rocks of Pennsylvanian age in central New Mexico. A lower, clastic succession called the Sandia Formation was distinguished from an upper, carbonate succession called the Madera Limestone. Although rocks equivalent in age to those of the Magdalena Group are found in southern New Mexico, the two lithologic units described by Gordon cannot be recognized there. In fact, in the region surrounding Santa Rita, a lower unit, the Oswaldo Formation, is predominantly limestone, and an upper unit, the Syrena Formation, is predominantly shale or silty limestone—a lithology just the reverse of that described by Gordon in localities only 60 miles north of Santa Rita. Attempts to correlate strata of Pennsylvanian age throughout the region solely on the basis of similarities in lithology have not been successful. The confusion in nomenclature was graphically illustrated by Kelley and Silver (1952, fig. 11).

As reported by Spencer and Paige (1935, p. 24), the 800-foot-thick section of Pennsylvanian beds lying above the Lake Valley Limestone and below the distinctive red beds of the Abo Formation in the Silver City–Santa Rita region was divided into six lithologic units by the geology staff of the Empire Zinc Co. The usefulness of this division is restricted to the Central mining district, for beyond this district the various lithologic boundaries cannot be identified.

A persistent even-grained hornblende quartz diorite sill, locally called the Marker or Hanover sill, is found in much of the quadrangle at levels ranging from 40 to 120 feet above the base of the Magdalena Group. In the eastern part of the quadrangle a similar sill is from 60 to 200 feet above the base. Local geologists refer to the limestone between the Marker sill and the Parting shale as the Middle Blue, and the limestone above the Marker sill but below the top 60–70 feet of banded or so-called striped beds, as the Upper Blue.

Spencer and Paige (1935, p. 23) divided the Magdalena Group into two formations—the Oswaldo Formation at the base and the Syrena Formation at the top—that virtually correspond to Schmitt's (1933b) "Lower and Upper Magdalena." According to Thompson (1942, p. 23), the Oswaldo and Syrena Formations include "large portions of at least two series of the Pennsylvanian and are not useful as regional stratigraphic units." Thompson (1942, p. 18 and pl. 1) measured a section near Santa Rita and noted that, although it is one of the thinnest sections of Pennsylvanian rocks (only 800 ft) in the area, it contains fossils from all four ages of the Pennsylvanian: the Derry of Thompson (1942), the Des Moines, the Missouri, and the Virgil.

Recognition of the lower contact of the Magdalena Group is not difficult; the basal unit of the Magdalena is generally a siliceous shale or grit 20–40 feet thick, although locally it is missing or is very thin. Spencer and Paige (1935, p. 23) stated:

> Although there is a considerable stratigraphic hiatus above the Lake Valley Limestone throughout the Silver City region, the beds above and below the break appear to lie in parallel position, and the only physical evidence that can be cited as suggestive of unconformity is a bed of white chert which occurs in many localities at the top of the crinoidal limestone member of the Lake Valley Formation.

The top of the Magdalena is not readily recognizable, especially where the group is metamorphosed or is overlain by the Abo Formation, which contains red mudstone similar to that in the topmost part of the Syrena Formation. According to Flower (1953, p. 111), "In New Mexico the (Pennsylvanian) Magdalena limestone is considered as extending up to the top of the last marine bed * * *," and "it is perhaps futile to worry about a systematic break between the Pennsylvanian and Permian, for this is a part of the world where Pennsylvanian-Permian deposition was essentially continuous." In the Santa Rita area the disconformity is not obvious where reddish-brown beds at the top of the Magdalena are overlain by red sedimentary rocks of the Abo; for this reason, the Syrena-Abo contact is shown as "approximately located."

In this report the division of the Magdalena Group into the Oswaldo and Syrena Formations is used, and each formation is described separately.

OSWALDO FORMATION

The Oswaldo Formation, which is predominantly gray limestone containing many thin shale partings and beds, was named after a patented mining claim about 1 mile south of the Hanover Post Office (Spencer and Paige, 1935, p. 22–23). The base of the Oswaldo is regarded as the bottom of the basal siliceous 20 to 40-foot-thick shale unit which locally is known as the Parting shale. The Oswaldo Formation rests disconformably on the Lake Valley Limestone, as indicated by a thin basal conglomerate in places, and by the small-scale unevenness of the surface of the Lake Valley. The top of the Oswaldo is assigned as the base of the lowest black fissile to blocky limy shale unit of the Syrena Formation, which is commonly 40 feet thick (fig. 11*A*). This horizon may not coincide with a formal time division of the Pennsylvanian, as Thompson stated (1942, p. 23), but it is a convenient and mappable horizon. The uppermost bed of the Oswaldo Formation in the Santa Rita quadrangle is a massive 2- to 6-foot-thick exceptionally pure aphanitic limestone that is generally free of silt and chert and is readily recognizable. Beneath it is 30–50 feet of alternating thin (1–3 in.) limestone and silty limestone beds. These beds are known locally as the striped beds, because the limestone weathers gray and the silty limestone tan.

The total outcrop area of the Oswaldo Formation in the Santa Rita quadrangle exceeds that of any other sedimentary formation. The formation underlies a broad area east of the Hanover-Fierro pluton between the Barringer fault system and an irregular line that approximately coincides with State Highway 90. The Oswaldo is covered in places, particularly north-northeast of Santa Rita, by younger formations. Around the south lobe of the Hanover-Fierro pluton it forms concentric belts between concentric strips of the Marker sill. A tongue of Oswaldo projects southeastward from this belt to the northern part of the stock at Santa Rita on a surface that in part is almost a dip slope. The details of the outcrop pattern near Hanover reflect the tight folding incident to the intrusion of the south lobe of the Hanover-Fierro pluton. The Oswaldo also underlies a large area west of the intrusion. The outcrop pattern is controlled by the dip away from the intrusion, the dip into the Barringer fault, the doming over a laccolith, and the general south-to-west dip of the beds. The Oswaldo has been penetrated by all the major zinc-producing mines in the southwest quarter of the quadrangle, where the formation has no surface exposure.

The Oswaldo is composed dominantly of limestone and silty limestone but contains many thin shale beds 1–8 feet thick (fig. 10). The basal shale unit is much the thickest of the shale beds, having a maximum thickness of about 40 feet. The limestone beds weather blue gray, range from crinoidal to argillaceous, and contain abundant chert nodules. Most of the limestone beds are 1–3 feet thick except near the top of the unit, where they are commonly thinner. (See fig. 10.) The texture ranges from sublithographic to coarsely crystalline. Two shale beds, each 4–6 feet thick and separated by a limestone bed, are present about 135 feet above the base at a locality 2 miles east-northeast of the Pewabic mine. Lenses of crudely sorted sandstone, composed of coarse subangular to angular grains, crop out in the northeast quarter of the Santa Rita quadrangle; these lenses are at levels of from 70 to 125 feet above the base of the Oswaldo. The thickest lens exposed is on the north slope of Fierro Hill, in the SE¼ sec. 3, T. 17 S., R. 12 W. In the following measured sections the sandstone was not recognized; if present, it must be very thin.

FIGURE 10.—Oswaldo Formation cut by quartz latite porphyry dike. Roadcut on Gooseneck Hill.

The thickness of the Oswaldo Formation can be accurately measured in few localities because of faulting or folding and possible plastic deformation. The Oswaldo is about 437 feet thick in a drill hole east of the Peerless mine, 410–420 feet thick near Hanover (Spencer and Paige, 1935, p. 25), and 405 feet thick in the Groundhog mine. Northeast of the Pewabic mine, the section measured by the authors is 417 feet thick.

Measured sections.—Lithologic details of the various beds of the Oswaldo Formation are given in the following stratigraphic sections:

Partial section of Magdalena Group, Beartooth Creek, approximately at boundary line between secs. 18 and 19, T. 17 S., R. 12 W.

	Thickness (feet)
Syrena Formation, limy mudstone.	
Oswaldo Formation:	
Limestone, black to blue-gray; weathers pink, buff, gray; finely crystalline; contains sparse chert nodules	5
Limestone, gray, and brown silty limestone in alternate beds; silty limestone is black on fresh fracture; contains some pure crinoidal beds and some chert. Bottom 10 ft composed of well-defined thin beds (½–1 in. thick), alternating gray and tan. This unit known locally as the striped beds	55
Limestone, gray, massive, coarsely crystalline	5
Limestone, silty, orange-brown to tan; contains nodular masses of gray limestone to about 40 percent of volume; black on fresh fracture. Very fossiliferous; fetid	10
Limestone, light-gray to gray, coarsely crystalline, thick-bedded; contains no shale or chert except at top. Fossiliferous (mostly crinoids and brachiopods). Forms cliff	31
Limestone, gray, coarsely crystalline, fossiliferous; prominent shale parting every 4–6 in. Slabby, no chert; wisps of tan silty limestone cut across beds in places	2
Limestone, light- to dark-gray, finely crystalline, cherty, fossiliferous; thin wavy partings of buff shale 4–6 in. apart. Black chert makes up 50 percent of unit, occurring in large pods 12–18 in. long and 4 in. thick; pods are generally bedded, but also discordant on small scale	2.5
Limestone, like that above but without chert; weathered surface locally contains large pits; forms ledge	3
Shale, variegated, dark-green to black; top 4 in. red	3
Limestone conglomerate; blue to gray to black limestone fragments cemented by aphanitic limestone	.5
Partial thickness Oswaldo Formation	117

230-093 O—66——3

Oswaldo Formation northeast of the Pewabic mine, SE¼ sec. 15, T. 17 S., R. 12 W.

	Thickness (feet)
Syrena Formation, 35-foot limy mudstone.	
Oswaldo Formation:	
Limestone, almost pure, aphanitic to fine-grained, smooth-weathering	2
Limestone, argillaceous, fine-grained; thin beds containing nodules and irregular masses of blue-gray limestone alternate with shaly material, which is hornfels in places. Limestone layers appear as irregular bands, lenses, and nodules. Medium-grained crinoidal beds in lower part	20
Covered. (A few hundred feet off the line of section there is fine-grained limestone with small chert nodules and a few thin beds of crinoidal limestone.)	15
Limestone, blue-gray, aphanitic to fine-grained; contains small chert nodules; crinoidal bed at top. Some beds are streaked with impurities. Upper beds sheared	25
Limestone, blue-gray except where sheared, aphanitic to fine-grained; partly covered	45
Limestone, gray, argillaceous, nearly chert-free; some shearing near middle	14
Hornblende quartz diorite sill (14 ft thick).	
Limestone, cherty, blue-gray, aphanitic to fine-grained, crudely bedded	114
Limestone, light-bluish-gray, thick-bedded to massive, fine-grained to aphanitic	43
Quartz diorite sill (10 ft thick).	
Limestone, dark-gray to black; partly recrystallized and containing tremolite needles; large black chert nodules in middle part	19
Hornblende quartz diorite sill, the "Marker or Hanover sill" (72 ft thick).	
Limestone, light-gray, thoroughly recrystallized, sheared	83
Shale, epidotized and silicified. Upper 10 ft is covered and may be altered limestone. This is the so-called Parting shale	37
Total Oswaldo Formation	417
Lake Valley Limestone.	

SYRENA FORMATION

The Syrena Formation was named after a patented mining claim about 1 mile south of the Hanover Post Office (Spencer and Paige, 1935). The base is regarded as the bottom of a basal 30- to 40-foot-thick black limy shale unit. The upper limit of the Syrena is regarded as the top of the stratigraphically highest gray limestone bed below typical red beds of the Abo Formation or, where the red beds are missing, below the Beartooth Quartzite of Late(?) Cretaceous age.

Intensely altered exposures of the Syrena Formation crop out along the northwest side of the Hanover-Fierro pluton, north of the Barringer fault. South of the Barringer fault the Syrena crops out near the central north edge of the quadrangle in fault blocks and as cappings on the higher hills. It forms much of the high ridge north of Santa Rita, and thin remnants underlie areas northeast of the ridge. It is exposed in both the north and the south pits of the Chino mine, in a belt extending eastward from the Chino mine to the east margin of the quadrangle, and in irregular patches northwest of the north pit of the Chino mine as far as Bull Hill. In part of this area the surface is nearly a dip slope, and much of it is deeply mantled with hornfels and magnetite debris; the mapped borders in this area are necessarily somewhat diagrammatic. In the west-central part of the quadrangle, the Syrena crops out in a roughly circular belt that is interrupted only on the east, near the town of Hanover.

The lower and middle parts of the Syrena Formation in the Santa Rita quadrangle form a persistent lithologic sequence. The basal 40 feet is predominantly black blocky to fissile fetid silty limestone or limy mudstone containing lenses of gray fossiliferous limestone 3–5 feet thick and 200–500 feet long (fig. 11*A*). In some places lenses of black chert conglomerate also occur, and in other places, limestone conglomerate containing distinctive pebbles coated with algal limestone. This basal unit is overlain by about 30 feet of beds containing 3- to 6-inch-thick nodules of blue-gray limestone embedded in an aphanitic matrix of dark-gray to black silty limestone that weathers to a tan surface of porous silt (fig. 11*B*); on fresh fracture, the matrix is not easily distinguishable from the nodules. This unit tends to form steep slopes and is overlain by 10–40 feet of olive-green to brown fissile limy shale. Above this shale the beds resemble the underlying ledge of nodular silty limestone.

The upper part of the Syrena in the Santa Rita quadrangle is not characterized by persistent lithologic units. Instead, it consists of alternating groups of beds of gray limestone (including crinoidal layers), silty limestone, and nodular limestone similar to that in lower ledges. Brown, yellow, and red shale and mudstone alternate with beds of limestone near the top.

The algal conglomerates are not restricted to the basal 40-foot-thick shale unit; they are also found, although less commonly, in the upper half of the formation. Where exposures are limited, the argillaceous limestone beds above the two thick shale units of the lower part of the Syrena may be easily confused with similar beds near the top of the Oswaldo Formation. However, the argillaceous material is usually in well-defined layers in the Oswaldo, and the limestone beds between them are commonly crinoidal.

A B

FIGURE 11.—Syrena Formation half a mile north of Santa Rita, N. Mex. *A*, Cliff exposures of basal limy shale unit. *B*, Closeup of nodular limestone in ledge overlying cliff of limy shale shown in *A*. Weathered pattern is typical of many beds in Syrena Formation.

Where the Syrena is weathered but not otherwise altered, the shaly material in much of the impure limestone is reddish brown or orange brown, in contrast to the blue gray to pinkish gray of the purer limestone.

The thickness of the Syrena Formation is variable, ranging from 170 to 390 feet (Lasky, 1936, p. 19). It is about 320 feet thick on the west slope of Topknot Hill and about 350 feet thick 4 miles to the west, in secs. 18 and 19, T. 17 S., R. 12 W.

The topographic expression of the formation is characteristic, particularly that of the lower 100 feet or so of alternating limy shale and impure limestone; the limy shale units, except where toughened by metamorphism, form benches and low-angle slopes on which the limestone units stand out as moderately well-defined ledges.

Measured sections.—The following stratigraphic sections give detailed observations of the character of the Syrena.

Syrena Formation northeast of the Kearney mine, west slope of Topknot Hill

	Thickness (feet)
Abo or Syrena Formation:	
Hornfels with chloritic(?) spots and epidote	34
Syrena Formation:	
Limestone, argillaceous, somewhat altered. Thin irregular bands, lenses, and nodules of grayish-white limestone alternating with similarly irregular silicified shale. Lower 7 ft forms a prominent ledge. Partly covered	21
Limestone, argillaceous; contains numerous nodules of silicified shaly material	21
Hornfels, brown to tan. Conglomerate of brown chert pebbles in limestone near base	37
Limestone, argillaceous; alternating thin nodular beds of limestone and altered shale; much less shale in upper 10 ft	37
Limestone and silicified shale, in alternating thin irregular beds; forms conspicuously banded outcrops	46
Covered	16

Syrena Formation northeast of the Kearney mine, west slope of Topknot Hill—Continued

	Thickness (feet)
Syrena Formation—Continued	
Limestone, argillaceous; in nodular layers and lenses alternating with irregular shale beds	21
Shale and limy shale	21
Quartz diorite sill (16 ft thick).	
Limestone, argillaceous; alternating nodular limestone and shale; forms ledge	31
Shale and limy shale, partly covered	36
Total Syrena Formation	321
Oswaldo Formation.	

Syrena Formation, Beartooth Creek, approximately at boundary line between secs. 18 and 19, T. 17 S., R. 12 W.

	Thickness (feet)
Abo Formation (basal contact poorly exposed and somewhat arbitrary).	
Syrena Formation:	
Limestone, gray; limestone nodules in brown mudstone matrix except thin zone 8 ft from top, where mudstone is red	15
Covered	21
Limestone, gray, argillaceous; forms poorly defined ledge	15
Limestone, gray, pure, with abundant crinoid stems and other fossils	15
Limestone; large gray nodular limestone masses in brown silty limestone	15
Largely covered, but probably all buff, yellow, and red limy shale	39
Limestone, gray, rather pure, dense; forms weak ledge	10
Limestone and limy shale, brown to gray. Limestone predominates in upper half. Some coarse-grained gray nodular limestone beds	70
Limestone, dark-gray, pure, fossiliferous; beds 6 in. thick	10
Limestone, gray, argillaceous and silty, crinoidal; contains gray crystalline limestone nodules 6–12 in. long and wisps of brown silty limestone	32
Limestone, gray, massive, with dark-gray streaks 4 in. thick near top	7
Limestone, brown, silty, with gray limestone nodules. Middle part covered	30
Shale, olive-green to brown, fissile, limy; brown on fresh fracture. Grades upward into overlying gray nodular beds	5
Limestone, gray, aphanitic, with brown silty wisps and partings	13
Section below offset 100 ft to south.	
Limestone, gray, silty. Typical gray nodular beds in brown-weathering silty limestone that on fresh fracture is dark gray to black and is distinguished from fresh surface of limestone only by finer grain. Forms a ledge in places	36
Limy mudstone, black; weathers tan; blocky; effervesces readily except on tan weathered surfaces. Possibly some of section is missing because of a small strike fault	17
Total Syrena Formation	350

Partial measured section of Syrena Formation, SW¼NE¼ sec. 25, T. 17 S., R. 11 W. (1.75 miles east of Santa Rita)

[Summarized from description by A. F. Shride, written commun., 1954]

	Thickness (feet)
Abo Formation, mudstone.	
Syrena Formation:	
Limestone, grayish-red to brownish-gray; weathers light brownish gray; aphanitic; thin bedded (3–8 in.); somewhat silty; fossiliferous: corals, cephalopods, bryozoa, crinoid stems, brachiopods	7. 0
Limestone, dark-gray; weathers olive gray; aphanitic; silty; nonfossiliferous. Contains chips of gray chert	1. 5
Limestone, pale-yellowish-brown mottled by pale red; weathers orange pink to light gray; aphanitic; thin bedded (6–18 in.); silty; shale partings; fossiliferous: brachiopods, bryozoa, and crinoid stems common, fusulinids rare to abundant	21. 5
Limestone, pale-brown; weathers light gray to orange pink; finely crystalline to aphanitic; beds 1 ft thick; fossiliferous: brachiopods and bryozoans abundant	2. 0
Shale and limestone interbedded; shale is reddish orange, fissile or blocky, calcareous, nonfossiliferous. Limestone is olive gray to pale brown, mottled; weathers light gray; silty parts weather grayish orange; thin bedded (2–10 in.); silty, with nodules of pure limestone; fossiliferous: fusulinids large and abundant, *Tetrataxis* sp., *Bradyina* sp., *Triticites* sp. aff. *T. ventricosus*; also echinoid spines, bryozoa, brachiopods	10. 0
Limestone, medium-dark-gray, mottled by brownish gray; weathers light and orange gray; aphanitic; thin bedded (1–2 ft); silty; contains chert grains; fossiliferous: small brachiopods	5. 0
Limestone, grayish-olive, silty, weathers grayish red to light gray; aphanitic; massive, very thick bedded; top 3 ft very shaly; contains light-brownish-gray limestone nodules; fossiliferous, principally brachiopods	9. 0
Shale, light-olive-gray, very calcareous; weathers pale olive gray; contains calcareous nodules; fossiliferous: brachiopods, bryozoa, abundant crinoid stems, rare trilobite fragments	9. 0
Limestone, olive-gray; weathers yellowish gray; single massive bed; fragmented fossils very abundant, include brachiopods, bryozoa, crinoid stems	1. 0
Shale, yellowish-orange; contains abundant dark-greenish-gray limestone nodules 1–4 mm in diameter. No fossils found	18. 0
Limestone, dark-gray, mottled by pale red, aphanitic; limestone nodules in earthy silt matrix; thin bedded; nonfossiliferous	5. 0
Limestone; brownish-gray nodules in pale-red silty limestone; aphanitic; thin bedded (1–2 ft); fossiliferous, brachiopods and bryozoa common	12
Partial thickness Syrena Formation	111

FOSSILS, AGE, AND CORRELATION

Fusulinids are plentiful in the Pennsylvanian, and because of the wide distribution and the short stratigraphic range of the species, they are excellent index fossils. Needham (1937, p. 13), who made a special study of fusulinids throughout New Mexico, identified

Fusulina eurysteines Thompson from chert about 110 feet above the base of the Magdalena Group (Oswaldo Formation) north of Santa Rita. Although many other excellent exposures of fusulinids have been observed, no systematic paleontological study of them has been made by the U.S. Geological Survey.

The following fossils were collected by the authors from the lower 100 feet of the Oswaldo Formation on the south slope of Bear Mountain, NE¼ sec. 14, T. 17 S., R. 15 W.: Algae (red?), Textulariidae (genera not determinable), *Climacammina* sp., *Endothyra* sp., *Millerella* 2 sp., *Fusulinella* sp., and *Tetrataxis* sp.

According to L. G. Henbest, who identified the fossils, these foraminifera and algae are characteristic of the Bend Group of central Texas and correlate with the Atoka Series of the midcontinent region; he stated that this part of the Oswaldo Formation is early Middle Pennsylvanian in age.

The following fossils were identified by R. C. Douglass in samples taken from the Syrena Formation 32–42 feet below the Abo Formation in sec. 25, T. 17 S., R. 12 W., and secs. 29 and 30, T. 17 S., R. 11 W.: *Tetrataxis* sp., *Bradyina* sp., and *Triticites* sp. aff. *T. ventricosus*. He also identified *Triticites* sp. aff. *T. ohioensis* in specimens from beds about 140–143 feet below the Abo in secs. 29 and 30, T. 17 S., R. 11 W.; this fossil is of the kind generally found in rocks of early Late Pennsylvanian age in Missouri. Pratt (1967) lists fossils from three collections in the Oswaldo Formation at Lone Mountain. These fossils suggest that the Oswaldo ranges in age from Middle to Late Pennsylvanian and that the Syrena is Late Pennsylvanian.

The Magdalena Group of New Mexico can probably be correlated with the lower part of the Naco Group of Arizona—more specifically, with the Horquilla Limestone and possibly with part of the Earp Formation. However, detailed correlations are not warranted at this time (J. S. Williams, in Gilluly and others, 1954, p. 31).

PERMIAN SYSTEM—ABO FORMATION

The red mudstone, shale, and conglomerate which in the Santa Rita region rest on the Syrena Formation and are overlain by the Beartooth Quartzite of Cretaceous age were correlated with the Abo Formation of central New Mexico by Spencer and Paige (1935, p. 27). The Abo Formation at the type locality in Abo Canyon, at the south end of the Manzano Range, consists of 300–800 feet of coarse-grained dark-red to purple arkosic and quartzose sandstone; usually the Abo is conglomeratic at its base and contains a subordinate amount of shale throughout. Regionally, the upper limit of the Abo is regarded to be just below the first gypsiferous beds of the Yeso Formation. The upper limit in the Santa Rita region is clearly defined by the unconformity at the base of the Beartooth Quartzite. The lower limit is not everywhere distinct in the Santa Rita region because of similarly colored red mudstones locally near the top of the Syrena. Commonly there is an abrupt change in lithology, however, and the underlying Syrena Formation contains a marine fauna.

The Abo Formation crops out in several areas in the northern two-thirds of the Santa Rita quadrangle, but it was eroded before Cretaceous time from the southern third of the quadrangle. The best exposures for lithologic study are in the southeast quarter of the quadrangle, 1 mile northeast and 2 miles east of Kneeling Nun. Exposures within the Chino pit, as well as those at Topknot Hill, at Humbolt Mountain, and near the Barringer fault, are so altered that the original character of the sediments is largely obscured. The limy siltstone of the formation was particularly susceptible to metamorphism and was converted to hornfels in places where adjacent limestone or shale is not noticeably altered.

The thickness of the Abo Formation in the Santa Rita quadrangle ranges from 0 to 265 feet. The formation seems to be about 200 feet thick in the central part of the quadrangle, but poor exposures and intense alteration do not permit accurate measurements. The southward pinchout of the Abo Formation can be seen along a ridge that parallels the west margin of the quadrangle, between Ansones and Beartooth Creeks, a few hundred feet west of the quadrangle margin. South of Beartooth Creek, the Beartooth Quartzite (Cretaceous) rests directly on the Syrena Formation.

In the Santa Rita area the lower part of the Abo Formation consists of reddish-gray shale, siltstone, and calcareous mudstone containing lenses of gray limestone conglomerate. The upper part is calcareous mudstone and very silty and argillaceous limestone, also containing lenses of limestone conglomerate. Between Ansones and Beartooth Creeks, where only 25 feet of the Abo remains, the section is predominantly limestone conglomerate in which fragments of gray limestone ⅛–1 inch in diameter are embedded in a red mudstone matrix. Beds of reddish-gray to purplish-red shale are also present. In other places the conglomerate contains pebbles of jasper and of white and gray chert, as well as of limestone. The mudstone is yellowish brown, grayish purple, or reddish gray, and commonly contains small calcareous nodules of similar hues. The limestone is reddish gray, grayish orange, or light brown, but never the typical white or blue-gray of the limestone of the Pennsylvanian and older periods.

The following proportions of shale, argillaceous limestone, mudstone, and conglomerate are present in two exposures of the Abo Formation east of Kneeling Nun: Shale, 21 and 30 percent; argillaceous limestone, 21 and 19 percent; mudstone, 55 and 50 percent; and conglomerate, 3 and 2 percent.

Measured sections.—Further lithologic details are given in the following representative sections.

Abo Formation, SW¼NE¼ sec. 25, T. 17 S., R. 11 W.

[Abstracted from description by A. F. Shride (written commun., 1954)]

	Thickness (feet)
Beartooth Quartzite.	
Abo Formation:	
1. Interbedded shale and limestone. Shale is calcareous, grayish red, and partly silty, and grades vertically into the limestone, which is very argillaceous and is grayish red, mottled light brown. Shale and limestone are in about equal proportions and appear to interfinger laterally	67.0
2. Limestone conglomerate, grayish-red, yellowish-brown; poorly sorted angular to rounded pebbles and granules of gray limestone and white to gray chert; in places crossbedded	3.5
3. Interbedded shale and limestone, very similar to unit 1	47.0
4. Limestone conglomerate, very similar to unit 2	2.5
5. Mudstone, dusky-yellow and grayish-red, earthy, calcareous; contains abundant small limestone nodules; weathers grayish red	135.0
6. Limestone conglomerate; 50 percent jasper, 10–30 percent white to gray chert, 20–40 percent gray limestone and mudstone. Grain size from 1 to 30 mm; matrix grayish-red limy mudstone	1.0
7. Mudstone, poorly exposed but probably much like unit 5	9.0
Total Abo Formation	265.0
Syrena Formation:	
Limestone, gray; fossiliferous: corals, cephalopods, bryozoa, crinoids, brachiopods.	

Abo Formation, southeast of Delk ranch house in W½NW¼ sec. 4, T. 18 S., R. 11 W. (about 1 mile east of Santa Rita quadrangle)

[Abstracted from description by A. F. Shride, written commun., 1954]

	Thickness (feet)
Beartooth Quartzite.	
Abo Formation:	
1. Limestone, yellowish-brown with red mottling, fine-grained, argillaceous, very thin bedded (0.5–5 in.); contains abundant gray chert pebbles (0.5–10 mm); poorly exposed	5.0
2. Limestone, grayish-red, very argillaceous, thick-bedded; contains nodules of gray limestone 0.25–5 mm in diameter. Easily eroded	12.0
3. Shale, grayish-red, earthy, very calcareous; contains abundant red ovoid calcareous nodules (0.5–5 mm)	32.0
4. Limestone conglomerate, dark-gray to grayish-red; light-brown pebbles of limestone, chert, jasper, and shale in reddish-gray limestone matrix	1.5
5. Shale, grayish-red, calcareous	20.5
6. Limestone, grayish-red, aphanitic, very argillaceous, massive, poorly indurated	15.5

Abo Formation, southeast of Delk ranch house in W½NW¼ sec. 4, T. 18 S., R. 11 W. (about 1 mile east of Santa Rita quadrangle)—Continued

	Thickness (feet)
Abo Formation—Continued	
7. Limestone, like above, but weathers pale yellowish orange to grayish orange and contains granules (2 mm) of purer light-gray limestone	8.5
8. Mudstone, grayish-red-purple, earthy, calcareous; contains abundant calcareous nodules locally	53.0
9. Limestone conglomerate, light-gray to grayish-purple; pebbles (1–30 mm, average 4–5 mm) are 95 percent gray limestone, 5 percent chert and jasper; pebbles moderately well rounded; matrix weathers yellowish brown, is calcareous mudstone	2.0
10. Mudstone, grayish-red-purple, earthy, calcareous, weakly cemented; contains calcareous nodules 55–77 mm	43.0
Total Abo Formation	193.0
Syrena Formation:	
Interbedded fossiliferous limestone and shale. Unit contains brachiopods, echinoid spines(?), and sparse fusulinids.	

Fossils, age, and correlation.—The Abo Formation contains few fossils except in pebbles derived from older formations. No fossils useful in establishing the age of the beds have been found in the Santa Rita region. Dating of the Abo Formation as Permian is based on its stratigraphic position, and, in the Santa Rita region, on its disconformable relationship to Upper Pennsylvanian beds of the underlying Magdalena Group. Faunas from the Hueco Limestone, which interfingers to the east with the Abo Formation (Thompson, 1942, pl. 2), establish the age of the Abo as late Wolfcamp and early Leonard. King (1942, p. 687, 690) reported fossil plants studied by C. B. Read as belonging to a Supai floral assemblage, supposedly of Leonard age. Kuellmer (1954, p. 26–27) summarized the current thought on the age of the Abo Formation as follows:

> Inasmuch as the Abo Formation is a lithologic unit and contains very few marine fossils, exact time-stratigraphic correlation with either the marine Leonard or the marine Wolfcamp series would seem impossible. Skinner (1946, p. 1871) and Lloyd (1949, p. 30–31) have conjectured that the Abo Formation actually crosses the time boundary represented by the Leonard-Wolfcamp contact. Thompson's cross section (1942, pl. II) and Miller and Parizek's (1948) faunal age determination suggest that most of the Abo Formation in New Mexico is of late Wolfcamp age.

The typical red sediments of the Abo Formation are not found in western Arizona, and the gypsiferous beds lie directly on the marine Naco Group, at least in the Empire and Santa Rita Mountains. The Colina Limestone and Epitaph Dolomite (Gilluly and others, 1954) formations of the Naco Group are considered to be of Wolfcamp and Leonard age and may be the correlatives of the Abo. (See Gilluly and others, 1954, p. 40.)

MESOZOIC ROCKS

Rocks of Triassic and Jurassic age are absent from southwestern New Mexico owing either to nondeposition or to erosion. Locally, the oldest rocks of the Mesozoic Era in southwestern New Mexico are of Early Cretaceous age. They consist of a thick series of volcanic rock, limestone, shale, and sandstone equivalent to formations of the Bisbee Group. They crop out south and southwest of the Silver City–Santa Rita region in the Cooks Range, in the Victoria Mountains, in the Little and Big Hatchet Mountains, and in the Peloncillo Mountains. In the Little Hatchet Mountains, in the southwest corner of New Mexico, this group, according to Lasky (1947, p. 13), "has an aggregate thickness of 17,000 to 21,000 feet, including as much as 5,700 feet of volcanic rocks."

Rocks of Late Cretaceous age are much more widespread in southwestern New Mexico than are rocks of Early Cretaceous age. (See Pike, 1947.) West of the Rio Grande, the Upper Cretaceous rocks are named the Beartooth Quartzite and the Colorado Formation (Lasky, 1936), or the Colorado Shale (Paige, 1916; Darton, 1917). The Cretaceous sequence in the Silver City region closely resembles that described by Kelley and Silver (1952) in the Caballo Mountains, just east of the Rio Grande, about 45 miles east of Santa Rita. The basal sandstone there was referred to by them as the Dakota Group, whereas in the Silver City region it is called the Beartooth Quartzite. The overlying thin-bedded black shale and limestone and olive-drab siltstone, apparently identical with part of a shale member of the Colorado Formation, was called the Mancos Shale. The uppermost Cretaceous beds, consisting of interbedded conglomerate, sandstone, siltstone, shale, and coal, were called the Mesaverde Formation. All these Cretaceous sedimentary rocks are absent from the Mimbres and Black Ranges, which lie about midway between the Santa Rita and Caballo Mountain regions. Apparently, prior to the accumulation of andesite and latite flows, tuffs, and volcanic conglomerates, 2,000 feet or more of Cretaceous rocks was eroded from a north-trending belt coinciding with the site of the Mimbres and Black Ranges. Presumably this erosion occurred in Late Cretaceous or early Tertiary time. Similar deep erosion of Cretaceous rocks in the Pinos Altos region, located 7 miles west of Hanover, N. Mex., preceded the earliest outbreak of volcanism, although intrusive activity predated that erosional time. South of the Cleveland mine, in the Pinos Altos region, andesite breccia locally rests directly on the Beartooth Quartzite.

UPPER(?) CRETACEOUS—BEARTOOTH QUARTZITE

The sandstones and interbedded shales which lie unconformably on the Abo Formation and older rocks, and which are overlain conformably by the Colorado Formation, were named the Beartooth Quartzite by Paige (1916, p. 5). The type locality is along Beartooth Creek, east of Fort Bayard.

Within the Santa Rita quadrangle, the Beartooth Quartzite is exposed on the west, east, and south sides of the Santa Rita stock and in a discontinuous curving belt that extends east and southeast of the stock to the southeast margin of the quadrangle. There are numerous exposures of it in the greatly faulted area west and northwest of Santa Rita. The Beartooth also crops out in a large irregular C-shaped belt that reflects the domal uplift centered northeast of Copper Flat. Isolated outcrops of Beartooth Quartzite cap Humbolt Mountain and Topknot Hill. North of the Barringer fault, west of Fierro, the Beartooth is exposed in a thin arcuate belt; the formation here was partly stoped by the Hanover-Fierro pluton, which apparently domed the Beartooth as well as the formations above and below.

The Beartooth Quartzite consists largely of light-gray and buff fine-grained to very fine grained sandstone which nearly everywhere has been changed to quartzite by silicification. It weathers reddish brown, is thin bedded to massive, is in places crossbedded, and contains various amounts of dark shale ranging in thickness from a few inches to several feet. Long thin lenses of conglomerate containing black and white chert and, locally, gray limestone are conspicuous features near the base and, as emphasized by Spencer and Paige (1935, p. 29), near the top, usually within the upper 10 feet. The weathered upper surface of many beds east of Fort Bayard is pockmarked with irregular pits. Some beds contain irregular wormlike markings and a few silicified fragments of wood. At the head of Beartooth Canyon the formation is capped by 2 feet of well-rounded quartzite pebbles, as much as 6 inches in diameter, which are firmly cemented in a fine-grained siliceous matrix. The gray to black carbonaceous shale that occurs locally near the top of the Beartooth Quartzite can be confused in isolated outcrops with the black shale of the overlying Colorado Formation.

Within the Santa Rita quadrangle the thickness of the Beartooth Quartzite ranges from about 50 to 140 feet. The thinnest section occurs in the area between the Groundhog and Princess mines (NW¼ sec. 33, T. 17 S., R. 12 W.). Lasky (1936, p. 22) found it to be 66 feet thick north of the Ivanhoe mine. From this locality to the west and southwest, the Abo Formation was eroded and the Syrena Formation was thinned prior to deposition of the Beartooth Quartzite. About a mile west of Vanadium, 103 feet of Beartooth Quartzite was penetrated by a drill hole. Lasky (1936, p. 22, 23) found the Beartooth to be about 142 feet thick at Yellowdog Gulch, a mile northwest of Vanadium. It is 132 feet thick about 4½ miles southeast of the Chino mine (Spencer and Paige, 1935, p. 29).

Measured sections.—Details of the stratigraphy of the Beartooth Quartzite are given in the following measured sections exposed in Yellowdog Gulch and in low hills just beyond the east boundary of the quadrangle.

Beartooth Quartzite in Yellowdog Gulch, Fort Bayard Reservation

[Modified from Lasky (1936, p. 23)]

	Thickness (feet)
Colorado Formation.	
Beartooth Quartzite:	
Sandstone, black, quartzitic	1.3
Sandstone, soft, brown; locally quartzitic. Lower 8 in. is a pebbly conglomerate	1.5
Sandstone, black, quartzitic; similar to top unit	1.0
Sandstone, dark-gray, shaly; contains thin shale partings	17.0
Sandstone, soft, greenish-brown	5.0
Sandstone, greenish-brown, quartzitic; locally conglomeratic	1.3
Shale, gray, fissile	.5
Sandstone, greenish-gray	1.7
Shale, greenish-gray, sandy	9.3
Shale, black	3.0
Unexposed	19.0
Quartzite, grayish-white, fine-grained	2.0
Shale, black	1.3
Sandstone, greenish-brown, shaly	1.5
Quartzite, pink, fine- to medium-grained; bedding planes 1–3 ft apart	48.0
Shale, light-grayish-yellow, bleached, siliceous	20.0
Quartzite, fine-grained, white, vitreous	9.0
Total Beartooth Quartzite	142.4
Syrena Formation.	

Partial section of Beartooth Quartzite southeast of Delk ranch house, W½NW¼ sec. 4, T. 18 S., R. 11 W.

[Measured by A. F. Shride (written commun., 1954)]

	Thickness (feet)
Beartooth Quartzite (present surface):	
Quartzite, light-gray, fine-grained; almost pure quartz sand; some intergranular clayey material. Beds 1–4 ft thick, crossbedded; firm silica cement; weathers light gray; iron stained; pitted; blocky jointing; forms resistant ledges	17.0
Sandstone, yellowish-gray to pink, fine-grained; almost pure quartz sand; somewhat clayey; beds 2 in.–4 ft thick; moderately firm silica cement; beds of light-gray silty shale separate sandstone beds; sandstone weathers yellowish gray to pink; stained by dark limonite; Liesegang banding common; forms ledges	33.0
Partial thickness Beartooth Quartzite	50.0
Unconformity.	
Abo Formation.	

The lithologic character of the Beartooth Quartzite throughout the region is ably generalized in the following paragraph quoted from Paige (1916, p. 5).

> The base of the formation at many places is a thin conglomerate containing black and white quartz pebbles an inch or more in diameter in a matrix of clearly washed, fine, glassy quartz grains. Kaolinized areas indicate the former presence of feldspar. The rock weathers brownish and reddish, and iron staining is rather prominent. At other places the basal beds consist of clean, clear, very small quartz grains set in a dull white matrix, at least in part calcareous. Variegated tones of white and pink are prominent. Microscopic examination shows the rock is cemented by secondary silicification, many of the grains having grown perfect crystal faces, but in places the cement is apparently clayey. Here and there the quartzite is beautifully banded by weathering in circular and subcircular patterns. A thin shale of irregular thickness is at some places intercalated near the top of the formation.

Hewitt (1959, p. 79) noted that "the Beartooth quartzite's basal contact with Burro Mountain granite is marked by 2 to 3 feet of hematite stained granitic debris and arkose, which grades upward into a 2-foot-thick bed of chert conglomerate * * *. The arkose is composed of angular fragments up to several centimeters in length, firmly cemented by white calcite."

As Hewitt (p. 79–80) pointed out, the lithologic features of the Beartooth Quartzite are typical of sediments deposited by a transgressive sea on an area of low relief.

In the Cooks Range the upper third of the Sarten Sandstone is about 300 feet thick (Jicha, 1954, p. 26) and is lithologically similar (a light-gray fine- to medium-grained quartz sandstone) to the Beartooth Quartzite. The middle third (approximately) of the Sarten Sandstone has yielded fossils of Early Cretaceous age.

Fossils, age, and correlation.—No fossils other than nondiagnostic plant remains have been found in the Beartooth Quartzite; hence, its age and correlation must be based on lithologic similarity and geologic relations. Spherical objects, which could conceivably be dicot fruits but could equally well be inorganic in origin (R. A. Scott, written commun., 1956), were found in the Beartooth Quartzite in the NW¼ sec. 33, T. 17 S., R. 12 W. A large specimen of petrified woody stem material was collected from an exposure of Beartooth Quartzite in Yellowdog Gulch, but no traces of diagnostic structure were recognizable.

The Beartooth Quartzite of the Silver City region was correlated by Darton (1928, p. 38) with the Sarten Sandstone in the Cooks Range, north of Deming. Fossils collected from limy beds in the middle of the Sarten by Darton, and more recently by the authors, are of Washita or Fredericksburg (Early Cretaceous) age (W. A. Cobban, written commun., 1961). Darton based his correlation on similar lithology and stratigraphic position. Cobban and Reeside (1952, p. 1011) agreed with Darton and showed the Beartooth as Lower Cretaceous, equivalent to the Sarten Sandstone. Pike (1947, pl. 12) also agreed with Darton, for he showed the Upper Cretaceous Dakota Sandstone as pinching out toward Santa Rita from both the north and east. However, the authors suggest that the Beartooth represents the initial stage of the cycle of sedimentation that also produced the beds of the Colorado Formation, whose age is firmly established as Late Cretaceous. Thus, if the Beartooth and Sarten are equivalent, we must assume that deposition of the Beartooth and Colorado sediments began in Early Cretaceous time and continued without interruption into Late Cretaceous time. However, the Beartooth Quartzite may be the correlative of only the upper part of the Sarten and the correlative of the Dakota Sandstone which conformably underlies the Mancos Shale, for the basal, fossiliferous shales of the Colorado Formation are equivalent to the Mancos Shale, or to the Graneros Shale.

UPPER CRETACEOUS—COLORADO FORMATION

The name Colorado Group was proposed by Hayden (1876, p. 45) and remains the established name for beds representing the lower half of the Upper Cretaceous in many areas in the Rocky Mountains. The clastic deposits overlying the Beartooth Quartzite were named the Colorado Shale by Paige (1916), who considered them equivalent to the Benton Shale of the Colorado Group. Colorado Formation may be used where the Colorado Group is not divided into formations, as in the Silver City–Santa Rita region. In this region Spencer and Paige (1935, p. 30, 31) recognized, but did not name, three possible lithologic subdivisions: (1) a lower carbonaceous shale member about 200 feet thick; (2) a middle member about 130–540 feet thick characterized by conspicuous beds of light-colored calcareous sandstone and sandy limestones; and (3) an upper member more than 220 feet thick made up predominantly of dull green shale, sandy shale, and fine-grained sandstone. Lasky (1936, p. 23–26) divided the Colorado Formation in the Vanadium area into a basal shale member about 220 feet thick and an overlying sandstone member of variable but much greater thickness. Because the authors found no consistent horizon at which to subdivide this sandstone member, the twofold division proposed by Lasky is followed.

The Colorado Formation lies with apparent depositional conformity on the Beartooth Quartzite. The upper limit of the formation is either the present erosional surface or an older one. The full sequence of beds is nowhere present in the report region.

The Colorado Formation is exposed in the pits at the Chino mine and crops out in a fairly continuous belt that extends east from the mine for 2 miles and thence south, to disappear under the Tertiary volcanic rocks. Small angular areas of the formation, bounded by faults and igneous rock, are common both south and west of the Chino mine. The formation was eroded from the central part of the quadrangle, south of the Barringer fault, except in an area within a minor structural basin northwest of Humbolt Mountain. The Colorado Formation underlies much of the area north of the Barringer fault, between the fault and the south margin of the Miocene(?) volcanic rocks, and encircles the south and west sides of the structural dome centered northeast of Copper Flat. More than any other formation in the area, the Colorado is extensively intruded by thin to thick generally concordant sheets of igneous rock and, in the northwest quarter of the quadrangle, by innumerable thin dikes as well as by sills.

It has not been practical to distinguish between the shale and the sandstone members in the geologically more complex part of the quadrangle—that is, in small areas west and east of the Chino pits. However, the members are differentiated elsewhere in the quadrangle.

The shale member of the Colorado is a distinctive and easily distinguishable unit. It consists of black generally fissile and well-bedded shale, in part sandy, that contains a few silty to fine-grained sandstone beds; a few beds are calcareous. One sandstone bed which persists throughout most of the Santa Rita quadrangle is 20–25 feet thick and occurs 80–100 feet above the base. A similar sandstone 30 feet thick occurs about 75 feet above the base of the shale member in the Cooks Range (Jicha, 1954, p. 27).

Preliminary results of X-ray analyses indicate that the shale consists of about 40 percent each of quartz and clay, 10 percent calcite, 5 percent dolomite, and 5 percent organic material. A calcareous layer contains about 60 percent calcite, 15 percent quartz, and 25 percent clay and organic matter.

The sandstone member of the Colorado Formation consists of an alternating series of shale, sandstone, and mudstone beds. The shale is commonly some shade of green—olive, yellowish, or gray green—or less commonly, black. The sandstone beds are tan, yellowish tan, white, light green, or brown; the light-colored sandstone is fine to coarse grained, arkosic, and commonly crossbedded. The mudstone in most outcrops weathers olive green, greenish gray, or purple, but it may also be black. In the lower 100–150 feet or more of the sandstone member are thin commonly fossiliferous beds of limestone, grading to limy sandstone, which generally weather brown or gray brown. In places, some sandstone beds are replaced by irregular masses of calcite. Carbonized plant fragments and petrified woods have been noted in many exposures. A coarse white pebble conglomerate can be traced southwestward from North Star Basin to a point northwest of Fort Bayard, a distance of about 4 miles. This bed, which is generally not more than 5 feet thick, contains well-rounded pebbles of clear quartz, granite, variegated chert, and other rock. Locally, the conglomerate contains fragments of feldspar and has a pink cast.

Microscopic examination reveals that some beds of very fine grained tan sandstone are largely made up of angular fragments of relatively fresh plagioclase, orthoclase, and quartz. Minor amounts of clay, muscovite, biotite, chlorite, epidote, zircon, pyroxene, apatite, and limonite are also present. Calcite is abundant in some specimens and rare in others. The angularity and composition of the grains indicate a nearby source and rapid burial.

S. G. Lasky and M. W. Cox (written commun., 1945) established a local sequence of beds in the lower part of the sandstone member in the area northwest of Vanadium that is useful in determining small displacements along faults and veins in that area. (See measured sections, p. 36–37.) White crossbedded sandstone containing petrified wood fragments, and limestone containing distinctive fossils, constitute reliable marker beds within a radius of 1–2 miles of Vanadium. Local lithologic variations in these key beds are known, however, and it is doubtful that the beds persist regionally, although similar thin fossiliferous limestone occurs above the shale member of the Colorado in a low ridge 1½ miles northwest of Copper Flat, in the adjoining quadrangle.

Because the upper limit of the Colorado Formation is erosional, the original thickness of the formation is nowhere preserved. Also, accurate measurements of the remaining thickness are difficult to obtain, as pointed out by Paige (1916, p. 6), who said,

> The great amount of intrusion which the shale has undergone, combined with the softness of the beds and their general distribution in basin-like form, has effectually prevented continued exposure and therefore measurement of their thickness. Probably the maximum thickness of the formation in the [Silver City 30-minute] quadrangle is not less than 2,000 feet.

Lasky (1936, p. 23–26) reported that the total thickness preserved in the Bayard area is at least 675 feet, of which some 220 feet constitutes the lower shale member. In general, this lower member is everywhere about 200 feet thick. North of the Barringer fault the upper sandstone member is about 650–700 feet thick; east of the Chino mine the same member is about 800 feet thick. Farther east, the total preserved thickness of the Colorado Formation is 920 feet (Spencer and Paige, 1935, p. 31). The total thickness of not less than 2,000 feet, as estimated by Paige (1916, p. 6), could probably be verified by detailed mapping and measurements in the Silver City 7½-minute quadrangle.

Measured sections.—Further details of the Colorado Formation appear in the following stratigraphic sections. The generalized section of the shale member of the Colorado Formation is typical, except possibly the sandstone unit 80–85 feet above the base, which is absent in some places.

Generalized section of the shale member of the Colorado Formation

[Modified from Lasky (1936, p. 24–25)]

	Thickness (feet)
Colorado Formation.	
Sandstone member.	
Shale member:	
Shale, dark-gray to black, calcareous and very sandy; parting planes wavy and imperfect and a fraction of an inch to several inches apart; breaks to rough surfaces—a characteristic feature. Not everywhere present	8–10
Shale, dark-gray to slate-gray, in part sandy; planar fabric; slabby	80–105
Gryphaea horizon	<1
Sandstone, buff, fine-grained, calcareous; loosely cemented locally; grades to dark-gray and black shaly sandstone that is not everywhere distinguishable from the overlying sandy beds	25
Shale, black to gray, generally fissile; planar fabric; includes a few thin sandy layers	80–85
Total	193–225
Beartooth Quartzite.	

Partial section of sandstone member of Colorado Formation in Gold Gulch and adjacent draws just north of Vanadium, N. Mex.

[S. G. Lasky and M. W. Cox (written commun., 1945)]

	Thickness (feet)
Sill of hornblende quartz diorite.	
Colorado Formation:	
Sandstone member:	
8. Sandstone and sandy shale, interbedded, light- to dark-green, thin-bedded; includes discontinuous lenses of sandy limestone 18 ft above the base	45
7a. Limestone, sandy, gray to buff, massive, locally fossiliferous; fairly widespread and a good marker	4
b. Sandstone, quartzitic, white to buff; beds as much as 3 in. thick, markedly crossbedded; contains logs of black petrified wood and is therefore a good marker	30
c. Limestone, sandy; contains abundant fossil oysters (*Ostrea soleniscus*) and, locally, shell beds of limited lateral extent	1–2
d. Sandstone, quartzitic, white to buff; beds ½–3 in. thick, notably crossbedded	8

Partial section of sandstone member of Colorado Formation in Gold Gulch and adjacent draws just north of Vanadium, N. Mex.—Con.

	Thickness (feet)
Colorado Formation—Continued	
Sandstone member—Continued	
6a. Sandstone, bluish-gray; weathers to a rough surface, green with brown splotches	11
b. Limestone, brown; sandy in lower part and fossiliferous in upper part; horizon of ammonites, *Neoptychites* and *Thomasites.* Fairly widespread, good marker. Upper surface irregular, presumably channeled	½–3
c. Sandstone, white to gray; weathers green with brown splotches; fine to medium grained; mostly thin bedded and slabby; partings a few inches to 2 ft apart; same as 6a	9
5. Sandy shale, dark-gray to black; weathers green. May not be everywhere present	3
4. Sandstone, light- to dark-gray, massive to thin-bedded, locally crossbedded and lenticular	10
3. Limestone, light- to dark-gray; in places very sandy; in Gold Gulch is composed of hummocky masses 2–4 ft in diameter. Locally discontinuous or absent, but generally fairly widespread and a good horizon marker. Locally fossiliferous, containing *Inoceramus labiatus* Schlotheim	2–4
2. Sandstone, white to dark-gray, thin-bedded to massive, crossbedded; upper surface irregular, apparently owing to scouring; interbedded with shaly sandstone	9
1. Sandstone, gray, fine-grained, massive; shaly in middle; thin bedded (4–6 in.) at top	6
Total sandstone member measured	138½–144

Composite surface and subsurface section of the Colorado Formation in northwestern part of the Santa Rita quadrangle

Surface section

	Thickness (feet)
Andesite breccia.	
Disconformity.	
Colorado Formation:	
Sandstone member:	
Mostly covered; buff sandstone, shale and mudstone	100
Sandstone, buff, medium-grained, arkosic; pebbly to conglomeratic in the upper half	40
Sandstone, buff, arkosic, silty, interbedded with greenish-gray and some dark-gray to purplish-gray shale and mudstone	135
Covered, probably shale; a thin bed of brown unfossiliferous limestone near base	35
Shale, gray-green, largely covered	90
Sandstone, light-brown to buff, medium- to fine-grained, arkosic to argillaceous, alternating with mostly covered greenish-gray to purplish-gray shale and mudstone; thin limestone bed near base	83

Composite surface and subsurface section of the Colorado Formation in northwestern part of the Santa Rita quadrangle—Continued

Subsurface section, from diamond-drill hole; continuous with surface section

	Thickness (feet)
Colorado Formation—Continued	
Sandstone member—Continued	
Sandstone, gray to buff, fine- to medium-grained, somewhat arkosic, alternating with grayish silty mudstone and shale	118
Shale and mudstone, medium- to dark-gray, partly sandy	101
Sandstone, light- to medium-gray, fine-grained, silty	81
Total sandstone member	783
Shale member (partial):	
Shale, light-gray, silty to sandy	15
Shale, dark-gray, silty. Abundant fossils in lower 2½ ft, the "*Gryphaea* bed"	24
Shale, medium- to dark-gray, partly silty or sandy; some limy beds near top. Two thin porphyry sills excluded	50
Sandstone, silty, and sandy shale; buff to dark-gray; fine grained	24
Possible fault?	
Shale, dark-gray	10
Total thickness shale member measured	123
Total combined thickness, Colorado Formation	906
Beartooth Quartzite.	

The drill hole from which part of the foregoing section was determined is in somewhat deformed rock near the Barringer fault. The thicknesses given are corrected for dip. Faults having considerable displacement are apparently absent from both the surface and drill-hole parts of the section; but fractures are abundant in places, and distributed movement along them may affect the accuracy of the thicknesses. About 70–75 feet of black shale seems to have been faulted out of the section between unit 2 (24 feet of silty sandstone and unit 1 (dark-gray shale).

Much of the shale and mudstone in the upper 200 feet of the drill-hole part of this section, if seen in weathered outcrop, would probably be greenish gray or purplish gray, as it is in weathered outcrops elsewhere in the quadrangle.

Fossils, age, and correlation.—Fossils are scarce in all but a few beds of the Colorado Formation. Lasky (1936, p. 23–24) stated: "a fossiliferous layer near the middle of the shale contains numerous *Gryphaea newberryi* Stanton and less abundant *Exogyra columbella* Meek, *Plicatula hydrotheca* White, and species of *Astarte, Ostrea,* and *Gyrodes.*" The fossils in the following list were collected by Lasky and others from limy beds in the sandstone member:

1. *Inoceramus labiatus* Schlotheim
2. *Inoceramus* cf. *I. perplexus* Whitfield
3. *Cardium pauperculum* Meek
4. *Mactra* (*Cymbophora*) *utahensis* Meek
5. *Mactra emmonsi* Meek
6. *Mactra* (*Triginella*?) *arenaria* Meek
7. *Gyrodes depressa* Meek
8. *Ostrea soleniscus* Meek
9. *Ostrea* sp.
10. *Pecten*(?) sp.
11. *Pseudoptera* sp.
12. *Parmicorbula* sp.
13. *Volutoderma*? sp.
14. *Volsella*(?) sp.
15. *Corbula* sp.
16. *Neritina*(?) sp.
17. ?*Rostellites gracilis* Stanton
18. *Neoptychites* n. sp.
19. *Thomasites* n. sp.

The ammonites *Neoptychites* sp. and *Thomasites* sp. are known only in the Greenhorn Limestone and equivalents, of Late Cretaceous age. Both are scarce in the interior region of the United States (J. B. Reeside, Jr., written commun. to S. G. Lasky, 1945). *Ostrea soleniscus* Meek is from unit 7c (p. 36), sandy limestone. Most of the other forms are from unit 6b. Forms 11, 12, 14, 15, 16, and 17 are from beds of the Colorado Formation in the Lone Mountain area—in the SE¼ sec. 23, T. 18 S., R. 13 W., in the main branch of Cameron Creek.

W. A. Cobban (written commun., 1956) identified pelecypods and ammonites from a bed in the sandstone member of the Colorado Formation in the Fort Bayard reservation, half a mile west of the mouth of Beartooth Creek. The specimens included:

Cardium pauperculum Meek
Tellina sp.
Vascoceras sp.

The ammonite *Vascoceras* sp. is confined to the Greenhorn Limestone or to equivalent rocks in Colorado and Wyoming, according to Cobban (written commun., 1956). It is associated with *Thomasites* sp., *Pervinquiere* sp., and *Inoceramus labiatus* Schlotheim in the uppermost, Pfeifer Shale Member of the Greenhorn Limestone, according to Cobban and Reeside (1952, p. 1018).

Darton (1928, p. 40, 41) stated that the fossil *Inoceramus labiatus* is characteristic of the Greenhorn Limestone, of early Benton age, in eastern parts of northern New Mexico. J. B. Reeside (written commun., 1945), who identified the fossils from the sandstone member, stated that the ammonites *Neoptychites* and *Thomasites* are known only in the Greenhorn and equivalents, whereas *Gryphaea newberryi* and *Exogyra columbella*, from the shale member, indicated an age equivalent to that of Graneros Shale, which underlies the Greenhorn and is the base of the Colorado Group in northern New Mexico. Thus, as Lasky (1936, p. 24) said, the sandstone member of the Colorado Formation in the Bayard area may be considered equivalent in age to the Greenhorn Limestone, and the underlying shale member, equivalent to the Graneros Shale.

No fossils are yet known in the uppermost beds of the Colorado Formation in the Santa Rita quadrangle, but future work should provide some evidence of the age and correlation of these beds.

Regional aspects.—The Colorado Formation was originally widespread in south-central New Mexico, but much of it was eroded in Late Cretaceous time, prior to deposition of volcanic rocks in Late Cretaceous or early Tertiary time. The thickest section preserved in the region is in the northern part of the Caballo Mountains, where it aggregates about 3,700 feet (Bushnell, 1955, p. 84). In the Black Range, which lies about midway between Santa Rita and the Caballo Mountains, the Laramide volcanic rocks rest on the Permian Abo Formation; no rocks of Cretaceous age escaped erosion. North and northeast of Silver City, a thick section of the Colorado Formation remains. Although it has not been measured, it is probably not less than 2,000 feet thick (Paige, 1916, p. 6). Farther west, at the north edge of the Big Burro Mountains, the remaining part of the Colorado Formation is estimated to be 1,100 feet thick, and there it is underlain by about 60 feet of Beartooth Quartzite (Hewitt, 1959, p. 81).

Southeast of the Santa Rita quadrangle, in the Dwyer quadrangle, the Colorado Formation is not exposed. It may have been eroded before deposition of the oldest volcanic rocks (Elston, 1957, p. 9). Southeast, in the Lake Valley quadrangle, which adjoins the Dwyer on the east, Jicha (1954, fig. 3) measured about 300 feet of Colorado Formation.

Rocks of Late Cretaceous age, the Beartooth Quartzite and the Colorado Formation or their equivalent, the Mancos Shale and the Mesaverde Formation, are apparently missing where rocks of Early Cretaceous age are thickest—that is, in the central part of the Sonoran geosyncline. Upper Cretaceous rocks are not found in the Florida Mountains, the Cedar Mountains, the Hatchet Mountains, nor the Peloncillo Mountains, all in the southwest corner of New Mexico. The Beartooth Quartzite may represent the near-shore deposits of a bay in the Late Cretaceous sea which expanded from the Rocky Mountain trough westward and southwestward as far as the northeast margin of the Sonoran geosyncline.

UPPER MESOZOIC(?) AND CENOZOIC ROCKS

Because of the absence of fossils and the lack of crosscutting relations, a definite separation of Upper Cretaceous rocks from lower Tertiary rocks is not possible in the Santa Rita quadrangle. Similarly, upper Tertiary rocks cannot be separated from lower Quaternary deposits. Table 1 shows the chronological sequence in which the principal rock types were deposited or intruded. The Lower Cretaceous rocks—the Bisbee Group and the Hidalgo Volcanics, which are present elsewhere in southwest New Mexico—do not occur in the Silver City–Santa Rita region and are described only in table 1.

The lower Tertiary quartz monzonite or granodiorite discordant plutons, which were emplaced after the sills, are not in contact with the Laramide volcanic rocks in the Santa Rita quadrangle, and their age with respect to those volcanic rocks cannot be established conclusively. At Pinos Altos, 6 miles west, a stock that is chemically and mineralogically similar to the plutons intrudes the Laramide volcanic rocks; this fact, together with the nature and degree of alteration within the volcanic rocks, suggests that the Laramide volcanic rocks are older than the stocks in the Santa Rita area.

Sills of syenodiorite porphyry and dikes of diorite are the oldest known igneous rocks in the Santa Rita quadrangle. They are present only in the northwest quarter of the quadrangle. Their early age is proved by the fact that parts of them were exposed by erosion before deposition of the andesite breccia, probably in Late Cretaceous time. Only one syenodiorite porphyry sill is certainly older than the Laramide volcanic epoch; the relative age of the other sills with respect to the volcanic epoch is less certain.

TABLE 1.—*Rocks of late Mesozoic and Cenozoic age in the Santa Rita quadrangle and southwestern New Mexico, and related episodes of mineralization*

Epoch	Sedimentary	Extrusive	Intrusive	Related mineralization
Recent	Younger alluvium, talus, and landslide debris. Older alluvium and colluvium.	Basalt flows and sheets of "mal-pais." (Not in Santa Rita quadrangle)		Placer gold deposits. Manganese oxide deposits. Supergene enrichment of old deposits.
—— Unconformity ——	Development of pediments			
Pliocene and Miocene(?)	Semiconsolidated gravels in the Mimbres River valley; basin-fill material similar to Gila or Santa Fe Formations.	Vesicular olivine basalt flows and silicic tuffs. (Not in Santa Rita quadrangle)	Few basalt plugs and dikes. (Not in Santa Rita area)	None.
—— Unconformity ——				
Miocene(?)	Gravel and sandstone deposits interbedded in volcanic sequence.	Predominantly basaltic andesite flows.	Few basaltic andesite plugs and dikes.	None.
		Rhyolite to quartz latite vitric-crystal tuffs and flows. (For example, Kneeling Nun Rhyolite Tuff and Sugarlump Tuff)	Few dikes and plugs of felsite, aplite, granite, and rhyolite porphyry.	Small deposits of tin, tungsten, lead, zinc, fluorite, silver, gold, copper, and beryllium, spatially and probably genetically related to granite and rhyolites. None in Santa Rita quadrangle, however.
		Rhyodacite and andesite flows, agglomerate, tuff, breccia, and conglomerate of the Rubio Peak Formation.		None.
—— Unconformity ——				
Miocene(?) to Late Cretaceous(?)	Conglomerate and sandstone filling Hanover Hole. Hole formed near close of intrusive series.		Plugs, stocks, and dike swarms of predominantly intermediate composition, granodiorite to quartz monzonite. Some quartz diorite sills may be earliest intrusives of this episode.	Major deposits of copper, zinc, lead, silver, iron, gold, and molybdenum. Porphyry copper deposits enriched before Miocene(?) volcanism.
	Shale and sandstone, similar to parts of Colorado Formation, interbedded in volcanic rocks.	Andesite-latite breccia, conglomerates, and flows; generally ubiquitously propylitized and compacted; deposited on deeply dissected surface.	Orthoclase gabbro and other mafic plugs and great swarms of mafic dikes.	No metalization genetically related to sills, laccoliths, or mafic plugs and dikes.
—— Unconformity ——				
Late Cretaceous(?)			Syenodiorite and some quartz diorite sills and few dikes; intrude Colorado and older formations in Santa Rita area.	
Late(?) Cretaceous and Late Cretaceous	Beartooth Quartzite and Colorado Formation.			
Early Cretaceous	Bisbee Group: limestone, shale, and sandstone in southwest corner of New Mexico only. Sarten Sandstone north of Deming, N. Mex.	Hidalgo Volcanics (Lasky, 1947): basalt, andesite flows, and pyroclastic material. Southwest corner New Mexico.		

INTRUSIVE ROCKS OF LATE CRETACEOUS(?) AND EARLY TERTIARY AGE—GENERAL FEATURES

More than 30 distinct varieties of intrusive rocks were intruded within the area of the quadrangle in the interval between Late Cretaceous(?) and Miocene(?) time. The intrusives formed sills, stocks, dikes, and a few plugs, in that sequence. Evidently few deep-seated discordant fractures existed in the Paleozoic and Mesozoic formations south of the Barringer fault prior to this igneous activity, for the initial intrusives spread laterally at various horizons in the stratigraphic column, and rarely formed dikes.

Although many of the sills are concordant with the invaded beds, some are broadly discordant and gradually cut across layering. Detailed examination of sill contacts suggests that this discordance resulted partly from abrupt steplike crossings of the bedding and partly from gradual migrations across the bedding at low angles. Almost invariably the magma invaded shale in preference to more competent sedimentary rocks. Many sills include lenticular masses of the host rock.

The addition of the sills to the stratigraphic column greatly increased its thickness and competency. That part of the stratigraphic column lying above the Percha Shale, the lowest unit in which extensive sills formed, was raised several hundred to a few thousand feet relative to that part of the column in adjacent areas where sills were not introduced. The fact that limestone of Pennsylvanian age is exposed at the surface in the central part of the Santa Rita quadrangle is attributable partly to the intrusion of sills in and just above the Percha Shale and partly to later intrusion by a large stock. For 10–12 miles west of the Santa Rita quadrangle, the present erosion surface truncates stratigraphically higher Upper Cretaceous to lower Tertiary formations. Paleozoic formations stand structurally high enough to be exposed again by erosion at the sill-and-laccolith area west of Pinos Altos Mountain.

Two medium-sized stocks and one small stock were forcefully intruded in the Santa Rita region, where numerous sills had previously been intercalated with the strata. These stocks and the feeders to the sills "bolted" the strata and the sills together, and "bolted" the whole to the crystalline basement. The relief of subsequent stresses in the strata may have been influenced by the location of these "bolts," for subsequent faults, dikes, plugs, and the Hanover Hole are concentrated in the triangular area that has the three stocks at its apices.

The shape of the stocks and the configuration of the surrounding rocks indicate that the magma was intruded forcefully and came to rest close to the surface of that time. The intrusive at Copper Flat and the south lobe of the Hanover-Fierro pluton diminish in size with depth, and each probably has one major rootlike extension. The host beds were crumpled and even forcibly thrust aside to make room for the outward and upward expansion of these two intrusives, especially the south lobe of the Hanover-Fierro pluton. The walls of the main mass of the pluton dip inward locally, but, at least at the present level of truncation, the main mass seems to have forced its way vertically and to have exerted little lateral pressure. The piercing nature of the intrusion is indicated by the sharply upturned strata along the east and west margins. The Santa Rita stock is more irregular in plan, and to the depth exposed its margins are mainly vertical, but again there is little evidence of laterally directed pressure from the magma. The major irregularities in the outline of the stock are related to preexisting fractures of northwest, northeast, and east trends, which, if projected, intersect within the limits of the stock. Forcible injection of the magma is indicated by the slight doming of the strata around the Santa Rita stock area.

After the stocks were emplaced, successive intrusions of magma into fractures in the stocks and country rock formed dikes and, near the end of the series of intrusions, two small plugs. Many fractures were opened repeatedly, so that composite dikes are common. In plan and section many dikes have blunt terminations. Many are en echelon, others branch and join along the strike or in the direction of dip, and some have sill-like apophyses.

The intrusive rocks of this time interval are generally similar in texture and mineralogy and are alike in color index—that is, in having a low ratio of heavy to light minerals. These rocks differ from each other chiefly in the proportion of minerals: the percentage of quartz, the ratio of alkali feldspar to total feldspar, and the presence or absence of certain accessory minerals. During the mapping phase of the work, much attention was necessarily given to any recognizable differences in mineral content, no matter how trivial. Such attention to minor differences should not obscure in the reader's mind the basic likeness of the rocks. Although the rocks range from syenodiorite to rhyolite in composition, about 95 percent of the exposed area of rock is granodiorite. The matrix of most of the rocks, constituting 50–70 percent of their volume, is generally cryptocrystalline; thus the relative amounts of the two feldspars in the rock can rarely be determined. The assignment of names by earlier workers and by the authors to many of the rocks was therefore necessarily arbitrary. In general we have retained the names that are familiar to workers in the district, even though modal and normative plots suggest the need for some revisions. (See figs. 11, 12.) Actually, from a statistical viewpoint, the amount of data still does not justify renaming the rocks.

The abundance of the major phenocrysts and of the accessory minerals, as set forth in several tables, was determined by the point-count method of Chayes (1949). Points falling on alteration minerals within recognizable phenocrysts were tallied with points falling on the phenocrysts. The relative abundance of any alteration products within each thin section was roughly estimated as abundant, common, or trace. If the host phenocryst could not be determined, the various alteration minerals were included as such in the count. In a few thin sections the relative abundance of the minerals in the matrix could be established; but, in general, no count was attempted because of the fineness of the grain and the uncertainty of identification.

A plot of the modal composition of those rocks in which the proportion of orthoclase to plagioclase could be determined is given in figure 12. Two of the rocks—hornblende-quartz diorite and quartz latite porphyry—at Copper Flat (pl. 2, and fig. 8, respectively), seem to be misnamed, but other factors (chemical data, district usage) must be considered.

Certain petrographic features are common to the individual minerals of nearly all these rocks, and they are generalized here. The most abundant phenocrysts are those of plagioclase, which constitute as much as 57 percent and generally 20–40 percent of each rock type. They range in size from a fraction of a millimeter to about 10 mm, are subhedral to euhedral, and are commonly zoned outward from andesine to oligoclase. Although the maximum anorthite content ranges from 8 to 57 percent, the average maximum is about 40 percent. No marked decrease is shown from older to younger rocks, as is common in a series of this kind. The calculated anorthite content of normative plagioclase ranges from 24 to 59 percent and averages about 35 percent. Most plagioclase phenocrysts are fractured and are partially or completely replaced by one or more of the following: albite, sericite, montmorillonite, kaolinite, calcite, epidote, and orthoclase.

Orthoclase phenocrysts within the size range of those of plagioclase are notably sparse in most rocks, but a few rocks contain poikilitic "phenocrysts" or porphyroblasts 2–3 cm long. Most of the potassic feldspar, as indicated by rock slices stained with sodium cobaltinitrite, is in the felsic matrix. In several rocks the matrix is composed of coarse anhedral orthoclase, and in a few this paragenetically late feldspar has partially replaced the phenocrysts.

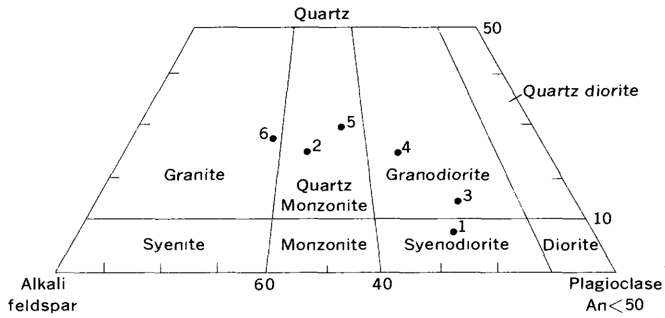


FIGURE 12.—Modal analyses of some intrusive rocks in the Santa Rita quadrangle. 1, Syenodiorite porphyry, average of 3 modes; 2, hornblende quartz diorite, 1 mode; 3, granodiorite from Hanover lobe of Hanover-Fierro pluton, average of 4 modes; 4, granodiorite from main mass of Hanover-Fierro pluton, average of 6 modes; 5, quartz monzonite porphyry of Santa Rita stock, average of 6 modes; and 6, quartz latite porphyry of pluton at Copper Flat, 1 mode.

Quartz phenocrysts occur in many rocks of the series, both as partly resorbed grains and as euhedral crystals—commonly hexagonal dipyramids. The volume percent ranges from 0 to nearly 14 and averages almost 5 percent. The volume percent of total quartz (phenocrysts and matrix) is, of course, much greater, as indicated by the amount of normative quartz, which ranges from 11 to 45 percent and averages 20 percent for the series.

Hornblende and biotite are the chief mafic constituents in most of the rocks, but the oldest rock in the series contains pyroxene as well. Hornblende is the only mafic mineral in some rocks, and biotite in some others, but generally both are present. Biotite rarely constitutes as much as 5 percent of any rock, but hornblende constitutes as much as 25 percent of some dikes, especially their margins, and 5–10 percent of several rocks. On the whole, the total of mafic minerals probably averages about 5 percent.

The accessory minerals are magnetite-ilmenite, sphene, apatite, zircon, allanite, and rutile. The accessories are not all present in each rock of the series, and their grain size and abundance are highly variable from one rock to another; however, the presence or absence of a particular accessory mineral is not a reliable criterion for distinguishing between rocks of the series.

The general chemical nature and the broad trends in chemical composition are shown in table 2 and in figures 13, 14, and 15. The general chemical similarity of the rocks is evident in the tabulation of atomic proportions (table 2). Seemingly insignificant differences in atomic proportions give rise, however, to appreciable differences in the norms, and to striking differences in the modes and textures of the rocks, for the modes and the textures are functions of the cooling history of the magmas as well as of chemical composition.

TABLE 2.—*Chemical analyses, norms, and atomic proportions of some intrusive rocks in the Santa Rita quadrangle*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Chemical analyses, in percent														
SiO_2	56.80	74.06	59.38	62.25	61.3	61.26	65.36	65.7	66.93	70.33	64.15	61.47	66.16	64.53
Al_2O_3	17.12	13.18	16.51	15.95	16.6	16.22	16.29	16.0	15.74	15.89	16.45	16.03	15.70	16.11
Fe_2O_3	3.53	.51	1.21	2.51	3.4	3.00	1.94	2.5	.25	.36	1.13	2.38	1.30	1.50
FeO	3.80	.27	3.50	2.16	2.2	2.38	1.88	1.8	2.23	.29	2.12	2.10	1.62	1.56
MgO	2.37	.50	2.26	1.57	2.2	2.57	1.76	1.5	1.36	.57	2.05	2.79	1.20	1.39
CaO	5.99	1.63	6.06	4.40	4.5	6.12	4.05	2.5	1.36	1.65	7.09	4.07	3.66	2.81
Na_2O	3.96	2.24	3.50	3.76	4.8	4.34	3.90	3.4	2.24	4.60	2.10	3.29	3.46	4.17
K_2O	2.57	4.47	2.16	3.02	2.3	2.61	3.29	4.2	6.70	3.31	1.66	3.14	3.58	3.21
H_2O+	1.28	1.28	1.92	1.78	1.4	.20	.52	1.3	.93	.93	1.40	2.03	1.62	1.53
H_2O-	.55	1.12	.38	.56	----	.15	.20	----	.27	1.40	.44	1.02	.40	1.55
TiO_2	1.01	.09	.53	.55	.62	.52	.45	.42	.37	.20	.48	.57	.37	.46
P_2O_5	.52	.02	.34	.21	.22	.48	.23	.31	.17	.06	.24	.25	.21	.24
MnO	.12	.10	.13	.15	.16	.08	.04	.04	.02	.02	.20	.11	.17	.08
ZrO_2	----	----	.01	----	----	----	----	----	----	----	----	----	----	----
CO_2	.04	.35	2.11	1.04	.36	.09	.06	.06	:01	.09	.13	.15	.21	.83
SO_3	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Cl	----	----	----	----	----	----	----	----	----	.02	----	.01	----	----
F	----	.02	----	.03	----	----	----	----	----	.05	----	.05	----	----
S	----	----	----	----	----	.05	----	----	1.17	----	----	----	----	----
BaO	----	----	.08	----	----	----	----	----	.16	----	.25	----	.11	----
		99.84		99.94					99.91	99.77		99.46		
Less O		.01		.01					.29	.02		.02		
Total	99.66	99.83	100.08	99.93	100	100.07	99.97	100	99.62	99.75	99.89	99.44	99.77	99.97
Norms, in percent [1]														
Quartz	9.5	40.4	19.0	17.5	13.9	13.9	19.4	22.5	23.2	26.9	26.8	18.1	23.5	20.8
Orthoclase	15.0	26.7	12.8	17.8	13.3	15.6	19.5	25.0	39.5	19.5	11.1	18.4	21.1	19.5
Albite	33.5	18.9	29.3	32.0	40.4	36.2	33.0	28.8	18.3	38.8	17.8	27.8	29.3	36.2
Anorthite	21.4	5.8	15.0	18.0	17.2	17.2	17.0	11.4	6.7	7.8	30.0	18.1	14.7	12.2
Corundum	----	2.5	3.0	----	----	----	----	1.6	2.5	1.9	----	----	.7	1.4
Diopside	1.9	----	----	1.7	1.5	3.0	.9	----	5.6	----	2.9	----	----	----
Hypersthene	7.7	1.3	10.2	3.8	5.6	5.8	5.2	4.5	----	1.9	6.8	8.1	4.8	5.1
Magnetite	5.1	.7	1.9	3.7	4.9	4.4	2.8	3.7	.5	.2	1.6	3.5	1.9	2.3
Hematite	----	----	----	----	----	----	----	----	----	.3	----	----	----	----
Ilmenite	2.0	.2	.9	1.1	1.2	.9	.8	.8	.8	.5	.9	1.1	.8	.9
Apatite	1.3	----	.7	.3	.3	1.3	.3	.7	.7	----	.3	.7	.3	----
Calcite	1.0	.8	4.8	2.3	.8	2.0	.2	.2	----	.2	.3	.6	----	----
Water	1.8	2.4	2.3	2.3	1.4	.4	.7	1.3	1.2	2.3	1.8	3.1	2.0	3.1
Pyrite	----	----	----	----	----	----	----	----	1.8	----	----	----	----	----
Atomic proportions [1]														
O	61.07	63.49	60.19	60.44	60.61	61.71	61.86	61.26	61.73	61.99	61.46	60.29	61.15	61.14
Si	20.32	24.57	20.45	21.30	20.90	21.51	22.63	22.28	22.96	23.89	21.84	20.87	22.59	22.26
Al	7.22	5.14	6.69	6.45	6.67	6.70	6.61	6.36	6.37	6.36	6.63	6.39	6.31	6.54
Fe^{+3}	.95	.12	.33	.66	.86	.80	.50	.65	.08	.12	.29	.61	.33	.37
Fe^{+2}	1.14	.08	1.01	.62	.63	.70	.54	.53	.66	.08	.59	.59	.04	.45
Mg	1.27	.24	1.18	.80	1.13	1.35	.92	.77	.70	.29	1.02	1.43	.61	.72
Ca	2.30	.58	2.23	1.62	1.63	2.30	1.50	1.01	.54	.61	2.60	1.47	1.23	1.03
Na	2.75	1.43	2.31	2.50	3.15	2.95	2.62	2.23	1.45	3.02	1.39	2.16	2.29	2.77
K	1.16	1.91	.95	1.31	.98	1.18	1.46	1.82	2.93	1.43	.74	1.34	1.56	1.41
H	1.33	2.39	4.42	4.07	3.19	.46	1.21	2.92	2.15	2.12	3.15	4.60	3.69	3.11
Ti	.28	.02	.12	.14	.17	.13	.10	.10	.10	.06	.12	.14	.10	.12
P	.17	----	.08	.04	.04	.21	.04	.08	.29	.04	.08	.08	.04	.04
Mn	.04	.02	.02	.15	.04	.02	.02	----	----	----	.06	.02	.04	.02
Ba	----	----	----	----	----	----	----	----	.02	----	.04	----	----	----

[1] Calculated by W. R. Jones.

1. Sample JC–1–58: hornblende-augite syenodiorite porphyry; composite sample from three sills in northwest quarter of Santa Rita quadrangle; M. R. Kittrell, analyst.
2. Sample WRJ–1: rhyolite porphyry, sill, 1634 drift, Groundhog mine, sec. 5, T. 18 S., R. 12 W., Grant County, N. Mex.; Dorothy J. Taylor, analyst.
3. Sample CA–2–53: quartz diorite porphyry, sill, northern facies; L. D. Trumbull, analyst.
4. Sample JC–1–61: quartz diorite porphyry, sill, southern facies; C. L. Parker, analyst.
5. Sample JC–3–56: hornblende quartz diorite, sill; W. W. Brannock, analyst.
6. Granodiorite porphyry, Hanover-Fierro pluton, equigranular facies, south lobe, Empire Zinc mine (Kerr and others, 1950, p. 299).
7. Sample P–19: granodiorite porphyry, Hanover-Fierro pluton, porphyritic facies, main mass (Schmitt, 1939a, p. 782).
8. Sample JC–110–54: quartz monzonite porphyry, Santa Rita stock, Chino mine, north pit; P. L. D. Elmore and P. W. Scott, analysts.
9. Sample JC–110–58: quartz monzonite porphyry, Santa Rita stock, Chino mine, south pit; F. H. Neuerburg, analyst.
10. Sample L–2–50: quartz latite porphyry, Copper Flat pluton; C. L. Parker, analyst.
11. Sample P–21: granodiorite porphyry, dike, Pewabic mine (Schmitt, 1939a, p. 782).
12. Sample JC–2–61: granodiorite porphyry, dike, Groundhog mine area; C. L. Parker, analyst.
13. Sample 1–PQM: quartz monzonite porphyry, dike, Groundhog mine; L. D. Trumbull, analyst.
14. Sample P–22: rhyodacite porphyry, dike, Pewabic mine (Schmitt, 1939a, p. 782).

In the normative plot (fig. 13), normative quartz, orthoclase, and plagioclase (albite plus anorthite), calculated to 100 percent, are plotted on part of a triangular quartz-orthoclase-plagioclase diagram. Most norms fall within a narrow band that extends from just above midpoint on the quartz-orthoclase side toward the plagioclase corner. As in a similar diagram for rocks from the Sierra Nevada batholith, "This pattern shows that the ratio between normative quartz and orthoclase is essentially constant and is very close to 1:1, and that quartz plus orthoclase is inversely proportional to plagioclase" (Bateman and others, 1963, p. D–28). Rocks unusually rich in potassium, such as one facies of quartz monzonite porphyry in the Santa Rita stock (9) and the orthoclase gabbro from a plug in North Star Basin (15), or unusually rich in quartz, such as the alaskite sill in the Kearney mine (2b) and the rhyolite porphyry sill in the Groundhog mine (2), stand out in this diagram. The reader will note that rock names based on modes do not always correspond with those based on norms, even though the limiting proportions are adjusted to compensate for the presence of albite in orthoclase. The pattern of plots cannot be considered a trend associated with time—as from basic to acidic (mafic to felsic)—for one of the earliest rocks (2, 2a, 2b) is the most acidic, and some of the latest rocks (11, 12, 13, 14) are of intermediate composition. To avoid this impression, we have not drawn a median line through the plots, as Bateman did, to indicate the general path of differentiation of a deepseated parental magma. The absence of plots in the plagioclase (Ab+An) corner supports Moore's (1959) contention that parental rocks in the underlying crust in this region are more potassic than their counterparts nearer the Pacific coast.

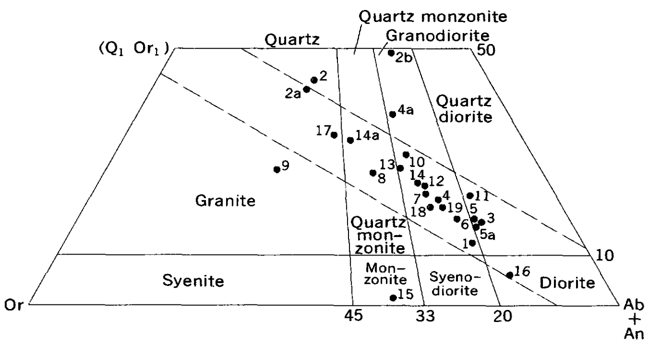


FIGURE 13.—Normative plot of some intrusive and extrusive rocks in the Santa Rita and adjacent quadrangles, Grant County, N. Mex. Limiting proportions are derived empirically from plot of Nockolds' (1954) average norms.

1. Syenodiorite porphyry sill.
2. Rhyolite porphyry sill, Groundhog mine.
2a. Sill in Percha Shale, 4 miles east of Santa Rita.
2b. Alaskite sill, Kearney mine.
3. Quartz diorite porphyry sill, northern facies.
4. Quartz diorite porphyry sill, southern facies.
4a. Quartz-rich variety, quartz diorite porphyry sill, 1 mile northeast of Kneeling Nun.
5. Hornblende quartz diorite sill, Bayard area.
5a. Hornblende quartz diorite sill, Pewabic mine area.
6. Granodiorite (equigranular facies), Hanover lobe, Hanover-Fierro pluton.
7. Granodiorite (porphyritic facies), main mass, Hanover-Fierro pluton.
8. Quartz monzonite (equigranular facies), Santa Rita stock.
9. Quartz monzonite (porphyritic facies), Santa Rita stock.
10. Quartz latite porphyry of Copper Flat pluton.
11. Granodiorite porphyry dike, Pewabic mine area.
12. Granodiorite porphyry dike, Groundhog mine area.
13. Quartz monzonite porphyry dike, Groundhog mine area.
14. Rhyodacite dike, Pewabic mine area.
14a. Quartz latite dike of Lasky (1936), Slate mine area.
15. Orthoclase gabbro plug, south of Pinos Altos, N. Mex.
16. Bear Springs Basalt (Tertiary) of Elston (1957).
17. Kneeling Nun Rhyolite Tuff (Elston, 1957).
18. Kneeling Nun Rhyolite Tuff, Bayard area.
19. Flow in Rubio Peak Formation (Elston, 1957).

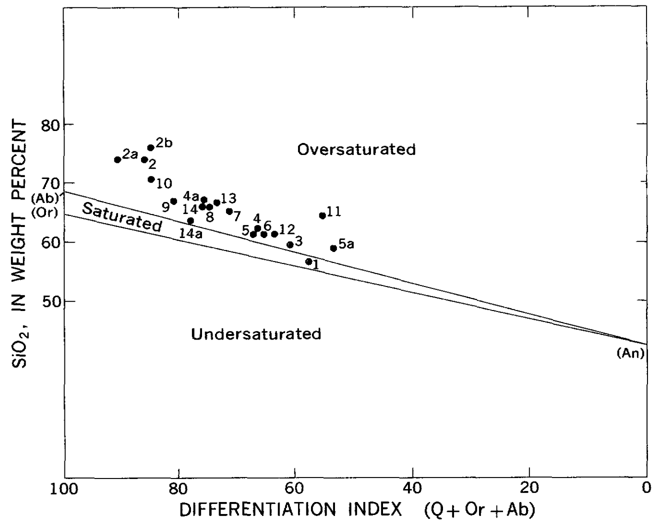


FIGURE 14.—Silica-differentiation index diagram of intrusive rocks of Late Cretaceous(?) and early Tertiary age, Santa Rita quadrangle, N. Mex. (Thornton and Tuttle, 1960, fig. 10).

1. Syenodiorite porphyry sill, composite sample.
2. Rhyolite porphyry sill, Groundhog mine.
2a. Sill in Percha Shale, 4 miles east of Santa Rita.
2b. Alaskite sill, Kearney mine.
3. Quartz diorite porphyry sill, northern facies.
4. Quartz diorite porphyry sill, southern facies.
4a. Quartz-rich variety, quartz diorite porphyry sill, 1 mile northeast of Kneeling Nun.
5. Hornblende quartz diorite sill, Bayard area.
5a. Hornblende quartz diorite sill, Pewabic mine area.
6. Granodiorite (equigranular facies), Hanover lobe, Hanover-Fierro pluton.
7. Granodiorite (porphyritic facies), main mass, Hanover-Fierro pluton
8. Quartz monzonite (equigranular facies), Santa Rita stock.
9. Quartz monzonite (porphyritic facies), Santa Rita stock.
10. Quartz latite porphyry of Copper Flat pluton.
11. Granodiorite porphyry dike, Pewabic mine area.
12. Granodiorite porphyry dike, Groundhog mine area.
13. Quartz monzonite porphyry dike, Groundhog mine area.
14. Rhyodacite dike, Pewabic mine area.
14a. Quartz latite dike of Lasky (1936), Slate mine area.

In the silica-differentiation index diagram (fig. 14), all but one rock plots in the "oversaturated" field. The exception, a syenodiorite, plots in the saturated field; however, the norm of this rock (table 2, col. 1) shows 9.5 percent quartz.

In the Larsen plot (Larsen, 1938, p. 505; fig. 15), two groups of normative minerals are plotted as two points on a triangular diagram and are joined by a line. In such plots the positions, slopes, and lengths of the lines are all significant and characteristic of the province. The plot also shows the Na_2O, K_2O, and CaO of the normative feldspar, the oversaturation or undersaturation of the rock, and the proportion of femic minerals in the rock. The plot for the rocks of the Santa Rita quadrangle is very similar to the plot for the lavas of the San Juan Mountains, Colo., and very unlike the plot for the rocks of the batholith of southern California or for the rocks of the Highwood Mountains, Mont. (Larsen, 1938, p. 518–519, figs. 7, 9, 10).

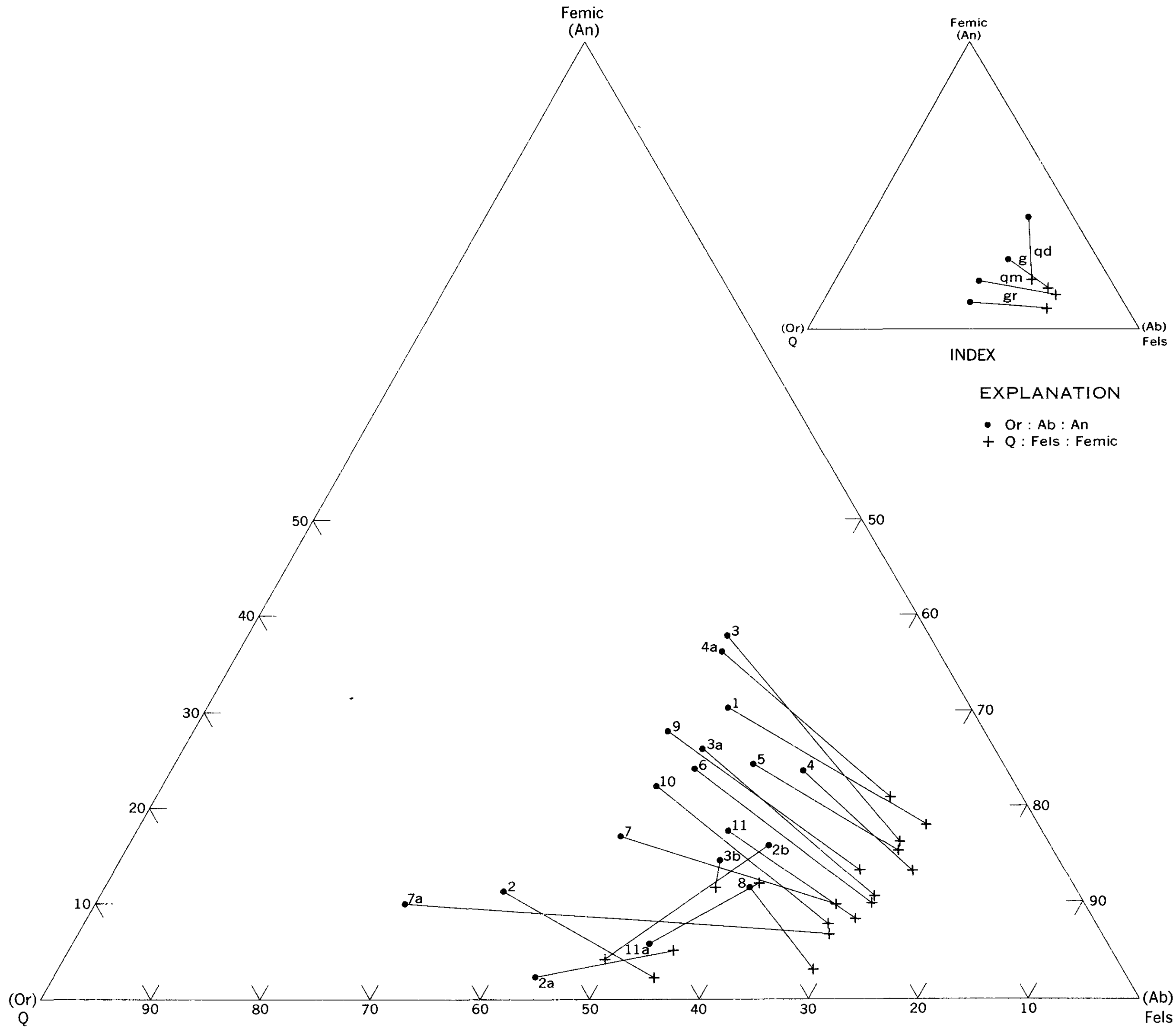


FIGURE 15.—Larsen plot of certain normative constituents of some intrusive rocks of Late Cretaceous(?) and early Tertiary age in the Santa Rita quadrangle, Grant County, N. Mex. Index shows similar plot of several average plutonic rocks (Nockolds, 1954).

Age group 1:
1. Syenodiorite porphyry sill.
2. Rhyolite porphyry sill, Groundhog mine. 2a. Rhyolite porphyry sill in Percha Shale, 4 miles east of Santa Rita. 2b. Alaskite sill in Kearney mine.
3. Quartz diorite porphyry sill, northern facies. 3a. Quartz diorite porphyry sill, southern facies. 3b. Quartz diorite porphyry sill, southern facies.
4. Hornblende quartz diorite, Bayard mine area.
4a. Hornblende quartz diorite, Pewabic mine area.

Age group 2:
5. Granodiorite, Hanover lobe of Hanover-Fierro pluton (Kerr and others, 1950).
6. Granodiorite, main mass of Hanover-Fierro pluton (Schmitt, 1939a).
7. Quartz monzonite, north wall of north Chino pit, Santa Rita stock.
7a. Quartz monzonite porphyry, east wall of south Chino pit, Santa Rita stock.
8. Quartz latite porphyry at Copper Flat.

Age group 3:
9. Granodiorite porphyry dike, north of Groundhog mine.

Age group 4:
10. Quartz monzonite porphyry dike, at Groundhog mine.

Age group 5:
11. Rhyodacite porphyry dike (Schmitt, 1939a).
11a. Quartz latite dike of Lasky (1936).

Index: Q, quartz; Fels, total normative feldspar; Femic, diopside, hypersthene, magnetite, ilmenite; qd, average of 22 hornblende-biotite tonalites (quartz diorites); g, average of 65 hornblende-biotite granodiorites; qm, average of 41 hornblende-biotite adamellites (quartz monzonites); gr, average of 6 hornblende-biotite calc-alkali granites.

For quartzose calc-alkalic rocks in general, the total amount of normative feldspar is rather uniform, ranging from about 65 percent to 70 percent of the rock. The value of total normative feldspar for rocks in the Santa Rita quadrangle seems to be bimodal, with values concentrated at 70 and 57 percent. The lower value is found generally in the more potassic rocks, for these usually contain a higher proportion of quartz. Line 2b (fig. 15), representing an alaskite sill, is the most erratic, sloping up to the right rather than to the left. The relative proportion of normative albite in the alaskite is unusually great for the quartz–total feldspar content. A few erratic analyses and plots are common for rocks from most provinces (Larsen, 1938, p. 517). For rocks in a province in which most rocks are hypabyssal porphyries, as in the Silver City–Santa Rita province, one might expect more erratic plots and less correspondence with the plots of average plutonic rocks as shown in the index diagram of figure 15. Evidently the phenocrysts in the porphyries of the Santa Rita area either grew in place or were not appreciably segregated from the magma during intrusion. The protoclastic structure in many of the rocks indicates that some flowage occurred in the partly consolidated magmas; however, a great deal of fracturing of phenocrysts could result from viscous magma flowing a few tens of feet. Erratic analyses and plots may also result from postmagmatic processes, such as potassium, hydrogen, or silica metasomatism (Hemley and Jones, 1964).

The intrusive rocks can be grouped on the basis of form, as follows:

1. Generally concordant plutons—thin and thick sills and laccoliths:
    - Syenodiorite porphyry
    - Augite-hornblende andesite porphyry
    - Rhyolite porphyry
    - Alaskite porphyry
    - Quartz diorite porphyry
    - Hornblende quartz diorite
    - Trachyte porphyry
2. Discordant plutons—stocks and apophyses and upward-flaring masses (ethmoliths):
    - Granodiorite porphyry of the Hanover-Fierro pluton
    - Quartz monzonite porphyry of the Santa Rita stock
    - Quartz latite porphyry of the Copper Flat pluton
3. Dike swarms and plugs:
    - Granodiorite porphyry dikes
    - Quartz monzonite porphyry dikes
    - Quartz latite porphyry dikes and plugs
    - Rhyodacite porphyry dikes and plugs

In the remainder of this section, the distribution, geologic relations, petrography, and chemical composition of the intrusive rocks, including mineralogical variants or facies, are described in the order given, which is, broadly speaking, chronological. The section closes with a review of the evidence for the relative ages of the rocks. The groups and units of the intrusive sequence serve as time markers within the Late Cretaceous to Miocene interval and reveal stages of folding, faulting, and mineralization that otherwise might have occurred during a single episode (Hernon and others, 1953; Jones and others, 1961). Use of the intrusive sequence for chronological purposes is beset, of course, with several inherent difficulties and must be supplemented by geological reasoning.

GENERALLY CONCORDANT PLUTONS OF LATE CRETACEOUS(?) AGE

SYENODIORITE PORPHYRY

Distribution and geologic relations

Hornblende-augite syenodiorite porphyry underlies Hermosa Mountain and two irregularly shaped areas in the northwest quarter of the Santa Rita quadrangle. The mass underlying Hermosa Mountain crops out in a roughly rectangular area 7,000 feet long, southeast to northwest, and 5,000 feet wide. Its northwest margin is defined by the overlap of andesite breccia of the Laramide volcanic epoch. Parts of its contact with the enclosing rock cut steeply across the bedding, but parts of the southeastern, northeastern, and western contacts are concordant with the bedding. It thus seems to be largely concordant with the host rock, and the term "stock" used by Spencer and Paige (1935, p. 34) to describe the mass is not strictly applicable.

A second mass of hornblende-augite syenodiorite is exposed in an area 6,000 feet long and about 3,000 feet wide north of Hermosa Mountain; the central part of the mass is covered by a projection of Miocene(?) basalt. This mass was undoubtedly continuous with that of Hermosa Mountain a hundred feet or so above the present erosional surface. The west and east margins—corresponding to the upper and lower contacts, respectively—dip gently westward and appear roughly conformable to the bedding of the Colorado Formation. In the central part, the basal (east) contact is stepped about 1,600 feet to the east. This offset could be explained either by a slight vertical drop of the gently westward dipping base on a fault, as shown on plate 1, or by an abrupt stepping of the magma to higher levels in the Colorado Formation. The west-trending contacts are sheared and are shown as faults, but the faults cannot be traced for more than a few tens of feet eastward into the Colorado Formation. Hence, the shearing probably resulted from slight differential movement along an irregular basal contact after consolidation of the sill.

The third mass of hornblende-augite syenodiorite is south of the Barringer fault and southeast of Hermosa Mountain; it intrudes the lower or Ready Pay Member of the Percha Shale. Its general conformity with the bedding of the shale is obvious, in spite of deformation which has domed and folded the sill and the enclosing strata. The sill is approximately 400 feet thick in the vicinity of section *B–B′* (pl. 2).

Syenodiorite is more resistant to erosion than are its enclosing formations, and its outcrops are thus more prominent. Weathering and erosion have etched out the joints, and the erosional forms are similar to those of the quartz diorite porphyry sill described on the following pages.

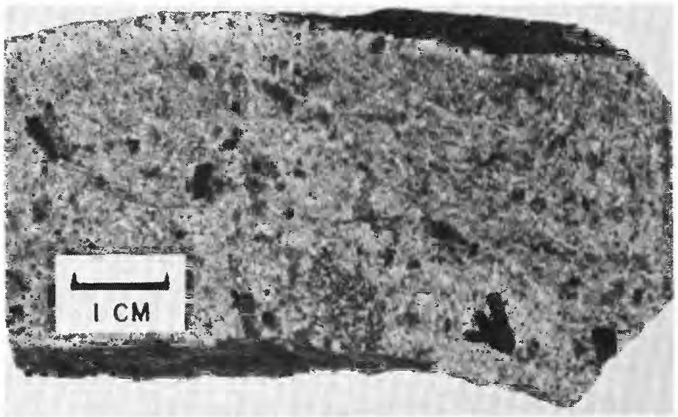
Petrography

The hornblende-augite syenodiorite porphyry is not uniform in appearance within each mass, but in general it is a medium-gray to greenish-gray holocrystalline porphyry which has a hypidiomorphic granular matrix (fig. 16). Slender black hornblende crystals and light-greenish-gray equant feldspar crystals are the most conspicuous phenocrysts. The matrix is light to dark gray and is either aphanitic or finely crystalline ($<$1 mm). The weathered rock is reddish brown.

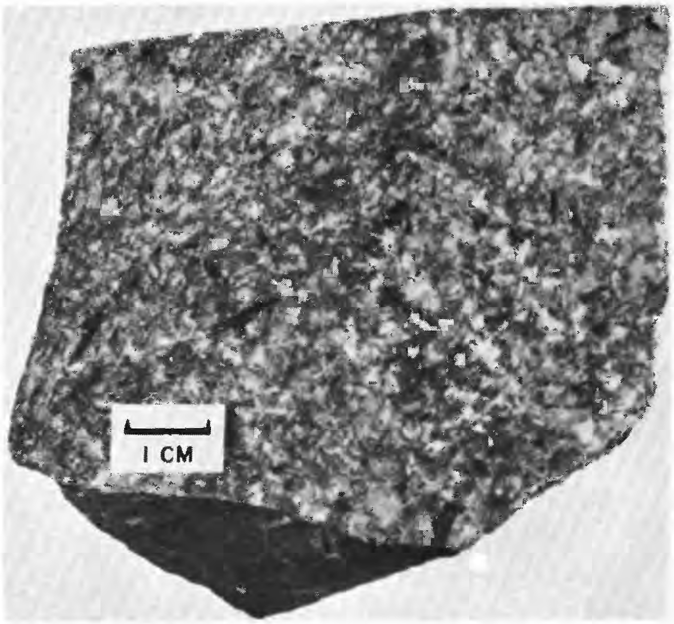
Thin sections of least altered specimens from each of the three masses show considerable variation in the mode (table 3). The major phenocrysts are labradorite-andesine, hornblende, and augite. Rectangular crystals of antigorite (bastite), probably pseudomorphs after hypersthene, are common in one specimen but constitute less than 1 percent of its volume. The primary hornblende phenocrysts are green, strongly pleochroic, and euhedral, but many are embayed by the matrix and have ragged edges; many also have marginal and crosscutting zones of minute opaque granules, probably magnetite or ilmenite partially altered to leucoxene. Blue-green uralite rims augite in some places. Hornblende phenocrysts constitute about 10 percent of the average specimen, and range in length from a fraction of a millimeter to 25 mm; laths about 5 mm long predominate.

The plagioclase phenocrysts are zoned normally and have labradorite or calcic andesine cores and andesine rims. They show albite and pericline twinning and are fractured, cloudy with inclusions, mottled, and flecked with epidote and sericite. In the samples studied, plagioclase phenocrysts constitute up to 25 percent of rock volume.

Phenocrysts of augite ($2V=55°–60°$) constitute less than 10 percent of each section examined, and average about 2 percent. The augite is colorless and euhedral to subhedral, and it is commonly replaced marginally and along fractures by uralite, which in turn is partly converted to chlorite. In one section, several crystals with the typical eight-sided outline of pyroxene are composed entirely of blue-green uralite.



A



B

FIGURE 16.—Syenodiorite porphyry. *A*, From sill in Percha Shale west of Union Hill. Dark minerals are hornblende; matrix is largely plagioclase. (Mode given in table 3, No. 4.) *B*, From sill 1.5 miles N. 70° W. of Hanover Mountain. Dark minerals are largely hornblende; light minerals are plagioclase. (Mode given in table 3, No. 6.)

The matrix consists of subhedral laths of andesine and orthoclase, sparse interstitial quartz, abundant granules of magnetite, sparse euhedral crystals of apatite and zircon, and small irregular clots of hornblende and augite granules. The proportions of the constituents are given in table 3. Stain tests reveal that a high percentage of the matrix is potash feldspar.

TABLE 3.—*Analyses, norms, and modes, in percent, of syenodiorite porphyry*

[nd, not determined; ng, not given; Tr., trace; ---, absent; A, abundant; C, common]

Chemical analyses

	[1]1	2		[1]1	2
SiO_2	56.80	56.00	H_2O+	1.28	0.92
Al_2O_3	17.12	16.81	H_2O-	.55	ng
Fe_2O_3	3.53	3.74	TiO_2	1.01	1.29
FeO	3.80	4.36	P_2O_5	.52	.33
MgO	2.37	3.39	MnO	.12	.13
CaO	5.99	6.87	CO_2	.04	ng
Na_2O	3.96	3.56			
K_2O	2.57	2.60	Total	99.66	100

Semiquantitative spectrographic analysis [2]

	1		1		1
Ba	0.07	Ga	0.0015	V	0.015
Be	.00015	La	.003	Y	.003
Co	.0007	Pb	.0015	Yb	.0007
Cr	.0007	Sc	.0015	Zr	.03
Cu	.003	Sr	.15		

Norms

	1	2		1	2
Quartz	9.5	7.2	Hypersthene	7.7	---
Orthoclase	15.0	15.6	Magnetite	5.1	5.3
Albite	33.5	29.9	Ilmenite	2.0	2.4
Anorthite	21.4	22.2	Apatite	1.3	.8
Diopside	1.9	15.6	Calcite	.9	ng

Modes

[Volume percent]

	3	4	5	6	7
Matrix	83	74	88	68	63
Quartz	9	5	4	C	C
Orthoclase	20	13	18	C	C
Chlorite and biotite	7	---	---	C	C
Hornblende	---	---	14	C	C
Andesine (An_{35-40})	47	56	52	A	A
Major phenocrysts:					
Plagioclase (An_{42-60})	---	---	---	25	25
Hornblende	---	[3]25	9	7	11
Augite	9	Tr.	1.2	Tr.	---
Accessory minerals:					
Magnetite	6.4	Tr.	Tr.	Tr.	Tr.
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.
Alteration minerals:					
Epidote	C	A	Tr.	C	A
Sericite	C	Tr.	Tr.	Tr.	Tr.
Albite	Tr.	C	Tr.	Tr.	Tr.
Chlorite	A	Tr.	Tr.	Tr.	C
Biotite	---	Tr.	---	C	C
Magnetite	---	---	---	Tr.	C
Leucoxene	Tr.	Tr.	Tr.	Tr.	Tr.
Uralite	Tr.	C	C	---	Tr.
Sphene	---	C	C	---	Tr.
Quartz	Tr.	Tr.	Tr.	Tr.	Tr.
Pyrite	---	Tr.	---	---	---
Bastite (antigorite)	Tr.	---	---	---	---

[1] Standard rock analysis, by M. R. Kittrell.

[2] Analyst: J. C. Hamilton. Figures reported to nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15. Looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Mo, Nb, Nd, Ni, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.

[3] Hornblende phenocryst replaced entirely by chlorite.

SAMPLE DESCRIPTION

1. Field No. JC-1-58; lab. No. E-1884. Composite sample made up of chips from three sills in northwest quarter of Santa Rita quadrangle.
2. Average doreites (syenodiorite) (Nockolds, 1954, p. 1018).
3. Field No. ITGL-50. Hermosa Mountain mass, elev. 7,576 feet.
4. Field No. JC-4-52. Sill in Percha Shale west of Union Hill, 3,650 feet N. 32° E. of Humbolt Mountain. (See fig. 16*A*.)
5. Field No. JC-4a-52. Within 100 feet of No. 4.
6. Field No. JC-67-52. Sill 1.5 miles N. 70° W. of Hanover Mountain.
7. Field No. JC-67a-52. Same location as No. 6. (See fig. 16*B*.)

As seen in thin section under highest magnification, the groundmass feldspar includes fresh andesine (An_{35-40}) and orthoclase as haphazardly arranged or irregularly interwoven lath-shaped grains.

The hornblende-augite syenodiorite porphyry is in general severely altered and somewhat weathered. Locally, as on Hermosa Mountain, epidote forms spheres 1–2 inches in diameter; it also coats joint surfaces and is distributed throughout the rock. Some dark specimens contain abundant flakes of green biotite, both disseminated throughout the matrix and within hornblende phenocrysts. In other sections, chlorite is the dominant alteration product. The plagioclase phenocrysts commonly are partially altered to sericite, clay, and epidote. On the south side of Hermosa Mountain the syenodiorite is replaced by a small body of magnetite; a magnetic map (Jones and others, 1964) suggests that an extensive body of magnetite underlies that area.

Chemical composition

A composite sample made up of chips from all three masses of the syenodiorite was analyzed chemically; the results are shown in table 3 (sample 1). Nockolds' (1954, p. 1018) chemical analysis of average doreite (volcanic equivalent of syenodiorite) closely approximates that of the composite sample and is listed as sample 2 for comparison. The results of a semiquantitative spectrographic analysis of the composite sample of syenodiorite are also given. In both normative diagrams, figures 13 and 15, the plot, point 1, falls within the field of granodiorite rather than syenodiorite. Nevertheless, except for the basalt, it is the most basic rock in the quadrangle, and it is somewhat arbitrarily called syenodiorite to distinguish it from the many and more typical granodiorites.

AUGITE-HORNBLENDE ANDESITE PORPHYRY SILLS NEAR GEORGETOWN

Distribution

Two thin sills of augite-hornblende andesite intrude the Percha Shale in the northeast quarter of the Santa Rita quadrangle, near Georgetown. The larger of the two is nearly continuous from a point southwest of the Georgetown cemetery to near the Cramer shaft, a distance of about 1 mile. The other sill extends northwestward about 2,000 feet from a point a third of a mile north of the Georgetown ruins.

Petrography

Where fresh, the rock is dark gray to nearly black; and where altered but not weathered, it is light greenish gray. Weathered specimens of altered rock are yellowish brown to brick red and contain abundant cavities caused by the leaching of secondary calcite.

Most unweathered specimens readily effervesce in dilute hydrochloric acid. Except in the chilled margins, the rock is porphyritic and contains small (<1 mm) sparsely distributed blades of hornblende. A few stubby crystals of hornblende 10 mm long and 4 mm across also occur in the rock. Plagioclase phenocrysts are more abundant, but they blend with the matrix and are less conspicuous. Pyrite, quartz, and calcite are the only accessory minerals seen in hand specimens. The groundmass is aphanitic.

In thin section the rock is seen to consist largely of elongate oligoclase crystals (An_{15}). These form a feltlike matrix in which are set phenocrysts of lath-shaped and equant subhedral andesine, euhedral to subhedral brown hornblende, a few greatly altered grains of colorless pyroxene (probably augite), and abundant small prisms of apatite. Several miarolitic cavities filled with calcite and quartz were also noted. Tiny granules of quartz and somewhat larger granules of magnetite or ilmenite are disseminated throughout the rock. Most andesine phenocrysts have a narrow rim of untwinned plagioclase which is probably more sodic than the interior.

The following data are from a modal analysis made of a typical relatively fresh sample:

	Volume (percent)	*Remarks*
Matrix	80.3	Oligoclase, and minor quartz, apatite, calcite, chlorite, leucoxene, and opaques.
Andesine phenocrysts	9.4	Subhedral-euhedral grains partially altered to clay, calcite, and chlorite. 0.3–3 mm.
Hornblende phenocrysts	4.0	Mostly unaltered, but some altered to chlorite and to calcite.
Augite phenocrysts	2.0	Largely altered to chlorite, calcite, sphene, and leucoxene.
Completely altered mafic silicate minerals.	2.3	Hornblende or augite altered to chlorite, calcite, and leucoxene.
Cavities filled with calcite and quartz.	2.0	Maximum dimension 0.10–2 mm.

The andesite is partially to completely altered to calcite, brown chlorite, clay, leucoxene, and minor amounts of sericite, hydromica, and epidote. Many plagioclase phenocrysts are completely altered either to clay or calcite, and not uncommonly to both, the calcite replacing the clay. The cores of many andesine phenocrysts are converted to clay, and the margins to calcite. In one section, hydromica is the only alteration mineral in phenocrystic andesine. The plagioclase laths in the matrix are generally less completely altered to brown chlorite, calcite, and leucoxene. Several prismatic crystals show calcite replacement in the cores and chlorite along the margins. Plumose and radiating aggregates of chlorite were the first to replace some mafic minerals; calcite replaced the chlorite. In the least altered thin section examined, one in which most of the hornblende was fresh, the augite crystals were largely replaced by patches and veinlets of calcite and chlorite. Globular grains of secondary sphene are concentrated within some crystals, but similar grains are also present throughout the section.

RHYOLITE PORPHYRY

The first published mention of rhyolite porphyry in the Central mining district of New Mexico was made by Lasky and Hoagland (1948), who, however, called the rock "albite quartz porphyry." Evidently the specimen examined by them was severely and unusually altered, as it contained only one feldspar—albite—virtually Ab_{100} in composition. Specimens of relatively fresh rock and of altered rock have been analyzed chemically and microscopically by the authors, and the results justify changing the name to rhyolite porphyry.

Distribution

Rhyolite porphyry is known in the quadrangle only in underground mine workings and in drill holes, but just east of the quadrangle a large sill crops out within the Percha Shale. Rhyolite porphyry has been penetrated by drill holes in an area extending from the Groundhog mine northeast to Hanover; in this area it forms concordant sheets ranging in thickness from a few feet to 350 feet. The largest known mass is an irregular lens in the Groundhog mine between the 1400 and 1800 levels that, measured parallel to the Groundhog fault system and over a distance of 1,600 feet, averages about 200 feet in thickness. The large masses of the rock found to date are in the lower part of the Oswaldo Formation and at the horizon generally occupied by the "Marker sill" (hornblende quartz diorite porphyry).

Petrography

In hand specimen the rhyolite porphyry is light greenish gray to nearly white. It is fine to medium grained and contains abundant small phenocrysts (rarely larger than 2 mm) of quartz, plagioclase (An_{10}), and orthoclase set in an aphanitic matrix. Many quartz phenocrysts are well-formed dipyramids, but others are rounded anhedra embayed by the aphanitic matrix. The feldspar phenocrysts are less conspicuous, because they do not contrast with the matrix as do the quartz grains (fig. 17). Phenocrysts of biotite and possibly of hornblende, completely altered to chlorite, sericite, and epidote, are present in some specimens. The least altered specimen contains a few grains of magnetite, but otherwise the rock lacks accessory minerals.

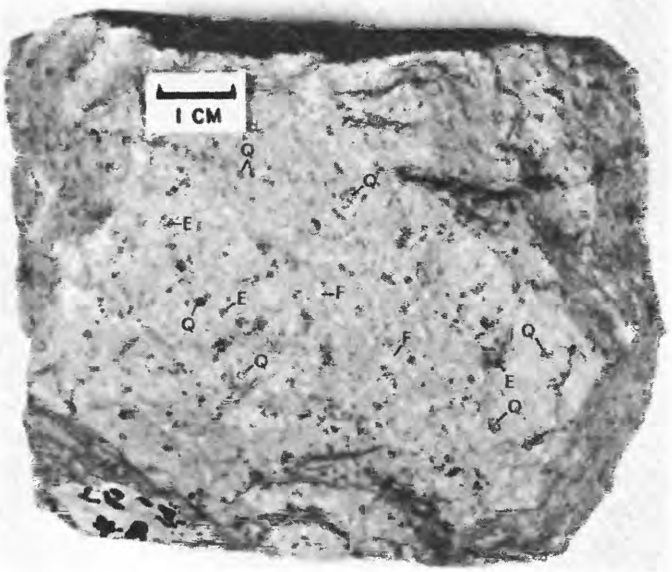


FIGURE 17.—Rhyolite porphyry sill rock from Groundhog mine. Gray to nearly black grains are quartz, Q; light-colored grains are cream-colored feldspar, F; epidote, E. Matrix is greenish gray and aphanitic.

Seventy percent of the rhyolite porphyry is cryptocrystalline matrix consisting predominantly of quartz and potassic feldspar, the latter clouded with clay particles. Quartz, potassic feldspar, and albite-oligoclase (An_{10}) are the most abundant phenocrysts and constitute about 25 percent of the rock (table 4). The average mode of two specimens, based on counts totaling 4,100 points, is given in table 4 (col. 1 under "modes"). As the epidote reported in this analysis is principally confined to the feldspar phenocrysts, a better idea of the primary abundance of feldspar is gained if half the epidote value is added to the amount of plagioclase, and half to the amount of potassic feldspar. Potassic feldspar totals about 45 percent, or more than four times the amount of plagioclase. Quartz content also totals about 45 percent; thus, 90 percent of the rock consists of quartz and potassic feldspar.

The intensity of alteration ranges from partial replacement of the feldspar by epidote, zoisite, or clinozoisite to complete alteration of all the phenocrysts except quartz to white aggregates of sericite, clay, and, more rarely, chlorite. The replacement of plagioclase by orthoclase and of biotite by muscovite preceded the formation of the epidote-group minerals, and it may be a late magmatic effect. In mildly altered rock, veinlets of epidote and calcite are common, and locally the rock is completely converted to pink clinozoisite or to epidote. The pervasive clay, chlorite, and sericite are apparently products of the latest alteration. Modal analyses of two intensely altered specimens from the 1634 and 1800 levels of the Groundhog mine are given in table 4 (cols. 3 and 4 under "modes"). In specimen JC–20–56 from the 1634 level the alteration products are predominantly sericite, clay, and calcite and include less than 0.5 percent epidote; specimen LC–47–47, however, from the 1800 level, contains only 1.4

TABLE 4.—*Analyses, norms, and modes, in percent, of rhyoliet porphyry*

[ng, not given; Tr., trace; ---, absent; C, common]

Chemical analyses

	[1] 1	2		[1] 1	2
SiO_2	74.06	73.66	H_2O-	1.12	ng
Al_2O_3	13.18	13.45	TiO_2	.09	.22
Fe_2O_3	.51	1.25	P_2O_5	.02	.07
FeO	.27	.75	MnO	.10	.03
MgO	.50	.32	CO_2	.35	ng
CaO	1.63	1.13	F	.02	ng
Na_2O	2.24	2.99	Total	99.84	100
K_2O	4.47	5.35	Less O	.01	---
H_2O+	1.28	.78		99.83	100

Semiquantitative spectrographic analysis [2]

	1		1		1
Ba	0.07	Ga	0.0007	Sr	0.007
Be	.00015	Nb	.0015	Y	.003
Cr	.00015	Pb	.0007	Yb	.0003
Cu	.0003	Sc	.0003	Zr	.007

Norms

	1	2		1	2
Quartz	40.44	33.2	Hypersthene	1.43	0.8
Orthoclase	26.69	31.7	Magnetite	.70	1.9
Albite	18.86	25.1	Ilmenite	.15	.5
Anorthite	5.84	5.0	Apatite	---	.8
Corundum	2.45	.9	Calcite	.80	---

Modes
[Volume percent]

	1	3	4	5
Matrix	69	72	71	79
Phenocrysts:				
Quartz	8	12	8	6
Orthoclase	9	---	---	---
Plagioclase (An_{10})	9	Tr.	Tr.	14
Biotite	---	Tr.	---	Tr.
Magnetite	---	---	Tr.	---
Alteration minerals:				
Epidote	[3] 4	Tr.	10	Tr.
Calcite	Tr.	3	---	[3] C
Sericite	[4] Tr.	6	1	[3] C
Clay minerals	Tr.	6	---	[3] C
Clinozoisite	Tr.	Tr.	---	---
Chlorite	Tr.	---	10	---
Leucoxene	Tr.	---	---	---
Quartz	---	1	1	---
Pyrite	---	Tr.	Tr.	Tr.
Limonite	---	---	---	Tr.

[1] Standard rock analysis, by D. J. Taylor.
[2] Analyst: P. R. Barnett. Figures reported to nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15. Looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Co, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, La, Li, Mo, Nd, Ni, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Te, Th, Tl, U, V, W, Zn.
[3] Replacement of plagioclase and orthoclase.
[4] White mica replacing hornblende or biotite.

SAMPLE DESCRIPTION

1. Field No. WRJ–1; lab. No. C–1162. Sill, 1634 level, Groundhog mine.
2. Average calc-alkalic rhyolite and rhyolite obsidians (Nockolds, 1954, p. 1012).
3. Field No. JC–20–56. Sill, intensely altered, 1634 level, Groundhog mine.
4. Field No. LC–47–47. Sill, intensely altered, 1800 level, Groundhog mine.
5. Field No. JC–16–56. Sill in Percha Shale half a mile east of Santa Rita quadrangle, 200 ft north of State Highway 90.

percent sericite but 10 percent each of epidote and chlorite, and has much additional chlorite in the groundmass, making the rock dark green. These two specimens, though, are not necessarily characteristic of the rocks at the levels from which they were collected; the distribution of the alteration types has not been investigated.

Chemical composition

Chemical and spectrographic analyses of rhyolite porphyry are given in table 4. The weight percent of SiO_2—hence, the amount of normative quartz—is exceptionally high compared with that in other rocks in the district, and the weight percent of Al_2O_3, Fe_2O_3, FeO, and MgO is low. The ratio of normative orthoclase to normative plagioclase (Ab+An) is 1.1:1, in contrast to an estimated ratio of 4:1 in the mode. This discrepancy suggests that considerable albite is held in the alkali feldspar counted as orthoclase. Nockolds' (1954, p. 1012) average chemical analysis of 22 specimens of calc-alkalic rhyolite and rhyolite obsidian is given (sample 2) for comparison.

ALASKITE PORPHYRY

A sill of alaskite porphyry as much as 40 feet thick is exposed in the workings of the Kearney mine (secs. 22 and 27, T. 17 S., R. 12 W.). The alaskite intrudes a siliceous shale, known locally as the Parting shale, at the base of the Oswaldo Formation. Exposures of the alaskite porphyry were recently identified at the surface about 1,500 feet northwest of the Kearney mine shaft. However, owing to the intense silicification and epidotization of the alaskite and of the enclosing shale in that area, the two have not been differentiated on the map (pl. 1).

The specimens of alaskite porphyry collected from underground workings are light gray on freshly broken surfaces but creamy white on joint surfaces. The lighter color of joint surfaces is attributed to shallow alteration of the matrix feldspar. The rock breaks with a hackly to conchoidal fracture and is difficult to penetrate with diamond drills. The alaskite is very fine grained and slightly porphyritic. The phenocrysts, which are quartz and feldspar, are about 2 mm in diameter and constitute only 1–3 percent of the rock volume. They are sparsely and unevenly dispersed; generally from one to five phenocrysts can be seen per square inch. Euhedral crystals, as well as partly absorbed crystal fragments of orthoclase, plagioclase, and quartz, are visible.

As seen with hand lens, the groundmass consists of minute gray quartz grains, 0.1–0.3 mm in diameter, evenly dispersed in light-colored feldspar. Staining tests show that both orthoclase (or an alkali feldspar) and plagioclase are present in unaltered specimens. As seen in thin section at high magnification, the groundmass consists of interlocking anhedral to subhedral quartz grains partly to wholly replaced by a potassium-rich alkali feldspar, which imparts a micrographic texture. The clear quartz remnants and the quartz in the micrographic intergrowth are in optical continuity; the alkali feldspar, commonly as lath-shaped grains oriented in two directions nearly at right angles, are also generally in optical continuity. The same is true where muscovite rather than alkali feldspar forms the oriented laths in the quartz. The groundmass plagioclase is sodic oligoclase or albite and occurs as very fine grained untwinned granules interstitial to the partly feldspathized quartz grains. The volume so occupied is variable, even within a single thin section. Within a fraction of an inch of some plagioclase phenocrysts the groundmass feldspar is all plagioclase.

The alaskite porphyry is distinguished from the rhyolite porphyry by the general sparseness of phenocrysts and by the absence of biotite, hornblende, or other mafic minerals. Although the matrix of the alaskite is fine grained, it is coarser than the matrix of the rhyolite porphyry examined by the authors. The unusual texture of the alaskite groundmass was noted in two thin sections of the rhyolite porphyry—one from the sill in the Groundhog mine and one from the large sill just east of the quadrangle. In these highly siliceous magmas, quartz evidently crystallized first. It was then partly converted to alkali feldspar or muscovite as the proportion of alkalis and aluminum in the remaining fluid increased. Plagioclase seems to have crystallized last.

The specimens examined show a varying degree of alteration. The plagioclase was most susceptible, and was replaced by montmorillonite and kaolinite or by sericite. Calcite is abundant in some specimens, and epidote is common in a few. The orthoclase is altered to sericite in some sections, but is unaltered in others. In exposures northwest of the Kearney mine the rock is completely silicified and veined by epidote. Small amounts of pyrite are present in some specimens.

Chemical composition

A sample of alaskite porphyry, collected in the manway connecting the 375 and 500 levels of the Kearney mine, was analyzed chemically and spectrographically; the results are shown in table 5. The analyzed sample, which came from the heart of the mine, was considerably altered; hence, the proportion of the base cations, especially Na^+, Ca^+, and K^+, is undoubtedly different from what it was originally. For such a siliceous rock, the potassium content is unusually low.

TABLE 5.—*Analyses and norm of alaskite porphyry from manway between 375 and 500 levels in Kearney mine, Santa Rita quadrangle*

[Sample: field No. JC-22-62; lab. No. I-4049. Analysts: standard rock analysis, C. L. Parker; semiquantitative spectrographic analysis, J. C. Hamilton; norm, W. H. Raymond]

	Percent		Percent		Percent
Chemical analysis					
SiO_2	75.92	H_2O+	1.13	S	.28
Al_2O_3	12.61	H_2O-	.99	Total	100.05
Fe_2O_3	.66	TiO_2	.08	Less O	.15
FeO	.11	P_2O_5	.01		99.90
MgO	.35	MnO	.03		
CaO	2.09	CO_2	.45	Specific gravity:	
Na_2O	3.31	Cl	.01	Bulk	2.57
K_2O	2.10	F	.02	Powder	2.63
Spectrographic analysis[1]					
Ba	0.02	Ga	0.0015	Y	0.003
Be	.0003	Nb	.002	Yb	.0003
Cr	.0003	Pb	.001	Zr	.005
Cu	.0007	Sr	.05		
Norm					
Quartz	45.42	Enstatite	0.90	Hematite	0.48
Orthoclase	12.23	Magnetite	.23	Corundum	2.24
Albite	27.77	Ilmenite	.15	Calcite	1.00
Anorthite	7.51				

[1] Results reported to nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, which represents approximate midpoints of group data on a geometric scale. Assigned group for semiquantitative results will include quantitative value about 30 percent of the time. Looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Co, Ge, Hf, Hg, In, La, Li, Mo, Ni, Pd, Pt, Re, Sb, Sc, Sn, Ta, Te, Th, Tl, U, W, Zn.

Whereas in many rocks the ratio of normative quartz to normative orthoclase is commonly close to 1:1, in this rock the ratio is about 3.7:1. The plot of the alaskite porphyry in figure 13 falls within the granodiorite field because of the abnormally low potassium content. A more atypical granodiorite could hardly be imagined. Some potassium may have been lost in the hydrolytic decomposition of orthoclase to muscovite or illite. Similarly, sodium and calcium may have been lost in the conversion of plagioclase to montmorillonite and kaolinite, as commonly happens. However, the analysis indicates that calcium may have been differentially retained by the formation of calcite; also, some calcium may have been added to the rock from solutions involved in the silication of limestones. Other analyses are needed before the extent of changes wrought by hydrothermal solutions can be assessed.

QUARTZ DIORITE PORPHYRY

Distribution and topographic expression

Quartz diorite porphyry ("earlier quartz diorite" of Lasky, 1936, p. 26–30) forms roughly concordant masses within the Colorado Formation in the southern half of the Santa Rita quadrangle, and within the Oswaldo, Syrena, and Abo Formations in the northeastern part of the quadrangle. A discontinuous sill of quartz diorite porphyry, or a series of thin sills or laccoliths, intrudes the upper part of the Syrena Formation about 1 mile south and southeast of the Copper Flat area. From the Barringer fault north into the adjoining Allie Canyon quadrangle, quartz diorite porphyry forms small and large sills with dike apophyses within the Colorado Formation. The two most extensive exposures of quartz diorite porphyry lie southwest and east of the Santa Rita stock; they may be continuous south of the Santa Rita stock, but if so, they are buried beneath the younger volcanic rocks and beneath extensive mine dumps.

Since the thickness and distribution of the quartz diorite sills have a direct bearing on the depth to the Paleozoic carbonate rocks, and, hence, on the depth to possible replacement-type ore bodies, these features are described in detail.

Geologic relations

Lasky (1936, p. 26–27) discussed two quartz diorite porphyry sills that are intruded largely into the Colorado Formation in the southwestern part of the quadrangle; he termed the lower one, stratigraphically near the Beartooth Quartzite, the "lower sill," and the one in the sandstone member of the Colorado the "upper sill." The thickness and the surface extent of the upper sill are much greater than those of the lower sill. Neither sill occupies a consistent stratigraphic position throughout the district; instead, each tends to gradually rise or fall in the stratigraphic section from one area to another. Locally the contacts are highly irregular and cross the beds at steep angles, so that large septa of the country rock may be engulfed within the sill. At many places the upper sill contains many elongate inclusions of the Colorado Formation, some of which are so extensive that the sill appears to be multiple. Northwest of Vanadium and less than a mile west of the Santa Rita quadrangle the lower sill is at the top of the shale member of the Colorado Formation. From this area east the lower sill cuts down to the Beartooth Quartzite, which it splits near the Bullfrog mine (pl. 2, section *J–J′*). Similarly, northward from the Groundhog mine it cuts downward in the stratigraphic column, splitting the Beartooth Quartzite in the area of Santa Rita Creek (pl. 2, section *L–L′*). Continuing northward, the sill enters the Syrena Formation, in which it gradually thins out. Between the Hobo fault and the Groundhog-Ivanhoe fault zone (pl. 2, section *K–K′*) it is in the Syrena Formation. Between the Bullfrog mine and Copper Flat it seems to bifurcate, the upper tongue staying above the Beartooth Quartzite and the lower tongue cutting down into the Syrena Formation. Both tongues crop out along the west margin of the Santa Rita quadrangle. The lower sill does not extend northeast of the Ivanhoe mine area, as it is not present in the Chino pit area (pl. 2, sections *G–G′* and *F–F′*). It reaches a maximum thickness of about 600 feet beneath San Jose Mountain and the Groundhog mine, near the Lucky Bill shaft (pl. 2, sections *J–J′* and *L–L′*). The sill was domed by later intrusions, and was subsequently broken by a set of northeast-striking normal faults.

The much more extensive upper sill crops out over a wide area from the Groundhog fault system eastward to the Santa Rita stock, which intrudes it. The sill apparently pinches out abruptly just beyond the present east margin of the Santa Rita stock, but farther south it may continue eastward beneath younger rocks and mine dumps to connect with another extensive sill of quartz diorite porphyry. The upper sill extends northward along the east (downthrown) side of the Groundhog fault system to Turnerville and cross-section line *F–F′*. It may have been eroded from a large area west of Turnerville.

The stratigraphic position of the upper sill in the Colorado Formation can be determined accurately at but few points. Near the No. 5 shaft of the Groundhog mine it appears to be at least 700 feet stratigraphically (excluding other sills) above the Beartooth Quartzite on the downthrown side of the Groundhog fault system. Its position east of the Santa Rita stock ranges from 300 to perhaps 700 feet above the Beartooth Quartzite. At Turnerville the upper sill is a little more than 200 feet above the Beartooth, and it appears in the lower part of the sandstone member of the Colorado Formation.

The original maximum thickness of the upper sill is not determinable. From the Groundhog fault zone to the eroded edge of the sill east of the Chino mine its original thickness was probably more than 500 feet, and may have been more than 1,000 feet (pl. 2, sections *K–K′* and *G–G′*). South of the Chino mine a drill hole penetrated the upper sill to a depth of 651 feet from its eroded surface at the base of the Miocene(?) volcanic rocks (pl. 2, section *H–H′*). It seems to be about 200 feet thick near Turnerville, but there it includes a lens of shale.

The largest sills of quartz diorite porphyry in the northern part of the quadrangle intrude the Oswaldo Formation a few feet above the so-called Marker sill (hornblende quartz diorite) on the southwest (footwall) side of the Mimbres fault. It extends in the same stratigraphic position from 1⅓ miles south of the quadrangle margin northward to the intersection of the Barringer and Mimbres faults.

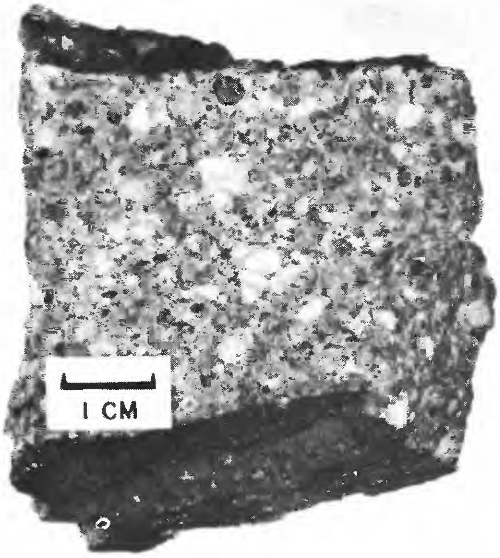
Petrography

The quartz diorite porphyry is subdivided into a southern facies and a northern facies; the petrography of these facies is discussed separately.

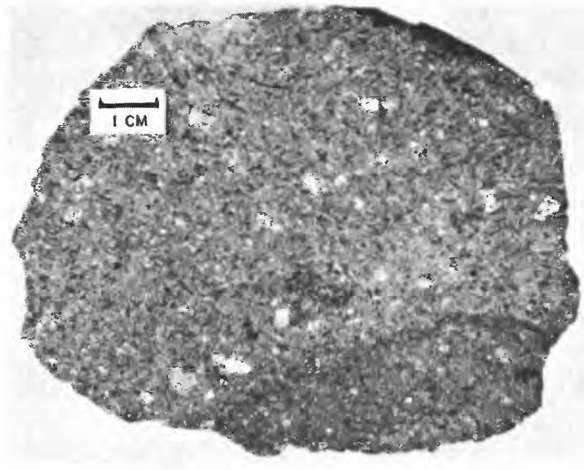
The following description of the quartz diorite porphyry of the southern part of the quadrangle is a slight modification of one given by Lasky (1936, p. 29–30). The rock is highly altered, greenish-gray, medium-grained, and porphyritic, and contains 30–45 percent phenocrysts set in an aphanitic felsic groundmass consisting largely of quartz and potassic feldspar (fig. 18). Alteration has nearly everywhere profoundly changed the composition of the rock, and in places has destroyed the original texture. Much of the rock consists of alteration minerals; the only original constituents are quartz and the resistant accessory minerals apatite, zircon, and magnetite.

The phenocrysts range in length from a fraction of a millimeter to nearly a centimeter. They include white feldspar; less abundant quartz, hornblende, biotite, and magnetite; and sparse apatite, allanite, sphene, and zircon. The quartz phenocrysts, which consist of medium- to coarse-grained strongly embayed individuals and clusters, constitute, in general, the most characteristic megascopic feature of the rock, though in places they are sparsely distributed. In six thin sections representing typical quartz diorite porphyry the volume percent of quartz phenocrysts visible in hand specimen ranged from 1 to 5, and averaged 3 percent (table 6, samples 10–15 and avg. 10–15). Many of them are bipyramids.

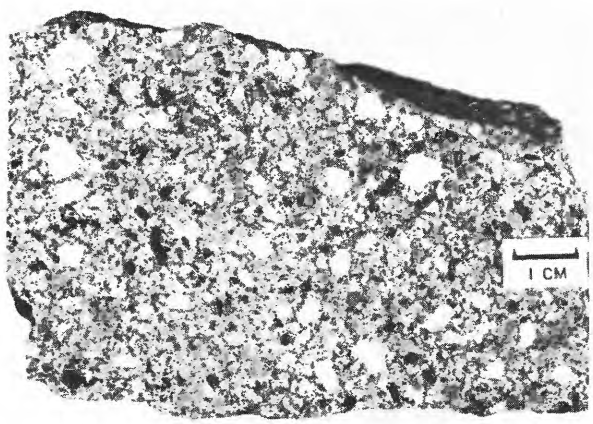
The feldspar phenocrysts seen in hand specimen consist of corroded patches and stubby sharp-cornered crystals with pitted faces; they range in length from 0.5 to about 7 mm. The feldspar phenocrysts are so intensely altered that their composition cannot be accurately determined. In most grains, however, albite twinning can be detected, and we can safely assume that the largest proportion is plagioclase rather than potassic feldspar. In point counts of six thin sections the plagioclase phenocrysts made up 22–30 percent of volume, and averaged 26 percent (table 6). The maximum extinction angle observed was 20°, from which a composition of An_{37} is inferred. Most of the plagioclase may be considered as having an average chemical composition of sodic andesine, for the margins of some grains are in the albite-oligoclase range. Potassic feldspar may constitute a small but unknown quantity of the feldspar phenocrysts, but most of it is confined to the felsic matrix and as such may constitute as much as 30 percent of rock volume. Completely altered hornblende and almost completely altered biotite are everywhere present and are locally common. Because hornblende and biotite could not always be distinguished by the shape of the pseudomorphic alteration



A



B



C

FIGURE 18.—Typical specimens of quartz diorite porphyry. *A*, Southern facies; porphyry is altered. Dark minerals are biotite, chloritized hornblende, magnetite, and quartz; white mineral is plagioclase. Matrix is greenish gray and aphanitic. Specimen from sill 5,200 feet N. 48° E. of Kneeling Nun. (Mode given in table 6, sample 10.) *B*, Marginal facies. Matrix is greenish gray and contains sparse grains of pyrite; plagioclase phenocrysts are white; black slender rods are chloritized hornblende. Little biotite or quartz visible. Specimen from north-central part sec. 36, T. 17 S., R. 12 W. *C*, Northern facies. Dark minerals are hornblende and biotite; white phenocrysts are largely plagioclase, but rock contains sparse orthoclase, some as poikilitic grains. Quartz phenocrysts are abundant but blend with matrix. Specimen from sill in sec. 1, T. 17 S., R. 12 W.

products, the amount of each could not be determined. Hornblende is generally the more abundant of the two and forms stout to long prisms, generally medium grained, some of which are perfectly formed crystals having typical elongate six-sided cross sections. The biotite consists of anhedral to subhedral flakes, and of pseudohexagonal books whose diameter is commonly about twice their thickness. However, a small exposure of quartz diorite porphyry 1,400 feet east of Turnerville contains many books of biotite whose thickness, measured normal to cleavage, is greater than their diameter.

Apatite phenocrysts, some as much as 2.5 mm long, are locally abundant, although this mineral constitutes less than 1 percent of the rock. Crystals of sphene and allanite are difficult to detect in specimens from the heart of the mining district, where the sill is intensely altered. Sphene has been found in the quartz diorite porphyry in the Groundhog mine; allanite has been found in the same rock at the surface, south of the Star shaft of the mine. In exposures of quartz diorite porphyry east of Kneeling Nun these minerals are commonly well preserved.

Within the mining district, most of the quartz diorite porphyry is severely altered and bears little resemblance to fresher rock exposed to the east. Hydrothermal alteration has destroyed the original texture and accentuated the porphyritic aspect. It has also changed the color to a darker shade where chlorite, secondary biotite, epidote, and pyrite have formed at the expense of original light-colored constituents, or to lighter shades (as light as creamy white) where the rock has been largely converted to albite, sericite, calcite, or quartz or to clay minerals commonly containing abundant pyrite. Weathering and supergene alteration have further modified the rock, turning it to various shades of red and yellowish brown. The original mineral constituents have been selectively attacked by fluids, in the following order of increasing resistance: hornblende or, locally, sphene; then plagioclase, biotite, orthoclase, apatite, and quartz. Zircon seems to have been the only stable mineral. Alteration products such as albite, chlorite, secondary biotite, and epidote, which were probably in part formed during deuteric alteration, were themselves unstable in a later hydrothermal fluid and possibly in supergene fluids, and were transformed into mixtures of clay, white micas, and calcite. Hornblende and biotite were transformed into chlorite or, less commonly, into aggregates of secondary green or brown biotite. Some hornblende and biotite were converted to poorly defined aggregates of chlorite, epidote, secondary quartz, calcite, iron oxides, and leucoxene. Many plagioclase phenocrysts were irregularly replaced along fractures by albite; in some crystals the conversion was complete. Lasky reported that nearly pure albite is the only feldspar present in a quartz diorite porphyry along Whitewater Creek. Feldspar phenocrysts were largely converted to zoisite, epidote, calcite, and secondary quartz, or to fine-grained mixtures of clay and sericite, or illite. The groundmass feldspar, presumably in part alkali feldspar, was locally replaced by aggregates of sheaves and foils of dull green chlorite, and less commonly by sheaves of green or brown biotite. Quartz phenocrysts were rarely affected, but a few show irregular replacement by sericite. Aggregates of secondary quartz, derived from the breakdown of primary silicates, resemble the quartz phenocrysts.

The quartz diorite porphyry in the northern part of the Santa Rita quadrangle is tentatively considered a facies of the quartz diorite porphyry in the southern part. The northern variety contains more sphene and mafic minerals and more phenocrysts than the southern variety, and it contains sparse orthoclase phenocrysts as much as 2 cm long (table 6, samples 6–9 and avg. 6–9). The apparent differences may be attributed to the much greater alteration of the southern facies rather than to original differences in primary mineral composition. On the other hand, the two magmas undoubtedly rose from different centers, and minor differences should be expected. The margins of both facies resemble those of the next younger intrusive, the hornblende quartz diorite, but contain fewer phenocrysts and are finer grained (fig. 18*B*).

The rock of the northern facies is a light-gray seriate porphyry containing phenocrysts of white feldspar, chiefly plagioclase; stubby and elongate prisms of hornblende; generally thin books of biotite; pheno-

TABLE 6.—*Analyses, norms, and modes of quartz diorite porphyry*

[nd, not determined; ng, not given; --, absent; Tr., trace; C, common; A, abundant]

Chemical analyses

[Percent]

	South facies			
	[2] 1	[3] 2	[2] 3	4
SiO_2	62.25	59.38	66.99	64.41
Al_2O_3	15.95	16.51	14.93	15.95
Fe_2O_3	2.51	1.21	1.84	1.46
FeO	2.16	3.50	1.54	3.81
MgO	1.57	2.26	1.18	2.45
CaO	4.40	6.06	3.18	5.36
Na_2O	3.76	3.50	3.41	3.39
K_2O	3.02	2.16	2.74	1.45
H_2O+	1.78	1.92	1.69	.80
H_2O-	.56	.38	.60	ng
TiO_2	.55	.53	.37	.62
P_2O_5	.21	.34	.13	.20
MnO	.15	.13	.14	.10
BaO	nd	.07	nd	ng
CO_2	1.04	2.11	1.06	ng
ZrO_2	nd	.01	nd	ng
Cl	nd	nd	.01	ng
F	nd	nd	.03	ng
Total	99.91	100.08	99.84	100
Specific gravity:				
Bulk	2.68	nd	2.64	ng
Powder	2.73	nd	2.71	ng

Semiquantitative spectrographic analysis [1]

[Parts per million]

	South facies		South facies
	5		5
Pb	10–50	La	<50–70
Mn	300–1500	Ag	<1
Cu	7–150	Sc	<10–10
Zn	<200	Cr	5–70
Zr	70–150	Ga	20–30
Ba	700–3000	Sn	<10
Ni	5–20	Ge	<20
Co	<5–20	As	<1000
V	30–100	In	<10
Mo	<5	Cd	<50
Y	15–30	Bi	<10
Sr	100–1000	Tl	<100
Be	<1	Sb	<200
B	<50–50		

Norms

[Weight percent]

	South facies			
	1	2	3	4
Quartz	17.46	13.57	26.58	22.7
Orthoclase	17.79	12.79	16.12	8.3
Albite	31.96	30.39	28.82	28.8
Anorthite	17.79	26.41	15.57	23.9
Corundum	--	--	3.16	--
Diopside	2.54	2.29	--	} 11.6
Hypersthene	4.02	11.47	2.55	}
Magnetite	3.71	1.86	2.55	2.1
Ilmenite	1.06	.91	.76	1.2
Apatite	.34	.67	.34	.5

See footnotes at end of table.

TABLE 6.—*Analyses, norms, and modes of quartz diorite porphyry*—Continued

Modes

[Volume percent]

	North facies					South facies[4]						
	6	7	8	9	Avg. 6–9	10	11	12	13	14	15	Avg. 10–15
Matrix (quartz and feldspar)	44	51	46	54	49	61	62	60	61	68	56	61
Major phenocrysts:												
Quartz	5	3	5	4	4	5	4	2	1	5	1	3
Orthoclase	Tr.	Tr.	Tr.	Tr.	Tr.							
Plagioclase	37	26	34	24	30	26	26	29	25	22	29	26
Range An content	nd	An_{10-45}	An_{45}	An_{40-47}		An_{5-36}	nd	An_{5-35}	An_{5-37}	An_{5-35}	An_{5-37}	
Hornblende	10	5	9	5	7	nd	nd	nd	nd	nd	nd	nd
Biotite	3	3	1	4	3	nd	nd	nd	nd	nd	nd	nd
Accessory minerals:												
Magnetite	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.	Tr.	C	Tr.
Sphene	Tr.	Tr.	Tr.		Tr.		Tr.					Tr.
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Allanite	Tr.	Tr.	Tr.		Tr.	Tr.	Tr.	Tr.				Tr.
Zircon	Tr.		Tr.		Tr.		Tr.				Tr.	Tr.
Alteration minerals:												
Epidote	2	1	4	2	2	Tr.	C	8	3	5	Tr.	3
Calcite	Tr.	4	Tr.	3	C	2	C	Tr.	C	C	2	C
Sericite	Tr.	Tr.	Tr.	Tr.	C	C	A	Tr.	Tr.	C	Tr.	C
Illite	Tr.				Tr.	C	A					Tr.
Clay	C			Tr.	Tr.	Tr.	A	Tr.	Tr.			Tr.
Zoisite										Tr.		Tr.
Albite									Tr.	Tr.		Tr.
Chlorite	1	A	4	5	C	C	C	C	Tr.	C	C	C
Biotite	C				Tr.				Tr.	11		Tr.
Zeolite	Tr.		Tr.		Tr.						A	
Magnetite	Tr.		Tr.		Tr.		C			Tr.	Tr.	Tr.
Quartz							Tr.	Tr.	Tr.	Tr.		Tr.
Pyrite								Tr.	Tr.			Tr.

[1] Analysts: E. F. Cooley and J. C. Hamilton.
[2] Analysis, standard rock, by C. L. Parker.
[3] Analysis, standard rock, by L. D. Trumbull.
[4] In all specimens, hornblende and biotite were generally too severely altered to be distinguished.

SAMPLE DESCRIPTION

1. Field No. JC-1-61; lab. No. H-3477. Sill, 1 mile north of Bayard, N. Mex. Middle W½ sec. 6, T. 18 S., R. 12 W.
2. Field No. CA-2-53; lab. No. 53-Z50ZCD. Sill, 1,900 feet N. 40° E. of BM 6932, S½ sec. 34, T. 16 S., R. 12 W.
3. Field No. JC-14-62; lab. No. I-4031. Sill, quartz-rich facies, 3,000 feet N. 75° E. of Kneeling Nun.
4. Average hornblende-biotite tonalite (Nockolds, 1954, p. 1015).
5. Nos. 1 and 3 and seven unnumbered samples.
6. Field No. MC-112-52. Sill, NW¼ sec. 1, T. 17 S., R. 12 W.
7. Field No. MC-10-52. Sill, 1,500 feet S. 80° E. of Shingle Canyon mine.
8. Field No. MC-106-52. Sill, middle east boundary sec. 35, T. 16 S., R. 12 W.
9. Field No. MC-8-52. Sill, same locality as No. 2.
10. Field No. JC-23-52. Sill, 5,200 feet N. 48° E. of Kneeling Nun.
11. Field No. JC-33-52. Sill, NE. cor. sec. 35, T. 17 S., R. 12 W., elev. 6,568 feet.
12. Field No. JC-34-52. Sill, NW¼ sec. 36, T. 17 S., R. 12 W., just west of windmill.
13. Field No. JC-35-52. Sill, diamond-drill hole, depth 800 feet, about 1 mile south of Chino mine.
14. Field No. LC-178-31. Sill, same locality as No. 1.
15. Field No. LC-189-31. Sill, same locality as No. 1.

crysts of frosted and glassy quartz, many with distinct pyramid faces; and sparse small phenocrysts of sphene, allanite, apatite, zircon, and magnetite. The inequigranular texture, perhaps the most striking characteristic, results from the contrast of blocky grains of white feldspar 1–5 mm long set in a gray to purplish-gray finely crystalline to aphanitic groundmass (fig. 18*C*). The rock is characterized also by rather obscure potassic feldspar phenocrysts, some of which are poikilitic; these phenocrysts may be so sparse that only one is visible in 10 square feet of exposure.

Examination of thin sections reveals that most feldspar phenocrysts are normally zoned andesine (An_{45-32}). One or two poikilitic anhedral grains of orthoclase were noted in one section. Many plagioclase grains are euhedral crystals, but most are fragments of euhedra; interlocking between different kinds of minerals is rare, but interlocking of plagioclase grains is common. Most plagioclase phenocrysts are moderately to severely fractured and moderately altered. They make up 24–37 percent of volume in the four thin sections examined (table 6), whereas orthoclase phenocrysts constitute a fraction of 1 percent; stain tests on polished surfaces indicated, however, that potassic feldspar constitutes as much as 25 percent of the groundmass. Quartz phenocrysts compose 3–5 percent of the rock; most are rounded, deeply embayed, and moderately fractured and have a thin cloudy reaction rim of low birefringence. Rectangular fracture patterns are common, but conchoidal fractures predominate. A few irregular grains of quartz penetrate into plagioclase crystals. Fresh and partly chloritized green hornblende crystals make up 5–10 percent of the rock; some are perfectly euhedral, and some are fragmentary. Biotite, which makes up 1–4 percent of volume, occurs mostly as thin books that are generally shredded and irregularly embayed by the groundmass and completely altered to chlorite and epidote.

No completely fresh rock has been found in the northern facies, but the least altered is considerably fresher than any known in the southern facies. The alteration is similar to that described for the southern facies, although biotite seems to have been most susceptible to alteration in the northern facies. Light-green and brown finely crystalline sheaves of secondary biotite replaced some hornblende, and was in turn converted marginally to green chlorite and, generally, to epidote or clinozoisite. The alteration in plagioclase ranges from sericite formed along fractures to complete conversion to fine-grained aggregates of clay, sericite, illite, epidote, and calcite. The few orthoclase phenocrysts found were clouded with clay. The accessory minerals in the relatively fresh rocks examined are unaltered.

Chemical composition

Analyses, norms, and modes of quartz diorite porphyry are given in table 6. Nockolds' (1954, p. 1015) average tonalite is listed (sample 4) for comparison. The abundance of epidote, chlorite, and calcite in the modes shows that the rocks analyzed were somewhat altered. Also, the northern facies is somewhat more mafic than the southern facies.

The range in trace-element content in nine samples of quartz diorite porphyry, most of which were from the sill exposed east of Kneeling Nun, is shown in table 6 (sample 5).

HORNBLENDE QUARTZ DIORITE

Distribution

Hornblende quartz diorite, called "later quartz diorite" by Lasky (1936, p. 30–34), forms extensive sills throughout the Santa Rita quadrangle and in adjoining quadrangles to the east, north, and west. Three major sills, locally enlarged to laccolithic form, occur in the Santa Rita quadrangle at three principal stratigraphic positions. The largest is in the Colorado Formation and is known locally as the middle sill, although Spencer and Paige (1935, p. 33) referred to it as the Fort Bayard laccolith. The second, known to some as the Groundhog sill, intrudes the lower part of the Syrena Formation; the third, known locally as the Marker sill, intrudes the lower part of the Oswaldo Formation. Less persistent sills intrude the Parting shale of local usage at the base of the Oswaldo Formation, the Percha Shale, and beds of shale in the Colorado Formation stratigraphically higher than the level of the middle sill. Thin dikes of hornblende quartz diorite occur east and southwest of the south pit of the Chino mine, in the North Star Basin and Hermosa Mountain areas, near the central north margin of the quadrangle, and in adjacent parts of the Allie Canyon quadrangle.

The most extensive mass of hornblende quartz diorite was named the "middle sill" by Lasky (1936) because of its position, in the Vanadium area, between two quartz diorite porphyry sills. The middle sill, or laccolith, intrudes the lower 400 feet of the Colorado Formation: its base is 200–400 feet above the Beartooth Quartzite in the southwestern part of the quadrangle, but only 70–120 feet above the Beartooth in the faulted area west of the Chino pits and from there west to the Princess mine. In the Princess mine area the sill evidently splits into two sills separated by 80 feet of shale (pl. 2, section *F–F′*). Before erosion the sill may have extended as far north as the Barringer fault. A thin lens of hornblende quartz diorite in the Colorado Formation northwest of the Continental mine may represent the north edge of the sill. In the northeast wall of the south Chino pit, beyond which the sill extends for a short distance, the sill is about 150 feet thick, and its base is approximately 250 feet above the Beartooth Quartzite (pl. 2, section *G–G′*). Questionable outcrops of hornblende quartz diorite, too small to show on plate 1, are found in the Colorado Formation farther east, about a mile north of Kneeling Nun. East and southeast of Kneeling Nun a thin sill or dike of hornblende quartz diorite intrudes both the quartz diorite porphyry and an elongate lens of the Colorado Formation within that porphyry.

The middle sill ranges in thickness from 0 to about 1,200 feet. The thickest part is in the Vanadium area near the Bullfrog 2 shaft (pl. 2, section *J–J′*). It thins northeastward and is only 120 feet thick southeast of Turnerville. Much local variation in thickness suggests that its upper and lower contacts are irregular. From Bayard northeastward to the Princess mine area the sill is broken by northeast-trending faults and is intruded by similar-trending dikes of at least three generations.

The second persistent sill, the Groundhog sill, lies stratigraphically below the middle sill at levels 80–150 feet above the base of the Syrena Formation. It persists from the Groundhog mine area northwestward to its outcrop south of Copper Flat, and northeastward to Humbolt Mountain and Topknot Hill.

The third persistent hornblende quartz diorite sill occupies a still lower stratigraphic position. Its thickest part is centered somewhat north of the exposures of the two overlying sills. Much of it underlies the domal uplift centered northeast of Copper Flat. Data from drill holes and from the Copper Flat mine show that this intrusion is laccolithic and has a maximum thickness of over 900 feet. It is intruded into the Oswaldo Formation at various levels from 35 to 110 feet above the base. The laccolith thins abruptly near Humbolt Mountain and splits into two thin sills, one in the basal, Parting shale unit of the Oswaldo, and the other about 90 feet stratigraphically higher. The higher sill is known as the Marker sill because of its persistence throughout the district. It is a conspicuous and useful horizon marker around the south lobe of the Hanover stock, and in the mines north of the Chino pits; it probably also persists below the surface within the Oswaldo Formation throughout the Santa Rita quadrangle. In two localities the sill bulges, forming sizable masses; one enlargement, in the east-central part of the quadrangle, extends north and south of State Highway 90 in a crudely spindle shaped outcrop; a second mass underlies Fierro Hill (pl. 2, section *B–B′*) and represents a local swelling of the sill in the basal shale of the Oswaldo. The roof rocks were uplifted about 800 feet by the expanding sill; the "hinge" is to the northeast.

Several thin sills of hornblende quartz diorite intrude beds of the Colorado Formation north of the Barringer fault. The horizons intruded are stratigraphically higher than those intruded by the middle sill, which is so extensive in the southern part of the quadrangle. Even less persistent are thin sills in the exposures of Percha Shale surrounding the Hanover-Fierro stock.

Sills of hornblende quartz diorite are generally concordant with the enclosing beds. Where discordance is evident, it is usually gradual, but in places the contact cuts sharply across the beds. Lasky (1936, p. 31) noted in the Bayard area "thin, fingering offshoot sills, some of which rejoin the main mass and envelop a slice of adjacent sediments * * *."

Structure

Locally, the hornblende quartz diorite is faintly gneissic, owing to the alinement of hornblende prisms. No evidence of crystal settling has been seen, even in the thickest masses. Most masses are strongly jointed normal to contacts and sheeted parallel to the contacts; the sheeting is less pronounced than in the quartz diorite porphyry. Locally, the rock between steep shear planes is broken into spherical masses ranging from a few inches to 18 inches in diameter; these masses give the outcrop what might be termed "stonewall structure." Masses of the hornblende quartz diorite thus jointed were favorable sites for ore deposition in the southern part of the area.

Petrography

In hand specimens, typical hornblende quartz diorite is mottled greenish gray, fine to medium grained, holocrystalline, and somewhat porphyritic. The rock is composed of white equant grains of feldspar generally less than 2 mm long, and black lath-shaped hornblende crystals generally less than 2 mm long but locally much longer, set in a greenish-gray fine-grained granular matrix (fig. 19).

In thin section the porphyritic nature of the rock is much more pronounced. The matrix consists mainly of interlocking anhedral grains of quartz and orthoclase and makes up 48–60 percent of the rock volume (table 7). The feldspar phenocrysts are sodic labradorite (An_{52}) and account for 10–31 percent of the rock (table 7); they show zoning, and albite, Carlsbad, and, less commonly, pericline twinning. A few grains are questionably identified as orthoclase. The hornblende phenocrysts, which constitute 5–15 percent of the rock, are brownish green and appear to have been corroded by the matrix. Small anhedra of quartz, not much larger than the quartz grains of the matrix, are sparsely disseminated throughout the rock. Small grains of magnetite are locally abundant, as are needles of apatite; but generally neither makes up more than 1 percent of the rock. Apatite crystals commonly have coronas and are corroded. Other accessory minerals are zircon, ilmenite, and sphene. Biotite is absent except in the large mass in the east-central part of the quadrangle, where a few sparse flakes were found. This mass also contains larger quartz grains, but otherwise is less porphyritic.

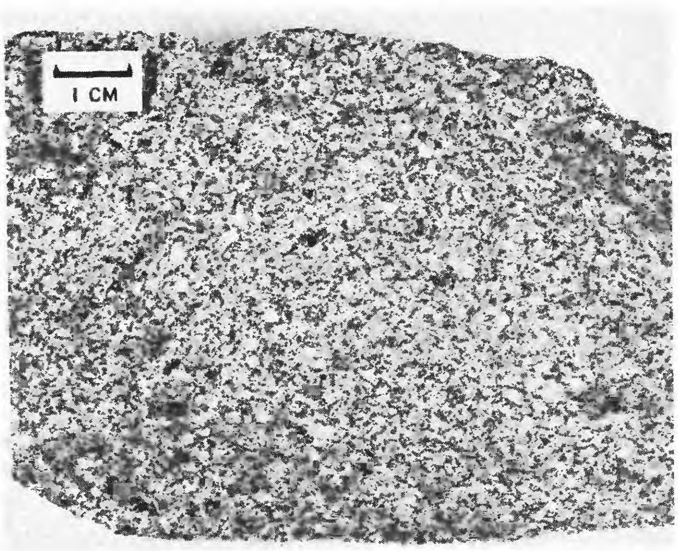


FIGURE 19.—Relatively fresh specimen of hornblende quartz diorite sill rock. Most minerals are hornblende and andesine. (Mode of this specimen is given in table 7, sample 1.)

Hornblende quartz diorite is in general moderately to severely altered. The rock in the freshest appearing outcrop, in a roadcut north of Central, in the Fort Bayard quadrangle (table 7, mode of sample 1), proved to be considerably altered. Alteration ranges from moderate saussuritization of plagioclase phenocrysts and marginal chloritization of hornblende to complete destruction of primary minerals, leaving pseudomorphic aggregates of quartz, epidote or clinozoisite, chlorite or biotite, clay, sericite, pyrite, and calcite. Any of these secondary minerals may predominate locally. Where epidote and chlorite predominate, usually with disseminated pyrite, the rock is dark green; where clay, sericite, pyrite, and calcite prevail, the rock is creamy white. The clay-sericite-calcite alteration may represent a late stage of alteration and is less extensive than the epidote-chlorite alteration. Epidote, ranging in size from grains a few millimeters in diameter to nodules more than an inch in diameter and, more rarely, to spherical masses as much as a foot in diameter, forms disseminated aggregates in the rock. Secondary quartz commonly is associated with the epidote.

TABLE 7.—*Analyses, norms, and modes, in percent, of hornblende quartz diorite*

[nd, not determined; ng, not given; ----, absent; Tr., trace; C, common; A, abundant]

Chemical analyses

	[1] 1	[2] 2	3		[1] 1	[2] 2	3
SiO_2	61.3	58.89	63.58	P_2O_5	.22	.4	.17
Al_2O_3	16.6	16.55	16.67	MnO	.16	.12	.11
Fe_2O_3	3.4	.55	2.24	BaO	nd	.15	ng
FeO	2.2	4.56	3.00	CO_2	.36	.45	ng
MgO	2.2	2.72	2.12	S	nd	.33	ng
CaO	4.5	7.60	5.53				
Na_2O	4.8	3.32	3.98	Total	100.06	100.2	100
K_2O	2.3	2.00	1.40				
H_2O+	1.4	1.49	.56	Specific gravity:			
H_2O-	nd	.33	ng	Bulk	2.60	2.57	ng
TiO_2	0.62	0.74	0.64	Powder	2.73	2.73	ng

Semiquantitative spectrographic analysis [3]

	[4] 4		[4] 4		[4] 4
Ba	0.07	Mn	0.15	Sr	0.15
Co	.003	Mo	.0015	V	.03
Cr	.003	Ni	.003	Y	.007
Cu	.015	Pb	.0015	Yb	.0007
Ga	.003	Sc	.0015	Zr	.03
La	.007				

Norms

	1	2	3		1	2	3
Quartz	13.93	11.89	19.6	Diopside	1.54	7.15	} 9.4
Orthoclase	13.34	12.79	8.3	Hypersthene	5.64	11.11	
Albite	40.35	28.30	34.1	Magnetite	4.87	.93	3.3
Anorthite	17.24	23.63	23.3	Ilmenite	1.22	1.37	1.2
Corundum	----	----	ng	Apatite	.34	1.01	.3
				Calcite	.80	1.00	ng

TABLE 7.—*Analyses, norms, and modes, in percent, of hornblende quartz diorite*—Continued

Modes

[Volume percent]

	1	[5] 2	5	6	7
Matrix	51	58	48	60	70
Quartz	19	1	21	28	nd
Orthoclase	32	10	27	32	nd
Plagioclase	----	42	----	----	----
Hornblende	----	5	----	----	----
Major phenocrysts:					
Plagioclase	31	25	28	10	25
Maximum An	An_{52}	An_{53}	An_{45}	nd	An_{52}
Hornblende	6	15	[6] nd	[6] nd	5
Accessory minerals:					
Quartz	Tr.	----	Tr.	Tr.	Tr.
Biotite	----	----	Tr.	----	----
Ilmenite-magnetite	4	2	1	1	Tr.
Sphene	Tr.	----	----	----	----
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	----	Tr.	----	Tr.
Alteration minerals:					
Epidote	.7	----	10	13	C
Calcite	Tr.	----	----	1	C
Sericite	Tr.	----	Tr.	3	C
Clay	C	----	----	----	----
Clinozoisite	4	----	----	----	----
Albite	C	----	Tr.	----	C
Chlorite	3	----	2	10	C
Biotite	Tr.	Tr.	10	----	----
Leucoxene	----	2	----	----	----
Quartz	----	Tr.	Tr.	----	----
Pyrite	----	Tr.	1	----	----
Siderite	----	Tr.	----	----	----
Ferro-tremolite [7]	----	2.5	----	----	----
Limonite	Tr.	----	C	----	----

[1] Analysis, rapid rock, by P. L. D. Elmore, K. E. Whits, and S. D. Botts.
[2] Analysis, standard rock, by A. Willman (Schmitt, 1939a, p. 782).
[3] Analyst: N. M. Conklin. Figures reported to nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, 0.07, 0.03, 0.015. Looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ce, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Nb, Nd, Os, P, Pd, Pr, Pt, Re, Ru, Sb, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.
[4] Chemical analyses by D. L. Schafer, J. P. Schuch, C. Huffman, and J. E. Wilson showed: eU, 0.002; U, 0.001; Mo, 0.001; As, 0.0089. U was analyzed by fluorimetric method; Mo and As, by colorimetric method.
[5] Determinations by H. A. Schmitt.
[6] Completely altered.
[7] Replacement of hornblende and plagioclase.

SAMPLE DESCRIPTION

1. Field No. JC-3-56; lab. No. 148448. Sill in roadcut north of center of sec. 35, T. 17 S., R. 13 W.
2. Field and lab. No. P-20. Premineralization sill in Pewabic mine. (See. Schmitt, 1939a, p. 783.)
3. Average dacite plus dacite obsidian (Nockolds, 1954, p. 1015).
4. Field No. JC-3-56; lab. No. 243702. From same location as No. 1.
5. Field No. JC-7-56. Altered; near powerline in south center sec. 1, T. 17 S., R. 11 W.
6. Field No. MC-12-52. Sill in Oswaldo Formation 2,600 ft S. 65° E. of BM 6932, sec. 3, T. 17 S., R. 12 W.
7. Estimated average mode of 27 thin sections (Lasky, 1936, p. 33-34).

Chemical composition

Two specimens of the hornblende quartz diorite have been chemically analyzed: one from the middle sill, in a road cut north of Central, well out of the strongly mineralized area, and the other from the Pewabic mine area (table 7, samples 1 and 2). Appreciable differences appear in the weight percent of Fe_2O_3, FeO, CaO, and Na_2O, and consequently in the percentage of normative diopside, albite, and anorthite. Recalculation of total iron as FeO gives nearly identical percentages for the two analyses—5.3 for the specimen from the middle sill, and 5.1 for the specimen from the Pewabic mine area. The higher percentages of CaO and MgO and lower percentages of SiO_2 and Na_2O in the specimen from the Pewabic mine could be explained by metasomatic addition and subtraction; however, metasomatic alteration, largely epidotization, of a granodiorite dike in the same area produced a marked increase rather than a decrease in the ferric iron content. The two bulk analyses are comparable without calculating the oxides to grams per cubic centimeter, because the bulk and powder specific gravities of the two are almost identical.

The average of 50 dacites plus dacite obsidians (table 7, sample 3) listed by Nockolds (1954, p. 1014) is shown for comparison. Although considerably richer in quartz and less rich in orthoclase and albite, this average analysis is more similar to the analyses of the hornblende quartz diorite of the Santa Rita quadrangle than are any of the other average analyses listed by Nockolds.

Analyses of trace elements in the hornblende quartz diorite are also given in table 7.

TRACHYTE PORPHYRY

Distribution

Masses of trachyte porphyry are exposed at the mouth of Myers Canyon, near its confluence with Shingle Canyon. Other small masses of this rock crop out 1,200 feet to the southeast and 3,000 feet and 4,000 feet northwest. Small bodies of similar rock crop out farther to the northwest, in the Allie Canyon quadrangle. The distribution of trachyte porphyry is restricted to this narrow northwest-trending zone on the southwest side of the Mimbres fault.

Geologic relations

The exposures of trachyte porphyry are varied in outline. The outline of the southernmost mass is lens shaped. The mass in Myers Canyon is triangular in outline and was emplaced at the junction of two short faults which form the east and south sides of a downdropped wedge of Oswaldo Formation. The two masses of trachyte porphyry farther north, near the mouth of Middle Shingle Canyon, are irregular dikes intruded along northeast-trending faults.

Petrography

The trachyte porphyry is a yellowish-brown intensely altered fine-grained rock which contains numerous phenocrysts of white feldspar, abundant slender prisms of black hornblende 1 cm long or more, and sparse irregular anhedra of quartz. The matrix is yellowish brown and finely granular to aphanitic.

As seen in thin section, the feldspar phenocrysts, which are subhedral andesine (An_{38}), range in size from a fraction of a millimeter to about 2 mm. Albite and Carlsbad twins are common, but few if any grains are zoned. Euhedral phenocrysts of hornblende are completely altered to calcite, chlorite, and epidote. A few six-sided forms composed of calcite, chlorite, and epidote aggregates may be pseudomorphs of biotite. Sparse quartz phenocrysts form irregular anhedra. Accessory minerals are magnetite and apatite. The matrix, which makes up 75–80 percent of the rock volume, consists mainly of potassic feldspar and contains minor amounts of plagioclase and quartz. The estimated mode of the unaltered rock is as follows:

	Volume percent
Matrix	75–80
Orthoclase	60–65
Quartz	7–8
Plagioclase	7–8
Phenocrysts:	
Andesine (An_{38})	10–15
Hornblende	5–10
Quartz	<1
Magnetite and apatite	<1

The trachyte porphyry is intensely altered; in fact, no specimens that are even moderately fresh have been seen by the authors.

Hornblende is the mineral most susceptible to alteration. In specimens of rock from the unweathered zone deep within joint blocks the hornblende euhedra are altered to calcite, chlorite, and epidote, and to minor amounts of secondary magnetite, leucoxene, clay, and quartz. Within half an inch of weathered surfaces, long slender voids partly filled with limonite are all that remain of this assemblage. The feldspar phenocrysts are flecked with illite, calcite, zoisite or clinozoisite, epidote, and clay, and many are completely converted to aggregates of these minerals. Much brownish-red secondary biotite is disseminated throughout the groundmass as small irregular flakes and as rims of a few hornblende pseudomorphs.

VOLCANIC AND SEDIMENTARY ROCKS AND RELATED MAFIC INTRUSIVE ROCKS OF LATE CRETACEOUS(?) AND EARLY TERTIARY AGE

Deposits of indurated mafic volcanic conglomerate, volcanic breccia, and agglomerate underlie an area of tens of square miles west of the Santa Rita quadrangle. Only the east tip of this accumulation of volcanic and clastic debris extends into the Santa Rita quadrangle, where, in the North Star Basin area, it underlies an area of about 1 square mile. The rock of this heterogeneous deposit is locally called andesite breccia, and it will be described under that name in this report.

During the episode of volcanism when this debris accumulated, the region was intruded repeatedly by mafic dikes, some of which radiated from a small orthoclase gabbro plug that is now exposed in the North Star Basin area of the Santa Rita quadrangle. Description of this plug follows that of the andesite breccia.

ANDESITE BRECCIA

The andesite breccia, although locally tilted, is in general a relatively flat-lying blanket. In North Star Basin, well-bedded tuffs strike north to east and dip 15°–35° west and north. The base is clearly defined by an uneven erosional surface that cuts across the Colorado Formation, a syenodiorite porphyry laccolith, and diorite porphyry dikes. The volcanic and clastic deposits rest on various horizons of the Mesozoic sedimentary sequence—from near the known top of the Colorado Formation, as in the Santa Rita quadrangle, to the top of the Beartooth Quartzite, as in the Silver City quadrangle, a stratigraphic range of about 900 feet. The upper surface of the deposit is either the present erosional surface or an older surface on which the Miocene(?) volcanic sequence was deposited. The original total thickness of the andesite breccia, therefore, cannot be determined; but judging from a known minimum thickness of 1,060 feet, 4 miles west of the quadrangle, it probably exceeded 1,100 feet, and may have been substantially greater in many places. Kuellmer (1954, pl. 1, section *B–C–D–E*) showed the formation as about 1,700 feet thick in the Black Range, 15 miles east of Santa Rita. The maximum thickness of the remnant within the Santa Rita quadrangle is about 500 feet.

Except where the formation is toughened around the orthoclase gabbro plug, it is easily weathered and eroded. The numerous mafic porphyry dikes that intrude the andesite breccia are somewhat more resistant and retard erosion of the adjoining breccia. A thin veneer of reddish-brown soil and rubble overlies most of the breccia.

The stratigraphic sequence within the volcanic-clastic deposit is not well known; correlation between exposures is extremely difficult, owing to the many dikes that intrude the sequence and to the similarity and lenticular nature of the various layers. Also, the effects of intense thermal metamorphism locally mask the identity of some layers.

In the adjoining Fort Bayard quadrangle the basal few hundred feet of these volcanic deposits contains red, light-green, and purplish-green tuffaceous sandstone and siltstone and, locally, light-colored coarse-pebble conglomerate. Elsewhere in the Fort Bayard and Santa Rita quadrangles the basal beds are composed of indurated volcanic breccia and volcanic conglomerate containing blocks and cobbles of older rocks. In the basal beds in North Star Basin, fragments of limestone, shale, sandstone, chert, augite and hornblende porphyries, quartz diorite, and syenodiorite have been recognized. Just west of this basin, an area of several square miles is underlain by thick massive light-greenish-gray deposits of indurated volcanic breccia. Locally in the same area the breccia has the purplish-dark-green color of typical andesite breccia and contains minute grains of white feldspar. In the light-greenish-gray deposits the blocks appear to grade into the matrix, but in some exposures the blocks are clearly defined.

Some layers are unquestionably sedimentary clastic deposits. Southwest of Pinos Altos, thin lenses of sandstone and greenish-brown shale identical with the upper beds of the Colorado Formation are underlain and overlain by volcanic breccia and volcanic conglomerate. In North Star Basin the beds just below the Miocene(?) basalt flows are composed of well-bedded tuffaceous sandstone. Adjacent to the orthoclase gabbro plug in the same area the volcanic breccia is black and so thoroughly indurated and thermally metamorphosed that breccia fragments are barely recognizable. As yet no flow rocks have been identified in the volcanic and clastic sequence, but mafic flows are abundant in the same deposits in the Black Range and within the Lake Valley quadrangle (Kuellmer, 1954, p. 30; Jicha, 1954, p. 39).

The well-bedded material is water laid and probably represents reworked tuffs and volcanic breccia; the mode of deposition of the poorly bedded material is less certain. As C. M. Gilbert (in Williams and others, 1954, p. 304) pointed out, "It is often difficult to distinguish between pyroclastic deposits and epiclastic deposits of volcanic derivation * * *." The distinction can rarely be made with assurance in the Silver City–Santa Rita region, especially in exposures of indurated volcanic breccia in which subangular blocks 1 foot in diameter or more are set in a poorly sorted matrix. Generally, no layering can be seen in such deposits, but the fact that it has been observed in a few deposits would suggest that the material may represent indurated mud flows, at least in part, rather than deposits of airborne ejecta (fig. 20).

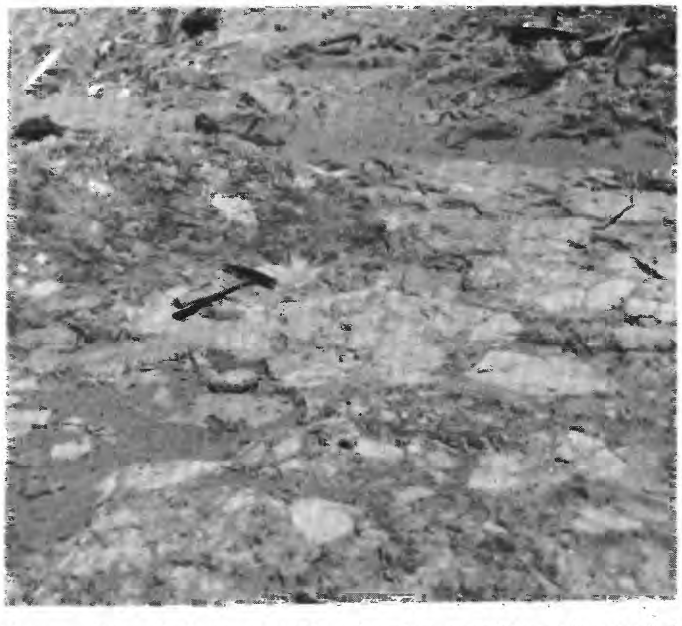


FIGURE 20.—Andesite breccia, showing angular and rounded blocks.

The following analysis of andesite breccia gives some idea of the chemical composition of the formation; but because of the diverse nature of the deposit, the analysis cannot be considered typical of the deposit as a whole. Any analysis of a small mass may not be typical of even that part of the deposit, much less of the whole deposit.

Chemical analysis and norm, in percent, of andesite breccia

Bulk analysis [1]		*Norm*	
SiO_2	59.1	Quartz	3.54
Al_2O_3	17.5	Orthoclase	30.02
Fe_2O_3	3.7	Albite	38.77
FeO	2.3	Anorthite	12.23
MgO	1.7	Ilmenite	.91
CaO	4.1	Magnetite	5.34
Na_2O	4.6	Wollastonite	2.67
K_2O	5.1	Enstatite	4.30
H_2O^+	.59	Ferrosilite	.39
TiO_2	.54	Apatite	1.34
P_2O_5	.52		
MnO	.14	Specific gravity:	
CO_2	<.05	Bulk	2.64
		Powder	2.72
	100		

[1] P. L. D. Elmore and P. W. Scott, analysts. Specimen, lab. No. 139765, from sec. 17, T. 17 S., R. 13 W.; elev. 6,350 ft.

The volcanic breccia and volcanic conglomerate are generally pervasively propylitized. Locally, the breccia has been converted to epidosite. Epidote is also dispersed in the rock fragments and coats joints. Most mafic minerals are chloritized. In a few places west of the Santa Rita quadrangle the deposits are irregularly replaced along fractures by radiating crystals of pink stilbite; in some of these places the stilbite is associated with fine-grained hematite. Locally the breccia is cut by thin calcite veinlets, and by quartz veins containing minor amounts of sphalerite, galena, and chalcopyrite. One such quartz-sulfide vein, which trends east through the center of North Star Basin, has been prospected to shallow depths. The wallrock immediately adjacent to the quartz veins is bleached, and presumably contains clay and sericite.

Age and correlation

The exact age of the andesite breccia is unknown, but the formation is part of a regional blanket of dominantly volcanic materials that accumulated during the Late Cretaceous or early Tertiary. Similar rocks were deposited throughout the Rocky Mountains from Montana to New Mexico, and from New Mexico to the Sierra Nevada (Callaghan, 1951). Volcanic rocks of this age are strikingly similar; they consist of dark-green to purple breccias and flows of intermediate to basic composition interbedded with clastic deposits ranging in grain size from fine silt to coarse boulders and massive blocks.

In the Caballo Mountains of central New Mexico, rocks similar to those in the Santa Rita quadrangle, and about 3,000 feet thick, overlie the Mesaverde Formation. These rocks were called the McRae Formation by Kelley and Silver (1952, p. 119), who stated, "the age of the McRae is poorly known except that the lower few hundred feet may be definitely placed in the Cretaceous and the upper part may be Tertiary." In the southern part of the Caballo Mountains is a sequence of reddish-brown clastic rocks and purplish-green andesite breccia and tuff called the Palm Park Formation. Kelley and Silver (1952, p. 114) uncertainly assigned these rocks to the Oligocene. In the Deming 30-minute quadrangle, Darton (1917) mapped and described a thick sequence of agglomerate, tuff, flows, and flow breccias of intermediate composition interbedded with siltstone, sandstone, and boulder deposits. The lower part of this sequence resembles the andesite breccia in the Silver City–Santa Rita region. The oldest volcanic series in the Black Range consists of some 1,700 feet of volcanic breccias, andesite flows, tuffs, and agglomerates interbedded with "red-violet, fine to coarse, essential or accessory tuff, and thick beds of light green, gray or purple lapilli tuff or agglomerate" (Kuellmer, 1954). The Macho Pyroxene Andesites of Jicha (1954, p. 39) in the Cooks Range and Lake Valley area are probably equivalent to the andesite breccia. West of Silver City and extending into eastern Arizona, similar deposits are widespread. According to Wolfgang Elston (written commun., 1961), the andesite breccia in western New Mexico is probably of Late Cretaceous age. The Virden Formation of Elston (1960), which overlies the breccia, contains plant fossils of latest Cretaceous age.

The andesite breccia cannot be dated exactly, but it apparently was deposited in the interval between the intrusion of some mafic sills or laccoliths and the intrusion of less mafic sills and stocks. It is younger than the syenodiorite porphyry laccolithic mass of Hermosa Mountain, but is probably older than the hornblende quartz diorite which forms extensive sills in the Santa Rita quadrangle. About 4–6 miles west of the Santa Rita quadrangle, the andesite breccia is intruded by the Pinos Altos quartz monzonite stock, which is chemically and mineralogically similar to the Hanover-Fierro pluton and to the Santa Rita stock. These three plutons are probably of the same relative age; at least, all are older than the main episode of hypogene mineralization and metalization, and the two plutons in the Santa Rita quadrangle are definitely younger than the sills and laccoliths.

The andesite breccia is intruded by a great swarm of mafic porphyry dikes and by both small and large irregular masses of mafic porphyry. Some mafic porphyry dikes are somewhat older than the andesite breccia, and fragments of similar rocks are found in the breccia. All these mafic porphyries are considered to be genetically related to the volcanism that produced the andesite breccia.

Exploration geologists and prospectors should keep in mind that the andesite breccia and related rocks were emplaced prior to the main episode of base-metal mineralization and are a potential host for ores of that type.

MAFIC INTRUSIVE ROCKS

A small orthoclase gabbro plug and a multitude of mafic dikes are exposed in the northwest corner of the Santa Rita quadrangle. These intrusives are concentrated, although not confined, within the area underlain by the andesite breccia just described. The plug and radiating dikes probably mark the deeply eroded site of one of many Laramide volcanic centers in the region.

ORTHOCLASE GABBRO PLUG

In plan, the orthoclase gabbro plug in North Star Basin resembles a tadpole. The thick part, corresponding to the head, faces northeast; and the narrow part, corresponding to the tail, extends southwest but curves abruptly to the north near its tip. From the tip of the head to the tip of the tail, the plug measures about 3,000 feet. It is 900 feet across in the thickest part. The plug intruded through the andesite breccia, and beneath the breccia probably penetrated the syenodiorite mass that is exposed just south of the breccia. The andesite breccia was thermally metamorphosed for several tens of feet from the plug. At the southwestern extremity of the plug the breccia has been converted to a black aphanitic rock in which the outlines of breccia fragments are almost obscured. Around a similar but much larger mass about 5 miles to the west, the same intense metamorphic effects were noted; and there the chilled margin of the plug grades almost imperceptibly into the metamorphosed breccia. None of the other intrusives in the quadrangle caused thermal metamorphism of wallrock.

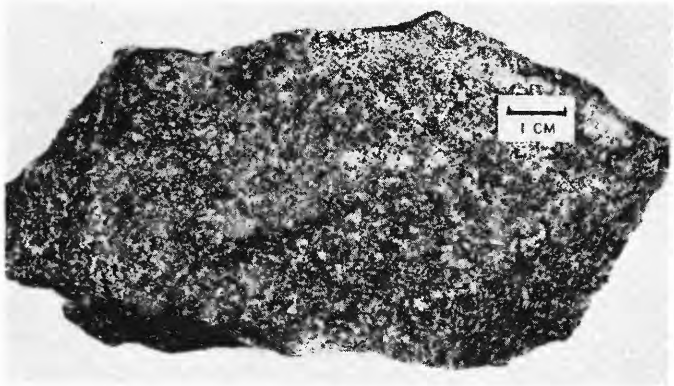
The orthoclase gabbro plug in the Santa Rita quadrangle has no chilled margin. The plug consists of two facies, which differ in texture and in color but not pronouncedly in mineral content. These facies were not differentiated on the map (pl. 1) because of scale limitations, but in general a west (porphyritic) facies is confined to the taillike section of the plug, and an east (granular) facies makes up the bulbous head and body section. The east facies is locally cut by closely spaced parallel veinlets of pink alkali feldspar a fraction of an inch thick.

Petrography

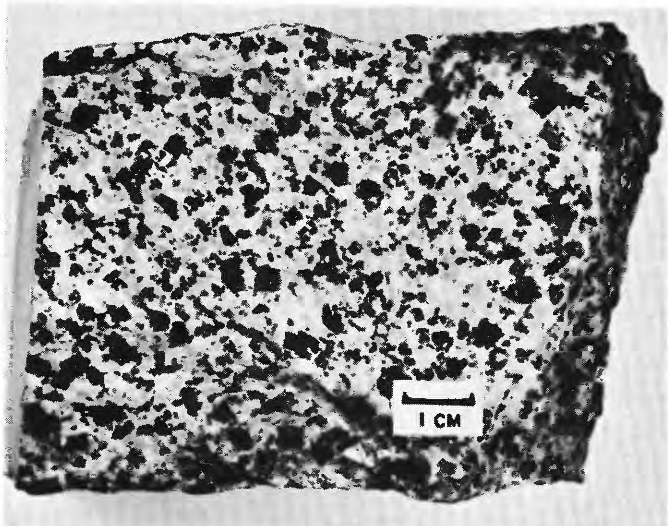
The rock of the plug ranges from a dark-gray granular rock without noticeable phenocrysts (fig. 21*A*) to a light-gray porphyry with large black phenocrysts (fig. 21*B*). In spite of this variation in appearance, the mineral content is surprisingly consistent (table 8). The constituent minerals and their average abundance, based on point counts of six thin sections, are given in table 8 (sample 6). Not all the specimens contain olivine or quartz; the two minerals tend to be mutually exclusive, but are not absolutely so, and the range in their proportions in the specimens studied is shown in table 8. Pyroxene and biotite occur as large phenocrysts in the west, or porphyritic, facies (fig. 21*B*), and plagioclase occurs as lath-shaped grains in the matrix; only rarely is any plagioclase crystal as large as one of the mafic phenocrysts. Biotite occurs as finely crystalline aggregates, as embayed phenocrysts, and as irregular replacements in augite crystals and in surrounding magnetite crystals. Hornblende is decidedly rare, appearing only as uralite, which was derived from augite. Apatite is present in sparse large stubby grains, but more commonly it occurs as abundant slender prisms in the plagioclase, augite, or orthoclase. Magnetite is scattered throughout all the specimens and commonly appears as minute grains zonally arranged within pyroxene and biotite phenocrysts. Olivine is present as large euhedral grains and, more commonly, as inclusions in pyroxene. Small grains of olivine are concentrated at the margins of some pyroxene grains or in poorly defined zones within them, near their margins. Many olivine grains are pseudomorphically replaced by serpentine or chlorite, but many are fresh or only partly altered. Orthoclase, as coarse anhedral individuals, embays or poikilitically encloses all the phenocrystic and accessory minerals. Traces of graphic intergrowth of quartz occur in some orthoclase, but more commonly anhedral quartz is interstitial between orthoclase grains. No reaction rims occur at the contact of the orthoclase with other constituents.

As the amount of alkali feldspar is almost the same in both facies, the difference in the ratio results from a lesser amount of plagioclase in the east facies. The east facies is less differentiated than the west, and contains about 4 percent olivine, no quartz, and more pyroxene than biotite; its color index is 37, compared to 23 for the west facies.

The modal analyses in table 8 show that as the amount of plagioclase decreases, there is a corresponding decrease in the amount of biotite, but an increase in the amount of pyroxene and olivine.



A



B

FIGURE 21.—Typical specimens from orthoclase gabbro plug in North Star basin, Santa Rita quadrangle. *A*, Eastern facies. Black minerals are biotite and pyroxene; white mineral is feldspar. (Mode given in table 8 (sample 8).) *B*, Western facies. Larger black phenocrysts are pyroxene; smaller black grains are biotite; light-colored matrix is feldspar. (Mode given in table 8 (sample 5).)

The ratio of orthoclase to total feldspar ranges from 0.57 to 0.76; the average ratio, based on six modal analyses, is 0.62. For the west facies the average value is 0.59, and for the east facies, 0.66.

R. E. Wilcox, of the U.S. Geological Survey, determined the significant optical data for some of the constituent minerals. The alkali feldspar is optically negative and shows a range in the optic angle of from 48° to 66°. The average optic angle of the alkali feldspar in one section (table 8, sample 4) is 56°, and in another (table 8, sample 7), 65°. The alkali feldspar is optically homogeneous. Although it is not perthitic, it probably contains considerable albite in solid solution. The plagioclase shows a pronounced zoning. Extinction angles ($X' \wedge 010$) in the plagioclase range from 0° at the rim to 38° in the center, indicating a range in anorthite content of An_{20} at the rim to An_{75} in the center. In section HC–13–52 the plagioclase has an average anorthite content close to An_{33} at the rim and An_{70} at the center, indicating a rapid change during its growth, from sodic bytownite to sodic andesine. The plagioclase is twinned in accordance with albite, Carlsbad, and pericline laws. Contacts between plagioclase and pyroxene grains are sharp.

The pyroxene phenocrysts range in size from 1 to 10 mm; many are euhedral, and others are embayed or penetrated by plagioclase laths or by the anhedral alkali feldspar in the matrix. Although black in hand specimen, the pyroxene phenocrysts are very light green and nonpleochroic in thin section. The extinction angle ($Z \wedge c$) is about 45°.

Pigeonite and calcic augite are evidently both present in the rock, although the two cannot be distinguished except by determination of the optic angle. R. E. Wilcox, using a universal stage, measured this angle in eight phenocrysts and noted a range of 51° to 56°. Microscopic examination of phenocrysts in oils revealed several grains with a (+)2V ranging from 0° to 10°, as well as grains having optic angles comparable to those found by Wilcox. The intermediate index of refraction for the pyroxene phenocrysts examined in oils ranges from about 1.695 to about 1.705. The grains with the smaller optic angles had the higher indices. It is not known whether pigeonite occurs as individual grains or as zones in the diopsidic augite. Orthorhombic pyroxene was not present in the specimens studied.

The deep-reddish-brown strongly pleochroic biotite has a 2V of 0°–5° and occurs as deeply embayed thin books and as irregular thin plates and small flakes. In one specimen, much of the biotite was altered to chlorite, but in most specimens it was fresh, black, and shiny.

The olivine phenocrysts invariably have a black opaque margin and are partly or completely altered to brown serpentine or to chlorite and magnetite. The grains are biaxial negative, 2V about 70°; thus, a chemical composition closer to fayalite than to forsterite is indicated.

Chemical composition

No chemical analysis of rock from the orthoclase gabbro plug in the Santa Rita quadrangle is available, but an analysis of a specimen from a plug of similar mode 5 miles west of the quadrangle probably would be representative. The mode of that specimen is similar to the average mode of six specimens from the plug in the Santa Rita quadrangle. (Compare last two columns of modes in table 8.) The chemical analysis is given with the calculated norm in table 8. Nockolds' (1954, p. 1017) average chemical analysis of 11 augite-biotite monzonites is given (sample 2) for comparison; it is nearly identical. The analysis given as No. 3 in table 8 is the average chemical analysis of 11 shoshonites and transitional rocks, computed from analyses by Iddings (in Hague and others, 1899, p. 340). The shoshonites are the intermediate members of a group of lamprophyre dikes, plugs, and flows located in Yellowstone National Park. The more mafic member of the series is called absarokite; the more felsic member, banakite. Rocks of this series (sample 3 in table 8) appear to contain considerably more water than do the specimens reported in the other two columns (samples 1 and 2), but it is not clear whether this amount is total water or only water freed at temperatures above 110°C. These lamprophyre dikes contain slightly less SiO_2, H_2O, and K_2O than do orthoclase gabbro plugs in Crandall Basin, Wyo., described by Iddings (in Hague and others, 1899, p. 260–261, 248–251).

The molecular proportion of Al_2O_3 to Na_2O+K_2O+CaO in the analyzed rock is 0.67; the ratio for the augite-biotite monzonite of Nockolds is 0.65. This low value seems to be characteristic of rocks that have crystallized without much reaction or separation between crystals and melt.

TABLE 8.—*Analyses, norms, and modes, in percent, of orthoclase gabbro*

[nd, not determined; ng, not given; ---, absent in thin section; A, abundant; C, common; Tr., trace]

Chemical analyses

	[2]1	2	3		[2]1	2	3
SiO_2	52.3	53.39	53.03	H_2O+	0.92	0.73	} 2.27
Al_2O_3	16.1	16.11	17.50	H_2O-	nd	ng	
Fe_2O_3	2.8	2.74	4.73	TiO_2	.93	1.07	.74
FeO	6.4	4.64	3.16	P_2O_5	1.0	.50	.54
MgO	4.3	4.84	4.19	MnO	.18	.11	Tr.
CaO	7.6	7.68	6.48	BaO	nd	ng	Tr.
Na_2O	3.3	3.44	3.39	CO_2	<.05	ng	Tr.
K_2O	4.5	4.75	3.57	Total	100.38	100	99.6

Semiquantitative spectrographic analysis [1]

	1		1		1
Cu	0.01	Cr	0.003	Yb	0.0004
Co	.003	V	.03	Zr	.01
Ni	.001	Sc	.002	Sr	.1
Ga	.002	Y	.009	Ba	.09

Norms

	1	2		1	2
Quartz	1.30	1.80	Diopside	13.38	} 15.19
Orthoclase	26.69	28.36	Hypersthene	2.28	
Albite	27.77	27.77	Magnetite	4.18	3.94
Anorthite	15.85	15.01	Ilmenite	1.82	2.13
			Apatite	2.35	1.68

Modes

[Volume percent] [3]

	West facies				East facies				Average west and east facies	1
	4	5	6	Avg. 4–6	7	8	9	Avg. 7–9		
Matrix	79	71	69	73	52	71	52	58	66	62
Quartz	2.3	2.9	.9	2	---	Tr.	Tr.	Tr.	1	Tr.
Orthoclase	44	39	43	42	34	42	39	38	40	39
Plagioclase	33	29	25	29	18	29	13	20	25	23
Major phenocrysts:										
Biotite	[4]11	[4]13	[4]15	[4]13	[5]8	16	4.2	9	11	16
Clinopyroxene	7	11	13	10	31	8	33	24	17	18
Olivine	---	---	---	---	[6]5	[6].5	8	4	2	---
Accessory minerals:										
Magnetite	1.8	3.1	2.3	2	3.9	3.1	3.1	3	3	2.9
Apatite	.8	1.1	.8	1	.6	1.5	.4	1	1	.7
Alteration minerals:										
Epidote	Tr.	.7	Tr.	Tr.	Tr.	C	Tr.	Tr.	Tr.	Tr.
Calcite	---	.4	---	Tr.	---	---	---	---	---	---
Sericite	---	---	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Chlorite	[7]6	[7]6	[7]2	[7]5	A	---	---	Tr.	C	Tr.
Serpentine	---	---	---	---	A	A	C	A	---	Tr.
Magnetite	---	---	---	---	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.

[1] Analyst: Harry Bastron. Looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ce, Ge, Hg, In, Ir, La, Li, Mo, Nb, P, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn.

[2] Analysis, rapid rock, by P. L. D. Elmore and P. W. Scott.

[3] Amounts >4.9 percent given to nearest percent; amounts <4.9 to >0.3 percent, to nearest tenth of a percent; amounts <0.3 percent, as trace amounts.

[4] Includes amount of chlorite listed below.

[5] Includes phenocrystal and finely crystalline biotite.

[6] Largely replaced by serpentine.

[7] Considered as biotite, which it replaces.

SAMPLE DESCRIPTION

1. Field No. JC-105-54; lab. No. 139767. Pluton, sec. 13, T. 17 S., R. 14 W., elev. 6,475 feet, Fort Bayard quadrangle.
2. Average augite-biotite monzonites (Nockolds, 1954, p. 1017).
3. Average shoshonites and transitional rocks (J. P. Iddings, in Hague and others, 1899, p. 340).
4. Field No. HC-12-52. Plug, 11,500 feet S. 84° W. of top of Hanover Mountain.
5. Field No. JC-6-57. Plug, same as No. 4, south margin.
6. Field No. JC-6a-57. Plug, 500 feet east of No. 5.
7. Field No. HC-13-52. Plug, 11,000 feet S. 84° W. of Hanover Mountain.
8. Field No. JC-6b-57. Plug, 300 feet north and 500 feet east of No. 5.
9. Field No. JC-6c-57. Plug, in creek east of No. 8.

Genesis

The genesis of rock similar to that of this small plug was explained by Bowen (1956). When small bodies of basaltic magma cool rapidly, crystallization is characterized by a high degree of fractionation (incomplete reaction) in the plagioclase series, the fractionation resulting in zoning (Bowen, 1956, p. 90). The large proportion of alkali feldspar in this rock is indicative of the failure of the residual liquid to be consumed in reaction with the early formed crystals—those of olivine, pyroxene, and calcic plagioclase. Because the early plagioclase contained far fewer albite and orthoclase molecules than was to be theoretically expected, these molecules must have been accumulated in the residual liquid. Most of the ferromagnesian material crystallized at a relatively early stage, and the remaining material of that nature, together with the more sodic plagioclase and the alkali feldspar, being in a strongly alkalic medium, crystallized as biotite instead of pyroxene. After the formation of biotite, free silica remained to crystallize as quartz (Bowen, 1956, p. 81). The absence of olivine in the norm indicates that olivine separated in amounts greater than its stoichiometric proportion, and that later some olivine reacted with the liquid to form pyroxene. As a consequence, free silica crystallized in a late stage (Bowen, 1956, p. 71). Thus, the small amount of quartz in the west facies is attributed to both the early separation and the partial reaction of olivine and pyroxene.

The high proportion of the alkali feldspar (locally about 40 percent of the rock) probably resulted from concentration of late residual magma from between the interstices of the mafic minerals by some mechanism as the magma rose in what appears to have been a volcanic pipe. The mineral content (presence of olivine) and pronounced zoning of plagioclase indicate that the magma cooled rapidly—so rapidly that reaction between crystals and liquid was decidedly limited.

DIORITE AND MAFIC PORPHYRY DIKES

Dikes radiating in all directions from the orthoclase gabbro plug crop out in North Star Basin. Only a small percentage of these dikes are shown on the map (pl. 1); those shown were selected to show prevailing strikes and distribution. The dikes are most abundant—hence, more closely spaced—near the plug, where they are concentrated in thin wedge-shaped sectors whose apices are at the plug. Most of the dikes are 1–10 feet wide, but a few are more than 25 feet wide. The largest dike, which cuts across the plug in a northerly direction, is 500 feet wide northwest of the plug and tapers to the normal width southward. This dike, as well as many others, is locally composite. In places, particularly near the plug, the dikes are so abundant that only slivers of the host rock remain between them; and in a few places no host rock has been found for distances of several hundred feet across the trend of the dike zone. The number of dikes per unit area decreases rapidly to the south and east, but a few dikes were mapped at a distance of more than 4 miles northeast of the plug, in the Allie Canyon quadrangle. Inexplicably, none crop out immediately south of the Barringer fault. One or two dikes of mafic porphyry less than 5 feet wide were recently discovered by W. W. Baltosser (oral commun., 1963) east of Santa Rita. Great swarms of similar dikes are exposed to the west, in the Fort Bayard and Silver City quadrangles.

The individual dikes differ greatly in mineral composition and in texture. Lovering (1953) distinguished the following rock types on his map of North Star Basin: Diorite, diopside diorite porphyry, augite andesite to augite syenite porphyry, biotite-plagioclase porphyry (ouachitite), and pigeonite diorite porphyry. In contrast, we simply distinguish between the less abundant and readily mappable diorite dikes and the great swarm of mafic porphyry dikes.

The diorite dikes are light greenish gray on fresh surfaces and shades of gray and brown on weathered surfaces. They are fine grained, and some have an ophitic texture. All contain plagioclase and hornblende phenocrysts, and some contain pyroxene phenocrysts; magnetite in minute grains is a common accessory, and epidote also is common. In one or two places the dikes contain amygdules of calcite. The rock of the large north-trending dike that cuts through the orthoclase gabbro plug is strikingly similar to the hornblende-augite syenodiorite porphyry underlying Hermosa Mountain; except for the somewhat finer matrix of the dike rock, the rocks look identical.

The mafic porphyry dikes are dark greenish gray to black and contain conspicuous phenocrysts of one or more of the dark minerals augite, pigeonite, biotite, and hornblende, but generally none of feldspar or quartz. The matrix ranges from aphanitic to finely crystalline and varies in color with the content of light-colored feldspar. In some augite syenites, black pyroxene crystals, commonly 1 cm long, are set in pink anhedral alkali feldspar.

Dikes of augite andesite are the most common, forming a network cutting the syenodiorite laccolith, the Colorado Formation, and the andesite breccia. In many places the dikes are so closely spaced and so intricately intruded that they cannot be mapped at any reasonable scale; the representation in such places is therefore diagrammatic. A few of the longer and wider dikes were mapped, however, to indicate the trend of the group. Several of these dikes contain closely spaced seams of alkali feldspar.

The dacite dikes are dark gray and contain sparse phenocrysts of augite and round quartz grains set in a cryptocrystalline groundmass. Two biotite-plagioclase porphyry or ouachitite dikes, although relatively thin, can be traced for more than a mile southeastward from the orthoclase gabbro plug. These dikes are olive gray in fresh exposures, weather olive tan to orange brown, and form rounded outcrops. In addition to biotite and plagioclase, thoroughly altered euhedral pyroxene crystals are present locally.

Age relations

Many dikes which radiate from the orthoclase gabbro plug are clearly apophyses of the plug. Several diorite dikes do not intrude the plug, or even the andesite breccia, which is older than the plug. The diorite dikes and the mafic porphyry dikes (some older than the breccia and some younger), the orthoclase gabbro plug and its apophyses, and the breccia itself, then, are interrelated both genetically and spatially, and are thus products of the Laramide volcanic epoch.

Crosscutting relationships between granodiorite porphyry dikes emplaced immediately after the Hanover-Fierro pluton and certain mafic dikes that formed during the Laramide volcanic epoch are revealed in exposures in the area north of Hanover Mountain. In each exposure the granodiorite dikes cut across the mafic dikes. In the same area (sec. 4, T. 17 S., R. 12 W.) a mafic dike cuts a small quartz diorite sill tentatively correlated with the masses of hornblende quartz diorite in the southern part of the quadrangle. Just west and northwest of Central, N. Mex., however, mafic porphyry dikes in the Colorado Formation terminate at the contact of the formation with the large mass of hornblende quartz diorite. Either the small quartz diorite sill is erroneously correlated with the large intrusive masses in the southern part of the quadrangle, or the fissures that later were intruded by mafic magmas near Central did not extend into the massive hornblende quartz diorite.

DISCORDANT PLUTONS OF EARLY TERTIARY AGE

GRANODIORITE OF THE HANOVER-FIERRO PLUTON AND APOPHYSES

For purposes of discussion, the Hanover-Fierro pluton is considered to consist of two parts: one, referred to as the main mass (Schmitt, 1939a), makes up about 80 percent of the pluton; the other, referred to as the Hanover lobe, makes up the remainder and forms the bulbous southern extremity of the pluton. Two distinct facies are recognized. One is medium- to coarse-grained hornblende-biotite granodiorite porphyry, which constitutes the main mass and extends into the Hanover lobe. The other, intermediate in composition between granodiorite and quartz diorite, is finer grained and equigranular and, except for one or two small isolated occurrences within the main mass, is confined to the Hanover lobe and to the margin of the main mass. The distribution of the two facies in relation to the main mass and to the south lobe is shown in figure 22. Both facies are locally cut by aplite dikes which have the same composition and texture as the matrix of the porphyritic facies.

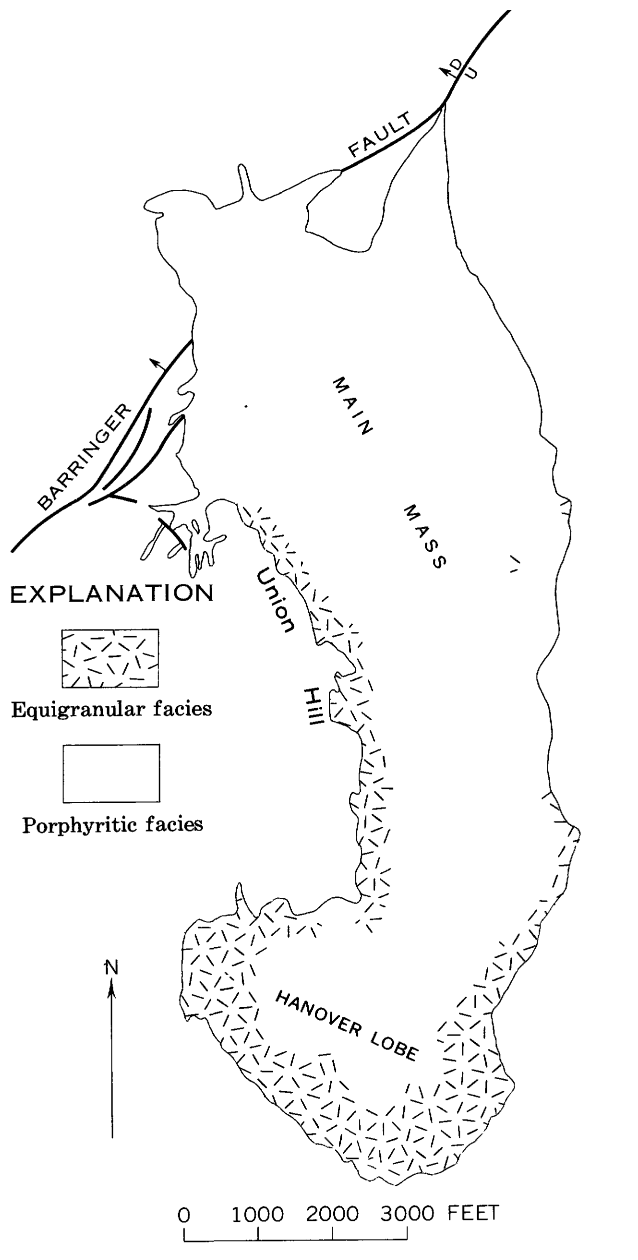


FIGURE 22.—Approximate limits of the equigranular and porphyritic facies of granodiorite of the Hanover-Fierro pluton.

The pluton is exposed principally in the valley that extends from Hanover to Fierro. It has one apophysis that extends a short distance north of Fierro along one of the links in the preexisting Barringer fault system, and several other short prongs that extend southwestward into the surrounding rocks near the north end of Union Hill. Minor bulges occur elsewhere along the contact. Most of the aplite dikes are confined to the stock, but a few extend into the surrounding rocks.

Geologic relations

The geologic relations of the main mass and of the south lobe are sufficiently different to warrant separate descriptions. Schmitt (1939a) showed that the south lobe is funnel shaped, as suggested by Spencer and Paige (1935, p. 37, 45). The base of the Hanover lobe dips gently toward a central root (Schmitt, 1939a). Except at its northeast margin, the Hanover lobe is surrounded by concentrically folded upper Paleozoic beds (Percha Shale, Lake Valley Limestone, and Oswaldo Formation) and hornblende quartz diorite sills. The folds are overturned away from the center of the lobe and locally bottom on a thrust fault that dips toward the center of the lobe, essentially parallel to the basal contact of the intrusion. According to Schmitt (1939a, p. 787), "On the south side of the Hanover lobe, deep level development in the Republic mine shows that the beds in the lower plate were nearly flat and unfolded, and that the pronounced peripheral anticlinal form so prominent on the surface disappears with depth."

The main mass pierced the Precambrian and Paleozoic formations without exerting pronounced lateral force—at least not at the levels now exposed. Along the east side of the main mass the contact dips steeply. At the Jim Fair mine the contact is almost vertical against the Precambrian gneiss, but Kelley (1949, fig. 15, section *B–B′*) showed the contact as vertical to the 185 level, dipping 40° W. between the 185 and 335 levels, and dipping steeply east below the 335 level. In his cross section *A–A′*, however, about 400 feet to the north, Kelley showed the contact as dipping 50° ENE. Evidently lateral force was exerted locally, as shown by outward bulges in the main mass. On the west side of the intrusion the dumps and surficial material greatly limit clear observation of the contact. Sections by Kelley (1949, fig. 12) show the contact of the stock as dipping from nearly vertical to 20° W., but his cross sections *B–B′* and *D–D′* show a reversal in dip 100 feet below the surface, where the intrusive locally bulges outward. A cross section by Kniffin (1930, fig. 2) illustrates the intrusive as a mass that gradually enlarges downward in the Precambrian basement; however, diamond-drill holes in the area (Kniffin, 1930, p. 5) range from only 200 to 500 feet in depth. The major part of the main mass is in contact at the surface with Precambrian(?) and lower Paleozoic formations. The host rocks dip away from the main mass at angles ranging from 5° to 60°; the steeper dips lie adjacent to the contact. Near the junction of the main mass and the Hanover lobe the Paleozoic beds and a sill of syenodiorite strike nearly east, and dip south. The main mass crosscuts these formations normal to their trend. North of the Barringer fault, which predates the intrusion, the main mass is in contact at the surface with the Syrena, Abo, Beartooth, and Colorado Formations. The semicircular pattern of their outcrop, with the older beds nearer the center, is evidence of arching over the intrusion.

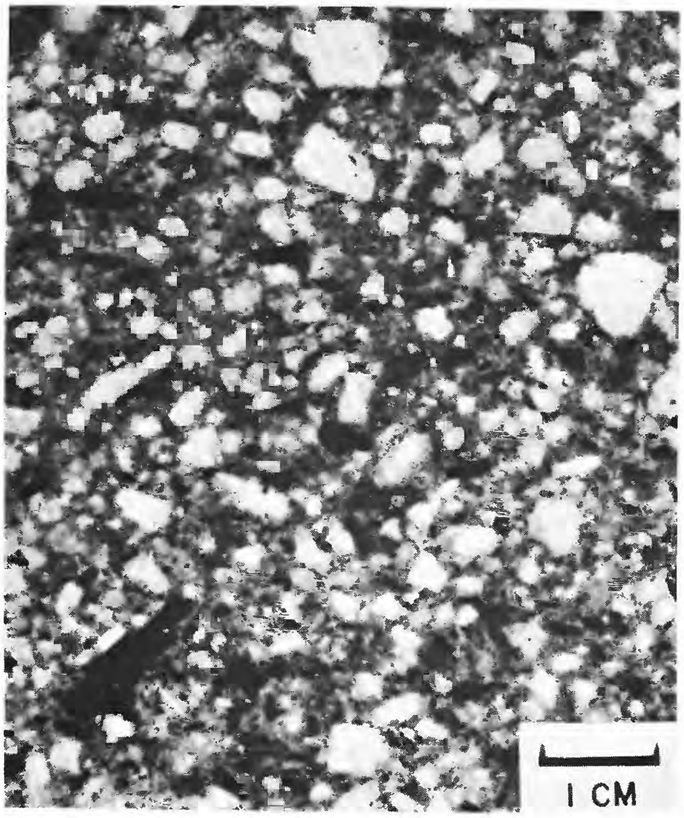
The Hanover-Fierro pluton is surrounded almost completely by a wide zone of metamorphism that decreases in intensity away from the contact. The metamorphic effects vary according to the nature of the host rock as well as to the distance from the contact. The metamorphism is typically pyrometasomatic and is characterized by metamorphic silicates associated with magnetite, iron-rich sphalerite, and small amounts of chalcopyrite. Much of the stock seems to be unaltered, but secondary quartz, biotite, sphene, and salite have formed in it locally.

The rock of the Hanover-Fierro pluton is less resistant to erosion than is the surrounding metamorphosed sedimentary rock, and consequently has been eroded by Hanover Creek and its tributaries to form a valley surrounded by ridges and hills of the metamorphosed sedimentary rock and sills. Where silicification was severe, the altered stock is resistant and forms hills. (See Spencer and Paige, 1935, pl. 6*A*.)

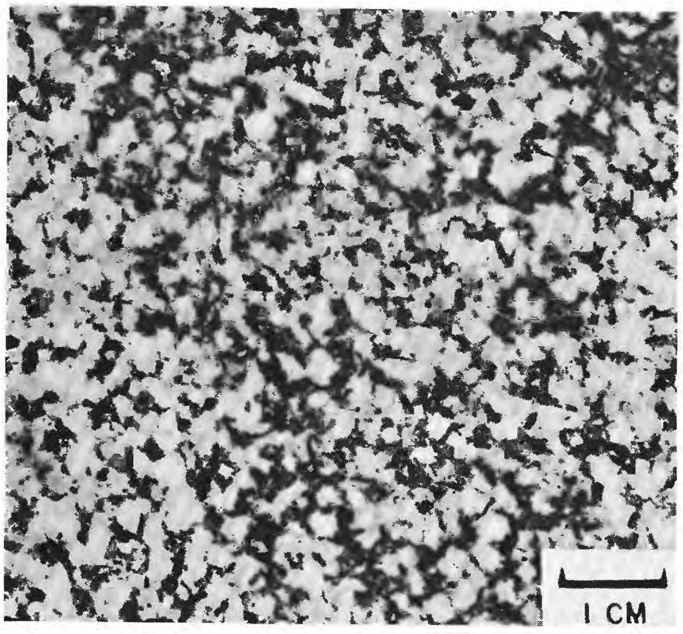
EQUIGRANULAR FACIES

Petrography

The equigranular facies is a greenish-gray, black-speckled, medium-grained (3–5 mm) rock which has a hypidiomorphic granular texture (fig. 23*A*). A typical hand specimen appears to consist mainly of feldspar and black hornblende. Modal analyses confirm this impression (table 9, No. 8). Andesine and orthoclase make up 74 percent of the rock volume and are in the ratio 3.3:1. Hornblende and quartz, in about equal proportions, make up most of the remainder. Accessory minerals are magnetite, sphene, apatite, and zircon. Some biotite flakes may be primary; but the great range in biotite content, with the greatest abundance near the contacts, suggests that most of it was formed subsequent to the primary constituents, probably during the time of metasomatic alteration and metalization. Andesine occurs as subhedral to an-



A



B

FIGURE 23.—Granodiorite from the Hanover-Fierro pluton. *A*, Equigranular facies from Hanover lobe. Most phenocrysts are andesine and hornblende. (Mode given in table 9, No. 8.) *B*, Porphyritic facies from main mass. Black platy phenocrysts are biotite; dark-gray laths are hornblende. Most white grains are plagioclase, but some are quartz. (Mode given in table 9, No. 9.)

hedral laths about 4 mm long; many of these laths are zoned and are twinned in accordance with albite, pericline, and Carlsbad laws. A few grains of andesine are replaced marginally by orthoclase, the partial replacement resulting in a poikilitic texture. The quartz, orthoclase, and most of the hornblende fill the angular interstices between the andesine laths. The hornblende phenocrysts are green euhedral to subhedral elongate prisms. The accessory minerals are generally euhedral. Belt (1955) studied individual zircon crystals and reported that they were colorless, euhedral, and well terminated.

Alteration of the equigranular facies ranges from slight to severe. The principal products are biotite, hedenbergite (salite), epidote, chlorite, and sericite. Alteration is relatively slight in the central and southern sectors of the Hanover lobe; it is most intense and widespread in the western sector, north of the Empire zinc mine, where hedenbergite, epidote, chlorite, and biotite may constitute as much as 25 percent of the rock. A small area of intense alteration occurs west of the Pewabic mine. In general, chlorite replaces hornblende and the earlier formed biotite and hedenbergite. The hedenbergite forms pseudomorphs after hornblende, and occurs as veinlets in the rock. Biotite is apparently a deuteric alteration product of hornblende, as Schmitt noted (1939a, p. 789). Epidote is everywhere present, although in many hand specimens it is difficult to detect. Some andesine phenocrysts are altered along fractures to albite, and others are flecked with sericite. In general, however, sericite and clay minerals, as well as the pyrite which usually accompanies such alteration products, are notably sparse in the equigranular facies.

Chemical composition

The only published chemical analysis of the equigranular facies is given in table 9 (No. 1). The specimen reportedly came from the Empire zinc mine and probably was not free from such alteration products as biotite, epidote, and hedenbergite. A calculated hypothetical chemical analysis is also given in the table (No. 2). Inasmuch as the exact chemical composition of the individual minerals is not known, this analysis should be considered as a rough approximation.

PORPHYRITIC FACIES

Petrography

The porphyritic facies of the Hanover-Fierro pluton is typical of many granodiorite-quartz monzonite porphyry stocks in the Southwest. As seen in outcrop, it is a light-colored holocrystalline medium- to coarse-grained porphyry containing easily distinguishable phenocrysts of white feldspar, black hornblende, biotite, and quartz set in a felsic matrix (fig. 23*B*).

In thin section its porphyritic aspect is even more pronounced. The phenocrysts comprise andesine (An_{32-39}), hornblende, biotite, quartz, and a trace of orthoclase; the matrix consists largely of microgranular quartz and orthoclase, and it contains minor amounts of andesine, hornblende, and biotite and accessory magnetite, sphene, apatite, and zircon. The andesine phenocrysts are euhedral to subhedral, square to oblong in outline, weakly zoned, and twinned in the normal way. The hornblende phenocrysts are euhedral to subhedral, green, and pleochroic; they have an extinction angle of about 20°. Phenocrysts of biotite are less numerous than those of hornblende; many are euhedral, but most are embayed by the matrix and are therefore irregular in outline. The length of many biotite crystals, measured normal to cleavage, exceeds the diameter, so that the crystals are barrel shaped. The quartz phenocrysts are rarely well formed; most are irregular anhedra, some are rounded, and others are deeply embayed by the matrix.

The matrix consists largely of microgranular quartz and orthoclase, and contains minor amounts of andesine, hornblende, and biotite. The texture is generally allotriomorphic granular, but small patches are granophyric; most grains are about 0.3–0.4 mm in diameter. The accessory minerals are generally small well-formed crystals.

TABLE 9.—*Analyses, norms, and modes, in percent, of granodiorite porphyry of the Hanover-Fierro pluton*

[nd, not determined; ng, not given; Tr., trace; ---, absent; C, common]

Chemical analyses

	1	2	3	4	5
SiO_2	61.26	60.4	65.36	62.7	65.50
Al_2O_3	16.22	18.7	16.29	17.6	15.65
Fe_2O_3	3.0	3.9	1.94	2.9	1.63
FeO	2.38	3.6	1.88	2.7	2.79
MgO	2.57	1.0	1.76	1.1	1.86
CaO	6.12	5.8	4.05	3.9	4.1
Na_2O	4.34	3.5	3.90	3.2	3.84
K_2O	2.61	2.3	3.29	4.8	3.01
H_2O+	.20	nd	.52	nd	.69
H_2O-	.15	nd	.20	nd	ng
TiO_2	.52	nd	.45	nd	.61
P_2O_5	.48	nd	.24	nd	.23
MnO	.08	nd	.04	nd	.09
CO_2	.09	nd	.06	nd	ng
S	.05	nd	ng	nd	ng
Total	100.07	99.2	99.98	98.9	100
Specific gravity:					
Powder	ng	nd	2.70	nd	ng
Lump	ng	nd	2.65	nd	ng

Semiquantitative spectrographic analysis

[Part per million]

	6		6		6
Pb	<10–10	Ni	10–20	Be	<1
Mn	300–1000	Co	7–15	Ag	<1
Cu	10–200	V	50–70	B	10
Zn	<200	Mo	<5	La	<50
Zr	150	Y	15–20	Sc	<10–10
				Cr	15-30

TABLE 9.—*Analyses, norms, and modes, in percent, of granodiorite porphyry of the Hanover-Fierro pluton*—Continued

Norms

	1	2	3	4	5
Quartz	13.9	17.5	19.4	14.4	20.0
Orthoclase	15.6	13.3	19.5	28.4	17.8
Albite	36.2	29.3	33.0	27.2	32.5
Anorthite	17.2	26.1	17.0	19.2	16.4
Corundum	---	.9	---	---	---
Diopside	3.0	---	.9	---	} 8.4
Hypersthene	5.8	5.3	5.2	5.4	}
Magnetite	4.4	5.6	2.8	4.2	2.3
Ilmenite	.9	.8	.8	---	1.2
Apatite	1.3	---	.3	---	.6
Calcite	2.0	---	.2	---	ng
Pyrite	.1	---	---	---	ng

Modes [1]

	7	8	9	10
Matrix	28	27	40	40
Quartz	11	10	12	18
Orthoclase	17	17	24	23
Plagioclase	---	---	5	Tr.
Hornblende	---	---	---	Tr.
Biotite	---	---	---	Tr.
Major phenocrysts:				
Quartz	---	---	3.3	3.4
Plagioclase	57	57	43	46
Maximum An	An_{37}	An_{32}	An_{39}	An_{32}
Hornblende	12	11	8	3.9
Biotite	.5	---	3.4	3.0
Accessory minerals:				
Magnetite	2.6	1.9	2.3	1.6
Sphene	.8	Tr.	.5	Tr.
Apatite	Tr.	Tr.	Tr.	.7
Zircon	Tr.	Tr.	Tr.	Tr.
Alteration minerals:				
Epidote	---	.6	---	C
Calcite	---	---	Tr.	---
Sericite	---	Tr.	---	Tr.
Clay	---	Tr.	---	Tr.
Clinozoisite	---	---	---	Tr.
Albite	---	Tr.	---	---
Chlorite	Tr.	1.0	Tr.	C
Biotite	---	1.7	---	---
Salite	---	---	Tr.	---

[1] Amounts <5 percent reported to nearest tenth of a percent; amounts <½ percent reported as trace amounts.

ANALYSIS OR SAMPLE DESCRIPTION

1. Granodiorite from Empire zinc mine at Hanover, N. Mex. (Kerr and others, 1950, p. 299.) Analysis by Silve Kallman.
2. Analysis calculated from average mode of equigranular facies. (See mode of No. 7.)
3. Field No. P-19. Granodiorite porphyritic facies (Schmitt, 1939a, p. 78a). Analysis by A. Willman.
4. Analysis calculated from average of 10 modes of porphyritic facies. (See mode of No. 9.)
5. Average hornblende-biotite granodiorites (Nockolds, 1954, p. 1014).
6. Field No. 59–63, 70–76; lab. No. Grd 1480. Range of 8 analyses; E. F. Cooley analyst. Sn <10, Ge <20, Ga <5, As <1000, In <10, Cd <50, Bi <10, Tl <100, Sb <200, W <100, Nb <50, Ta <50.
7. Average of 4 modes, specimens C–1, C–19, C–31, C–34, from equigranular facies in Hanover lobe. Determinations (weight percent) made by C. B. Belt.
8. Lab. No. JC–20–52. Selected as typical of equigranular facies of Hanover lobe; from NE¼ sec. 21, T. 17 S., R. 12 W. Mode (volume percent) based on count of 2,000 points in single thin section.
9. Average of 10 modes (weight percent) by C. B. Belt. Selected by author as least altered specimens of porphyritic facies.
10. Lab. No. JC–19–52. Selected as typical of porphyritic facies of main mass of pluton; from NE¼ sec. 22, T. 17 S., R. 12 W. Mode (volume percent) based on count of 2,200 points.

The proportions of the constituent minerals are given in table 9. The mode given for No. 9 is the average of 10 modes selected from 21 modes determined by Belt (1955) and selected on the basis of small range in mineral content and sparsity of alteration minerals. The mode of No. 10 is typical for specimens of the porphyritic facies. If the porphyritic nature of the rock, the coarse grain texture of the matrix, and the somewhat uneven distribution of quartz, hornblende, and biotite are considered, the percentages based on the count of a single thin section are found to be remarkably similar to those representing the average of 10 specimens (table 9, No. 9).

Most exposures of the porphyritic facies, except those in the northern extremity of the main mass, appear relatively fresh. In the northern extremity the stock is broken by closely spaced fractures that reflect postintrusion movement along the Barringer fault. Here the stock is extensively silicified along closely spaced joints and fractures and superficially resembles quartzite. The rock is bleached and iron stained, presumably as a result of argillic-sericitic alteration. This altered rock contains hematite and a small amount of pyrite, chalcopyrite, and malachite as stringers and as disseminated blebs. Elsewhere in the main mass the porphyritic facies appears relatively fresh, although many phenocrysts contain products of incipient alteration: sericite, epidote, and clay in andesine and orthoclase, and chlorite, epidote, magnetite, and some calcite in hornblende and biotite. Belt (1955) observed that hedenbergite replaced hornblende in a few specimens, and that secondary biotite replaced it in others. On a knoll south of Snowflake Canyon, thin coatings of dark-green actinolite occur on joint planes in the granodiorite porphyry.

Chemical composition

The chemical composition of the porphyritic facies was reported by Schmitt (1939a) and is given in table 9 (No. 3); this analysis represents what he termed the main mass. A hypothetical chemical analysis (No. 4) was calculated from the average of 10 of Belt's modes of the porphyritic facies.

An average analysis of 65 hornblende-biotite granodiorites listed by Nockolds (1954, p. 1014) is given as No. 5 and closely resembles the other analyses and norms. The range in amounts of trace elements in eight samples of the pluton collected by W. R. Griffitts of the U.S. Geological Survey in 1959 is also given in table 9 (No. 6).

QUARTZ MONZONITE PORPHYRY OF THE SANTA RITA STOCK

Distribution

The quartz monzonite porphyry forms an irregularly shaped stock measuring 1½ miles or more along a northwesterly axis and a few hundred feet to 1½ miles along a northeasterly axis; the stock is well exposed in the north and south pits of the Chino mine. (See pl. 1.) The northwesterly elongation of the mass might be more conspicuous if the southeastern extension of the stock beneath landslide debris and mine dumps were exposed. Also, the mass may extend for some distance northwest at depth, for a broad belt of severe alteration extends almost continuously in that direction and merges with the altered area surrounding the Hanover lobe of the Hanover-Fierro pluton.

Two thick dikes of granodiorite or quartz monzonite porphyry extend north-northeast for 1–3 miles from the northeast margin of the stock. These dikes, known locally as the Grant County dike system, are probably apophyses of the stock, because they apparently merge with it along the northeast contact and do not intrude it, although the critical area is not well exposed.

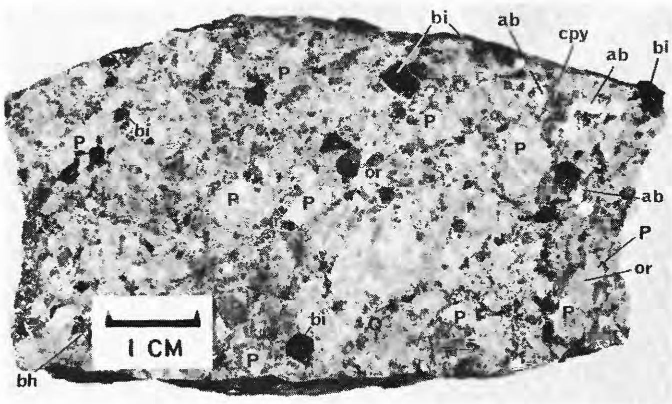
Facies

Variations in texture and in mineral proportions have been found from place to place within the stock. As Leroy (1954, p. 742) noted, the rock is porphyritic in most exposures, but in some it is nearly equigranular, although of the same mineral composition. Along the higher benches of the north wall of the south pit of the Chino mine the authors noted that north-trending dikes, as much as 50 feet wide, of medium to coarse quartz monzonite porphyry cut a finer grained and less porphyritic facies of the stock. These relations suggest somewhat later surges of magma into a cracked hood. Remnants of relatively fresh rock, especially of the matrix, from the east wall of the south pit and from the north pit differ in color and texture. (Compare fig. 24*A* and 24*B*.) Much of the stock is so severely altered that the original texture and mineral content are destroyed. For this reason it is impossible to map the various known facies, nor is it certain that other facies did not exist prior to alteration.

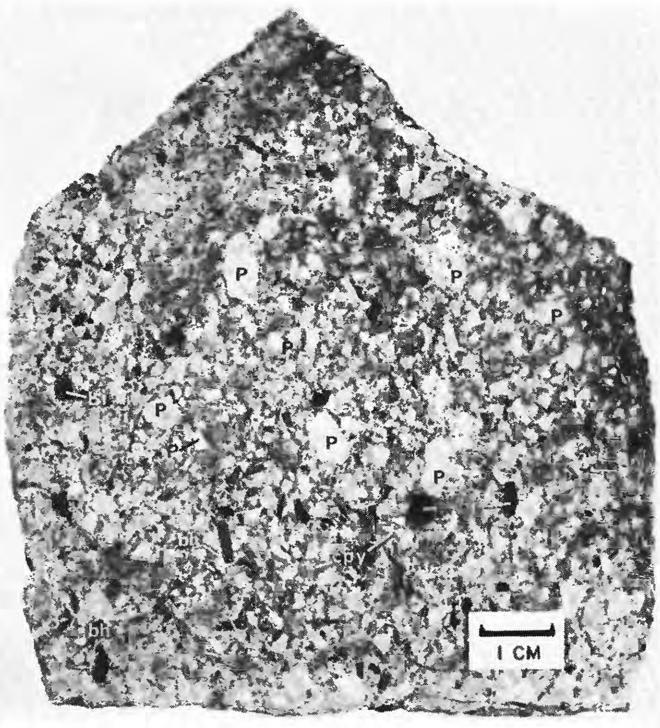
Dikelike bodies of aplite, which cut fresh quartz monzonite porphyry of the Santa Rita stock in the northeast sector and in the south pit, probably represent a final facies of the stock or an early hydrothermal alteration of it. They range in width from a fraction of an inch to tens of feet, and locally swell to 250 feet. The aplite consists chiefly of quartz and orthoclase, and contains minor amounts of biotite and interstitial magnetite and trace amounts of chalcopyrite and pyrite. It thus closely resembles the matrix of the stock rock.

Structure

The Santa Rita stock is intensely fractured, and within the central part of the north pit and of the "island" that separates the north and south pits it is coarsely brecciated. The abundance of mineralized fractures indicates that the stock rock was intensely fractured between the time of its consolidation and the ensuing introduction of quartz, pyrite, molybdenite, chalcopyrite, and other minerals.



A



B

Figure 24.—Quartz monzonite from Chino pits. *A*, Nearly equigranular facies from north wall of north pit. Orthoclase phenocrysts, or; albite, ab; chalcopyrite, cpy; biotite, bi; biotitized hornblende, bh; quartz, Q; plagioclase, P. (Mode for specimen given in table 10, No. 1.) *B*, Porphyritic facies from east wall of south pit. White plagioclase (P) grains partly altered to clay; black shiny fresh biotite, bi; and biotitized and chloritized hornblende laths, bh; set in gray aphanitic matrix. Sparse patches and seams of chalcopyrite, cpy. Most biotitized or chloritized hornblende grains contain minute specks of chalcopyrite or pyrite. Quartz phenocrysts blend with matrix. (Mode for specimen given in table 10, No. 9.)

The cemented fragmental rock exposed in the north-central part of the stock is pipelike and is known locally as the Whim Hill breccia. (See fig. 43.) This breccia pipe is within slightly to moderately altered Santa Rita quartz monzonite porphyry; it is crudely elliptical and extends downward for several hundred feet (W. W. Baltosser, oral commun., 1962).

The angular to well-rounded blocks of the breccia are predominantly quartz monzonite porphyry, but fragments of sedimentary rocks have been identified. These fragments range in diameter from a fraction of an inch to 12 inches (Kerr and others, 1950, p. 290). The cement consists of finely crystalline magnetite, quartz, orthoclase, and, locally, chalcopyrite and molybdenite. The Whim Hill breccia was fully discussed by Kerr (Kerr and others, 1950, p. 289–292) and by Landon (1932), and the reader is referred to their descriptions for more detail.

Geologic relations

The Santa Rita stock is localized at the junction of three sets of faults or fractures: one trending northwest, one northeast, and a third, less pronounced, due east. Where exposed, the walls of the stock are steep, and the bordering sedimentary beds dip 30°–60° away from the northwest-trending axis of the intrusive. The irregularities of the contact, as seen in plan, follow preexisting faults and fractures. The prong of quartz monzonite porphyry that extends northwestward from the south pit of the Chino mine is alined with a belt of faulting and intense shearing that strikes northwest. The northeast margin of the stock has a similar trend. A southwest-trending prong, in the center of sec. 34, T. 17 S., R. 12 W., is alined with the dominant northeast fracture system in the quadrangle. The east-striking contact between the stock and the sedimentary rocks in the northeast margin of the south pit is parallel to and in line with a belt of intense fractures and minor faults that is most conspicuous east of the pit.

Blocks of metamorphosed sedimentary rock tens of feet across—believed to be remnants of the Syrena Formation—appear to be engulfed in the quartz monzonite porphyry in the north wall of the south pit, and what appears to be a larger engulfed block of sedimentary rock occurs in the northwest corner of the south pit. The attitude and position of the layers within the blocks correspond to the attitude and position of the same beds at the northern contact of the stock, and the blocks are perhaps attached at depth or laterally below the surface, or are roof pendants.

Petrography

The rock of the Santa Rita stock is generally a light-colored medium- to coarse-grained porphyry that has notable variations in texture and mineral content from place to place. The textural variations result from differences in the degree of crystallinity and in the grain size of the dominantly felsic matrix. In the northern and northwestern parts of the stock the potassic feldspar and the quartz of the matrix is medium grained, and the rock appears granular; but along the east wall of the south pit the matrix is gray and cryptocrystalline, and the rock is decidedly porphyritic. In the six specimens of relatively fresh rock examined microcospically, the matrix makes up 38–69 percent of volume, and averages 52 percent. These six specimens do not necessarily represent all the variations to be found in the stock rock, as no attempt has been made to collect a complete set of fresh samples. The results to date (1965) indicate that the Santa Rita stock is not a homogeneous mass, but comprises several distinct facies. Thus, calculations based on the original composition of just one of the facies and purporting to show losses or gains in rock components by alteration are naturally suspect (Leroy, 1954).

The volume of the constituent minerals is notably different in the six specimens analyzed, and it is not surprising that the rock has been variously named. As can be seen from the modes listed in table 10, most minerals show a wide range in abundance. The potassic feldspar is largely confined to the matrix, and it rarely forms phenocrysts. It averages about 27–28 percent of volume, or only about 5 percent less than the average andesine content. Quartz, in both matrix and phenocrysts, ranges from about 19 to 34 percent, and averages about 25 percent. The amount of biotite ranges from 2.4 to 7.6 percent, and averages about 4.3 percent. Magnetite, apatite, and sphene are apparent in all fresh specimens, and zircon is apparent in thin sections; however, of these accessory minerals, magnetite is the only one in sufficient abundance to permit measurement of variations within the specimens examined—it averages about 1½ percent of volume.

The Santa Rita stock rock closely resembles the quartz diorite porphyry sill, which it intrudes near the south Chino pit. The average mode of the quartz diorite porphyry is given in table 10, No. 12, and can be compared in the table with the average mode of the Santa Rita stock rock (avg. 1, 7–11). The quartz diorite porphyry generally contains about 10 percent more matrix than does the stock rock, but it is doubtful that this difference would be evident in the field. The range in abundance of quartz, andesine, and mafic phenocrysts in the two rocks overlaps, so it is not significant that the average in one is somewhat greater than that in the other. Sphene is much easier to find megascopically in the stock rock, and allanite has been found only in the quartz diorite porphyry.

TABLE 10.—*Analyses, norms, and modes, in percent, of quartz monzonite porphyry of the Santa Rita stock*

[nd, not determined; Tr., trace (<0.3); ng, not given; ------, absent]

Chemical analyses

	1	2	3	4	5	6
SiO_2	65.7	64.87	64.90	66.93	65.15	65.88
Al_2O_3	16.0	16.63	17.55	15.74	ng	15.07
Fe_2O_3	2.5	2.36	[1] 1.65	.25	ng	1.74
FeO	1.8	2.35	[1] 1.50	2.23	ng	2.73
MgO	1.5	2.27	1.10	1.36	ng	1.38
CaO	2.5	3.24	2.05	1.78	1.96	3.36
Na_2O	3.4	5.71	3.40	2.24	2.81	3.53
K_2O	4.2	2.79	4.70	6.70	5.52	4.64
H_2O+	1.3	.15	.87	.93	ng	.52
H_2O-	nd	nd	.03	.27	ng	ng
TiO_2	.42	ng	ng	.37	ng	.81
P_2O_5	.31	ng	ng	.17	ng	.26
MnO	.04	ng	ng	.02	ng	.08
BaO	nd	ng	ng	.16	ng	ng
CO_2	.06	.08	ng	.01	ng	ng
S	nd	.22	.17	1.17	ng	ng
Cu	nd	.07	.093	nd	ng	ng
Total	100	100.74	98.01	100.33	ng	100
Less O	------	------	------	.29	------	------
	100	100.74	98.01	100.04	ng	100
Specific gravity:						
Powder	2.67	2.62	nd	2.66	ng	ng
Bulk	2.56	2.36	2.46	2.53	ng	ng

Determined by field geochemical methods [2]

[Parts per million]

	1	4		1	4
As	10	30	Mo	20	4
Co	<10	5	Ni	<20	25
Cu	[3] 30	[4] 900	Pb	<20	25
Ge	<4	ng	Zn	40	25

Semiquantitative spectrographic analyses

	1	4		1	4
Ba	0.2	0.07	Sc	------	0.0007
Co	.0002	.003	Sr	0.1	.07
Cr	.001	.0015	V	.007	.007
Ga	.001	.0015	Y	.004	.0015
La	------	.007	Yb	------	.00015
Mo	.002	.007	Zr	.02	.015
Ni	.0007	.0007			

Norms

	1	2	3	4	6
Quartz	22.50	10.81	20.58	23.16	18.8
Orthoclase	22.05	16.68	27.80	39.48	27.2
Albite	28.82	48.21	28.82	18.34	29.9
Anorthite	11.40	11.40	10.29	6.67	11.7
Corundum	1.63	------	------	2.45	ng
Diopside	------	3.34	------	5.55	} 7.6
Hypersthene	4.46	6.40	3.59	------	
Magnetite	3.71	3.48	2.55	.46	2.6
Ilmenite	.76	------	------	.76	1.5
Apatite	.67	------	------	.67	.6
Calcite	.2	------	------	------	ng
Pyrite	------	.5	.38	1.76	ng

See footnotes at end of table.

TABLE 10.—*Analyses, norms, and modes, in percent, of quartz monzonite porphyry of the Santa Rita stock*—Continued

Modes

[Volume percent]

	1	7	8	9	10	11	Avg. 1, 7–11	12	13
Matrix	54	50	38	57	43	69	52	61	51
Quartz	23	29	19	nd	18	26	23	nd	29
Orthoclase	30	21	19	nd	25	43	28	nd	22
Mafic minerals	Tr.	Tr.	Tr.	5	Tr.	Tr.	1	nd	nd
Major phenocrysts:									
Quartz	1.8	4.9	Tr.	4.0	2.3	Tr.	2	3.2	1.0
Orthoclase	1.5	Tr.	Tr.	Tr.	4.6	Tr.	1	----	Tr.
Plagioclase	34	36	47	28	33	[5] 20	33	26	25
Maximum An	An_{37}	An_{35}	An_{37}	An_{35}	An_{32}	nd	nd	nd	An_{36}
Hornblende	[6] Tr.	[6] 2.7	9	[6] 7	Tr.	----	5	4.5	[6] Tr.
Biotite	8	2.4	2.6	3.3	4.5	6	4.3		[6] Tr.
Accessory minerals:									
Magnetite	1.5	1.0	1.6	.7	2.1	1.5	1.4	Tr.	1
Sphene	Tr.	.4	Tr.	----	Tr.	Tr.	Tr.	Tr.	Tr.
Apatite	.3	.6	.4	.7	.4	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Alteration minerals:									
Epidote	Tr.	1.3	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Sericite-illite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Clay minerals	Tr.	.4	----	Tr.	----	[7] 20	Tr.	Tr.	Tr.
Clinozoisite	Tr.	Tr.	----	----	Tr.	----	Tr.	----	----
Albite	Tr.	----	----	----	----	----	Tr.	Tr.	----
Chlorite	1.0	2.6	Tr.	Tr.	2.8	2.8	1.5	Tr.	----
Biotite	Tr.	[8] 2.7	Tr.	[8] 7	----	Tr.	Tr.	Tr.	----
Magnetite	Tr.	----	----	Tr.	Tr.	----	Tr.	----	----
Leucoxene	Tr.	----	----	----	Tr.	----	Tr.	----	----
Quartz	Tr.	Tr.	----	----	----	Tr.	Tr.	----	----
Specularite	----	----	----	----	----	Tr.	Tr.	----	----
Pyrite	Tr.	Tr.	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Chalcopyrite	Tr.	----	----	Tr.	Tr.	Tr.	Tr.	----	----
Alunite	----	----	----	----	----	Tr.	Tr.	----	----

[1] Reported as total iron; ratio of Fe_2O_3 to FeO determined in No. 1 and 2, as all three samples are from same outcrop.
[2] Analysts: No. 1, J. T. Slayback and H. E. Crowe; No. 2, H. L. Neiman.
[3] Leroy (1954, p. 764) reported 600–2,300 ppm Cu in samples from same outcrop.
[4] Colorimetric method showed 1,300 ppm in No. 4, analyst: W. D. Goss; lab. No. 271657.
[5] Altered to clay.
[6] Completely altered to biotite.
[7] Replaces plagioclase.
[8] Replaces hornblende.

SAMPLE DESCRIPTION

1. Field No. JC–110–54; lab. No. 139777. Relatively fresh rock from north wall of north Chino pit. Chemical analysis, rapid rock, by P. L. D. Elmore and P. W. Scott; spectrographic analysis by Harry Bastron; mode average of two thin sections, 4,760-point count.
2. Field No. A–5. "Hard unaltered rock from north pit" (Leroy, 1954, p. 753). Chemical analysis by Silve Kallmann.
3. North wall of north Chino pit. Analysis by Hurley Laboratory of Kennecott Copper Corp.
4. Field No. JC–110–58; lab. No. F–2447. East wall of south Chino pit. Chemical analysis, standard rock, by F. H. Neuerberg; spectrographic analysis by J. C. Hamilton.
5. 300-foot level of Santa Rita mine; reported by Graton (in Lindgren and others, 1910); partial analysis by W. T. Schaller.
6. Average hornblende-biotite adamellites (Nockolds, 1954, p. 1014).
7. Field No. HC–10–49. Relatively fresh rock from northwest wall of north Chino pit; 2,000-point count.
8. Field No. JC–4–57. Freshest specimen; from north wall of north Chino pit; 3,545-point count in two thin sections.
9. Field No. JC–45–52. Same as No. 4; matrix is dark gray, cryptocrystalline; contains about 5 percent opaque dust; 2,000-point count.
10. Field No. JC–117–54. From depth of 223 feet in diamond-drill hole 1246. Contains some chalcopyrite and a quartz veinlet; 2,000-point count.
11. Field No. JC–5–57. Altered specimen from depth of 180 feet in diamond-drill hole 1225. 1,670-point count.
12. Average of quartz diorite porphyry in southern half of Santa Rita quadrangle.
13. Field No. JC–50–52. Biotized stock rock from northeast corner of south Chino pit; 1,767-point count.

The major phenocrysts have been corroded and partly resorbed by the late-crystallizing felsic fluid, which crystallized to interlocking grains of quartz and orthoclase or anhedral orthoclase alone. Most quartz phenocrysts are strongly embayed by the matrix, and well-formed dipyramids are rare; many andesine phenocrysts are subhedral and are embayed by orthoclase alone or by the felsic matrix. Some biotite phenocrysts, or pseudomorphs of chlorite after biotite, are similarly embayed, and many grains appear shredded and broken. However, well-formed elongate books two to three times longer normal to cleavage than parallel to it are conspicuous in most hand specimens. Only one of the six specimens examined contained unaltered hornblende, but pseudomorphs having typical hornblende form and consisting of finely crystalline biotite or chlorite were common in most thin sections. The small accessory crystals are generally euhedral.

The alteration of the quartz monzonite porphyry of the Santa Rita stock has been described at length by others (Kerr and others, 1950; Leroy, 1954). Briefly, the alteration effects can be classified as propylitic, argillic-sericitic, quartz-sericitic, and potassic. Potassic alteration, characterized by replacement or fissure filling by quartz, orthoclase, and biotite, is sparse except in the cement of the Whim Hill breccia. In some places the quartz-orthoclase matrix of the porphyry contains abundant black specks and patches of magnetite and finely crystalline biotite. Aplitic veinlets and patches of orthoclase and albite commonly contain blebs of chalcopyrite and pyrite (figs. 24*A*, 25), even though the andesine phenocrysts are unaltered, or nearly so.

The propylitized rock consists of secondary chlorite, biotite, epidote, clinozoisite and albite, and minor amounts of secondary sericite or hydromica. Phenocrysts of hornblende and biotite are more altered than other phenocrysts. Metal sulfides and oxides are sparsely disseminated throughout the propylitized rock.

In argillized rock, the plagioclase phenocrysts are partly or completely altered to mixtures of clay minerals, including montmorillonite, illite, kaolinite, dickite, and allophane. The hornblende and biotite are pseudomorphically replaced by leafy biotite, chlorite, and in greatly altered rock, hydromica or sericite. Chalcopyrite, pyrite, and molybdenite are disseminated throughout the rock and in fissures.

In rock affected by the quartz-sericitic type of alteration, only a few corroded grains of quartz may be visible, and the original texture is destroyed. Thin-section examination reveals trace amounts of kaolinite, dickite, allophane, hydromica, rutile, zircon, and limonite; but sericite, quartz, and pyrite predominate. The ultimate product seems to have been completely silicified rock.

The net chemical changes in the stock rock affected by hydrothermal solutions of both hypogene and supergene origin have recently been recalculated in terms of gram atoms and gram equivalents (Hemley and Jones, 1964, p. 545). In essence, the bulk of the alteration is characterized by the addition of hydrogen ions and the simultaneous removal of chemical equivalents of the base cations Ca^{+2}, Na^{+}, Mg^{+2}, and K^{+}. Silica derived from this hydrolytic decomposition of silicate minerals, principally plagioclase, moves away from the site of its release, but probably not very far, before precipitating in fissures or replacing neighboring rocks.

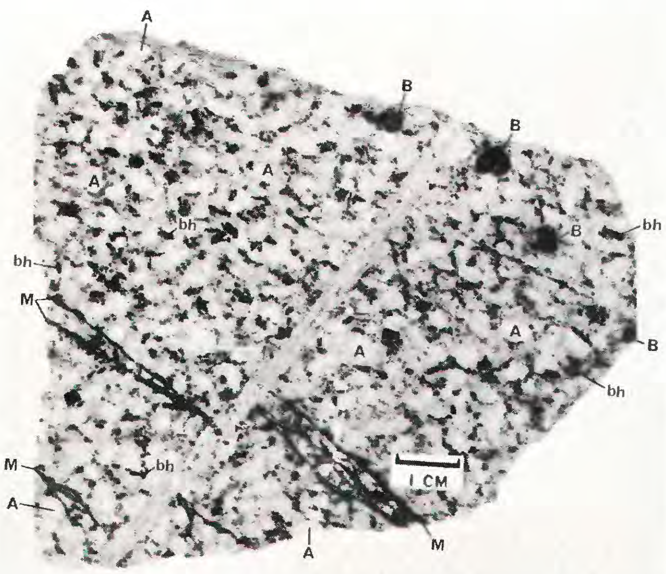


FIGURE 25.—Quartz monzonite porphyry from Santa Rita stock. Black specks and patches in the orthoclase-quartz matrix between fresh andesine phenocrysts, A, are magnetite (specks) and biotite (patches). Black veinlets are very fine grained magnetite, M. Light-colored veinlet consists of graphic intergrowths of quartz-albite and quartz-orthoclase; orthoclase and some white mica seem to replace the albite, especially along the margins of the veinlet. White grains in medial part of veinlet are second-generation albite which replaces orthoclase. Veinlet contains a few grains of chalcopyrite, pyrite, and magnetite. All hornblende, bh, and some biotite, B, are replaced by fine-grained biotite and magnetite.

Chemical composition

One partial and four fairly complete chemical analyses of least altered quartz monzonite porphyry are listed in table 10. The results of a quantitative spectrographic analysis and of two chemical analyses for certain metals are also given in table 10. The analyses of samples 1–3 are of a single relatively fresh rock exposed along the north wall of the north pit, east of the Whim Hill breccia. Sample 4 is stock rock from the east wall of the south Chino pit. Nockolds' (1954) average of 41 hornblende-biotite adamellites (quartz monzonites) is listed as sample 6 for comparison. The analysis by Leroy (1954, p. 753) listed as sample 2 differs from the other analyses in amounts of K_2O and Na_2O, although the total amount of the two oxides in all analyses is about the same. In the normative diagram of figure 13, one specimen (point 9) plots well within the granite field, whereas another specimen (point 8) plots within the center of the quartz monzonite field. At present the authors have no explanation for this discrepancy. Naturally, the same discrepancy is apparent in the normative diagram of figure 15. (Compare lines 7a and 7.)

QUARTZ LATITE PORPHYRY AT COPPER FLAT

Three irregular masses and two dikes of quartz latite porphyry crop out near the middle of the west side of the Santa Rita quadrangle, in an area called Copper Flat. The main mass is a composite pluton, irregular in outline, that is about 2,000 feet long and 1,000–1,200 feet wide at the surface. With depth it becomes smaller and breaks into rootlike dikes. Two small oval masses crop out 150 and 300 feet west of the main mass, and two east-striking dikes crop out 400 and 500 feet south of it.

Detailed mapping of the surrounding rocks by Lasky (pl. 3) showed that beds of the Oswaldo Formation around the periphery of the main mass were squeezed into peripheral folds and later altered to silicates and marble. The deformation, coupled with the bulbous shape of the mass, shows that the magma expanded at an elevation near that of the present surface; the rootlike apophyses of the mass cut through a sill of hornblende granodiorite about 900 feet thick.

Petrography of the main mass

Microscopic examination and modal analyses of specimens of the main mass show that phenocrysts constitute 30–40 percent of rock volume, that the aphanitic matrix consists largely of orthoclase and quartz, and that biotite and hornblende together make up less than 3 percent of the rock. Because of the similarity in color between the andesine phenocrysts and the matrix, and the small size of most phenocrysts, the porphyritic aspect is not striking in hand specimen (fig. 26).

Largely on the basis of the abundance and size of quartz and orthoclase phenocrysts, Lasky mapped three varieties within the pluton. The boundaries of these are shown on the map (pl. 3) but could not be shown on the cross sections because the varieties were not distinguished by the company geologists who mapped the mine workings.

The variety of quartz latite which makes up the northwest lobe of the pluton and forms a 10- to 20-foot-wide border zone around the northeast-trending protuberance, near the highway, is distinguished by the absence of quartz and orthoclase phenocrysts. The rock is a creamy-light-gray very fine to medium-grained porphyry containing phenocrysts of cream-colored plagioclase (An_{27-32}) 2–10 mm long, shiny black flakes and sparse thick books of biotite generally less than 1 mm across, and sparse needles of altered hornblende, all set in an aphanitic matrix. (See fig. 26*A*.) In one thin section the ratio of orthoclase to quartz in the matrix is about 1.7. The mode of this variety is given in table 11 (Nos. 3 and 4).

The other two varieties contain quartz and orthoclase phenocrysts. One is finer grained and contains fewer and smaller orthoclase phenocrysts. According to Lasky, the contact between these two varieties is sharp; the north and southwest contacts between the two follow steeply dipping sheeted zones in the central part of the pluton. Inclusions of foreign rock, ¼–1 inch across, are fairly common locally. The mode of the finer grained variety is given in table 11 (Nos. 1 and 5). The rock is pictured in figure 26*B*. Many of the quartz phenocrysts are well-formed dipyramids with and without intervening prisms, and they range from 1 to 10 mm in diameter and length. Crystal faces are frosted, but fractured crystals show that internally the quartz is clear and vitreous. Numerous quartz grains are corroded and irregular in outline; some appear to be slivers of quartz. The plagioclase is zoned from oligoclase (An_{12}) to andesine (An_{38}), and many crystals are largely replaced by albite. Poikilitic orthoclase is sparse; in one specimen it has a maximum length of 35 mm. In some places the biotite flakes, averaging 1 mm in diameter or less, are fresh, but in other places they are altered to chlorite and secondary biotite. A few patches of alteration minerals have the outline of hornblende, but no fresh hornblende was found in either section. Accessory minerals are apatite, magnetite, and zircon. The potassic feldspar of the matrix is largely converted to clay.

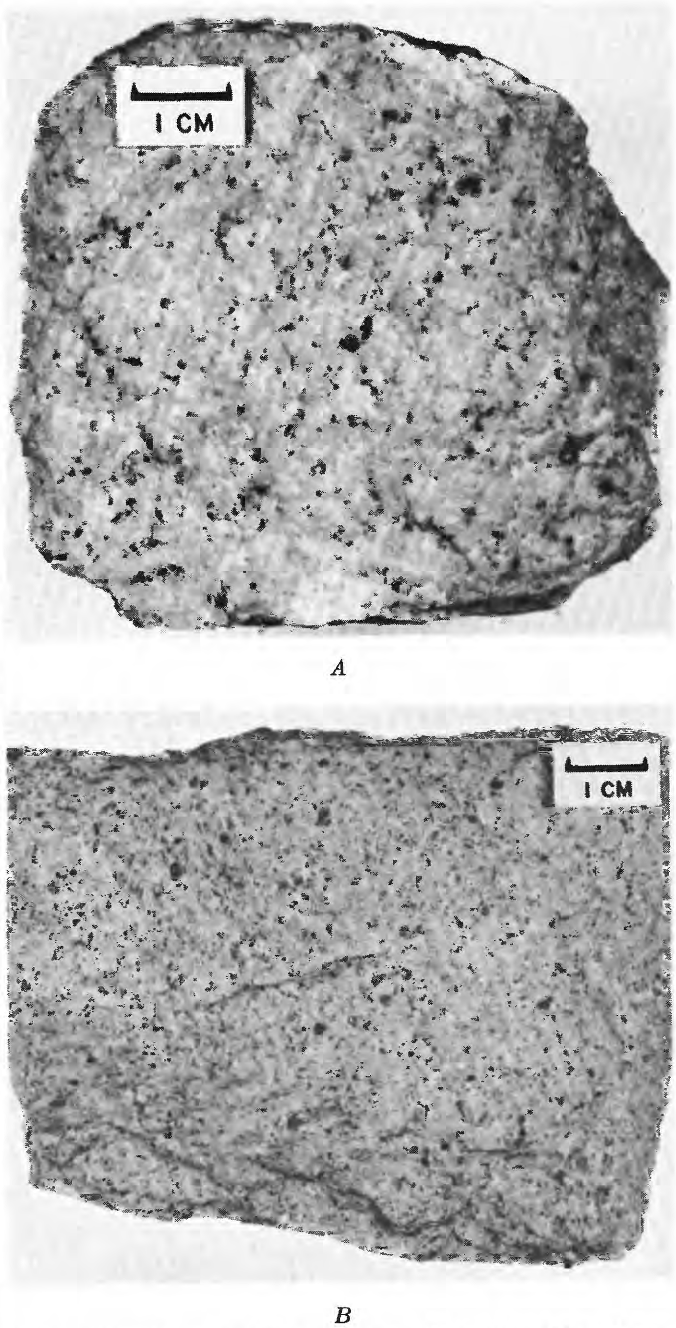


FIGURE 26.—Quartz latite porphyry of Copper Flat pluton. *A*, Biotite and hornblende (black grains) are fresh. Plagioclase white; matrix gray; specimen has appearance identical with that of the one for which mode is given in table 11 (No. 3). *B*, Black specks are flakes of biotite; larger dark grains are quartz. (Mode for specimen L–2–50 given in table 11 (No. 1.)

230–093 O—66——6

TABLE 11.—*Analyses, norms, and modes, in percent, of quartz latite porphyry at Copper Flat*

[nd, not determined; ng, not given; Tr., trace; ---, absent; C, common; A, abundant]

Chemical analyses

	1 [1]	2		1 [1]	2
SiO_2	70.33	70.47	CO_2	0.09	ng
Al_2O_3	15.89	15.50	Cl	.02	ng
Fe_2O_3	.36	.63	F	.05	ng
FeO	.29	2.12			
MgO	.57	.65	Total	99.77	100
CaO	1.65	1.91	Less O	.02	---
Na_2O	4.60	4.12			
K_2O	3.31	3.59		99.75	100
H_2O+	.93	.52			
H_2O-	1.40	ng	Specific gravity:		
TiO_2	.20	.03	Bulk	2.51	ng
P_2O_5	.06	.16	Powder	2.59	ng
MnO	.02	.03			

Semiquantitative spectrographic analysis [2]

	1		1		1
Ba	0.15	Ni	0.0005	Y	0.002
Cr	.0005	Pb	.0015	Yb	.0002
Cu	.070	Sr	.07	Zr	.007
Ga	.003	V	.0015		

Norms

	1	2		1	2
Quartz	26.9	27.1	Magnetite	0.2	0.9
Orthoclase	19.5	21.1	Hematite	.3	ng
Albite	38.8	34.6	Ilmenite	.5	.6
Anorthite	7.8	8.6	Apatite	---	.3
Corundum	1.9	1.7	Calcite	.2	ng
Diopside	---	} 5.4			
Hypersthene	1.9				

Modes

	3	4	5	1
Matrix	69	66	61	64
Quartz	25	nd	nd	nd
Orthoclase	44	nd	nd	nd
Major phenocrysts:				
Quartz	Tr.	Tr.	6	6
Orthoclase	---	---	Tr.	2.6
Plagioclase	27	33	[3] 30	25
Range An content	An_{27-32}	nd	An_{12-38}	An_{28}
Accessory minerals:				
Biotite	1.2	Tr.	.8	2.4
Hornblende	Tr.	Tr.	Tr.	Tr.
Magnetite	Tr.	1	---	Tr.
Apatite	Tr.	Tr.	Tr.	---
Zircon	Tr.	Tr.	Tr.	Tr.
Rutile	---	---	Tr.	---
Alteration minerals:				
Epidote	---	Tr.	---	Tr.
Calcite	Tr.	Tr.	---	1
Sericite	Tr.	---	Tr.	C
Clay	---	C	Tr.	C
Clinozoisite	Tr.	.9	---	---
Albite	Tr.	---	A	C
Chlorite	C	Tr.	C	Tr.
Biotite	Tr.	Tr.	1.1	---
Magnetite	Tr.	---	---	---
Quartz	Tr.	Tr.	Tr.	---
Limonite	---	Tr.	Tr.	Tr.

[1] Analysis, standard rock, by C. L. Parker.
[2] Analysis by J. C. Hamilton.
[3] Largely albitized.

SAMPLE DESCRIPTION

1. Field No. L-2-50, lab. No. H-3479. Dump of pit northwest of No. 2 shaft.
2. Average muscovite-biotite granodiorite (Nockolds, 1954, p. 1014).
3. Field No. HC-22-51. West of No. 4 shaft; 1,400-point count.
4. Field No. L-4-50. Narrow zone along northeast prong of pluton; 1,562-point count.
5. Field No. HC-2-50. 350 feet east of No. 4 shaft. Medium grained; contains abundant quartz phenocrysts and sparse poikilitic orthoclase phenocrysts.

No thin section of the coarser grained subfacies was available for modal analysis, but examination with a binocular microscope suggests that there is probably little difference in the abundance of minerals and that the same minerals are present in both varieties.

The main mass is partly to completely altered to kaolinite east of the highway and in parts of the northwestern lobe. In the latter area, however, pervasive replacement of the stock rock by massive black hematite, and subsequent extensive silicification, is much more pronounced than argillic alteration. The relations of hematite and quartz alteration are shown in figure 27. The map shows the major "ribs" of quartz and the general outline of the silicified area, but stringers of quartz extend beyond the boundary.

Chemical composition

The chemical composition and norms of part of the stock are given in table 11. Only two intrusive rocks in the area, the rhyolite and the alaskite porphyry sills, are more siliceous. The normative plot (fig. 13, point 10) falls within the granodiorite field, whereas the modal plot (fig. 12, point 6) falls within the granite field. Evidently, considerable albite is contained in the alkali feldspar as well as in the plagioclase. The normative plagioclase contains 83 percent albite, whereas, as determined from optical data, the actual plagioclase contains only about 70 percent albite, on the average. The difference may be due to the albite contained in the orthoclase. The content of several minor elements, as determined by semiquantitative spectrographic methods, is given in table 11. The copper content (0.07 percent) is markedly higher than is normal for granitic rocks.

Petrography of the dikes

Megascopically, the two east-striking dikes south of the Copper Flat pluton are quite different, and both are so thoroughly altered that the proportion of primary constituents, especially the mafic components, is difficult to estimate.

The northern dike contains numerous quartz phenocrysts generally 1-2 mm in diameter but rarely as much as 7 mm, moderately abundant small flakes of altered biotite, and sparse needlelike pseudomorphs after hornblende, all set in what appears to be a granular matrix of potassic and plagioclase feldspar. A small granule of allanite was seen in one specimen. No epidote was noted by us; however, Lovering (1953) reported epidote, along with calcite and chlorite, in altered mafic minerals in thin section. The alteration is dominantly argillic; pseudomorphs of the mafic minerals resemble what has been identified in other specimens as illite.

FIGURE 27.—Pervasive replacement of quartz latite porphyry by hematite (dark areas) and quartz at Copper Flat. Pencil indicates scale.

The southern dike is a light-greenish-gray fine- to medium-grained porphyry consisting largely of feldspar and green chloritic pseudomorphs after hornblende. Phenocrystic quartz is rare and is sparsely distributed. Epidote is disseminated throughout the rock. In thin section the porphyritic texture is obvious. The matrix has a felted texture and consists largely of plagioclase feldspar with subordinate equant granules of orthoclase and a little quartz, altered hornblende, and epidote. The hornblende phenocrysts are completely altered to columnar zoisite or to zoisite and calcite. The plagioclase phenocrysts are subhedral to anhedral and are severely fractured, mottled, twinned but not zoned, and partly replaced by epidote and, along fractures, by albite. No grains were suitably oriented in the thin section to determine the anorthite content. One aggregate of zoisite and leucoxene is doubtfully considered to be pseudomorphous after biotite. One crystal of allanite, rimmed with epidote, was enclosed in a plagioclase phenocryst. Patches of fibrous zoisite associated with calcite had a thin margin of granular epidote.

DIKE SWARMS OF EARLY TERTIARY AGE

GRANODIORITE PORPHYRY DIKES

Introduction

In earlier geologic reports (Spencer and Paige, 1935; Lasky, 1936) the granodiorite porphyry dikes were not mapped separately from the next younger swarm of quartz monzonite porphyry dikes, although Lasky (p. 35–37) recognized their distinctive character in the Bayard area, and later (in Lasky and Hoagland, 1948, p. 14) referred to one variety as granodiorite and to the other as quartz monzonite. Some dikes herein grouped as granodiorite porphyry were called hornblende quartz diorite porphyry by Schmitt (1939a, p. 784) and hornblende granodiorite porphyry by Kerr (Kerr and others, 1950, p. 294) and Leroy (1954, p. 748). Both Kerr and Leroy distinguished the hornblende granodiorite porphyry dikes from the quartz monzonite porphyry dikes; however, they called them quartz granodiorite porphyry dikes. The name used by Kerr and Leroy is not used in this report because one type of granodiorite porphyry recognized by the authors is characterized by abundant phenocrystic quartz.

Types

Dikes designated "granodiorite porphyry" on the maps and sections accompanying this report include three types of dike rock that were emplaced at closely spaced intervals, probably after (but possibly in part contemporaneously with) the intrusion of the Hanover-Fierro pluton and the Santa Rita stock and before the intrusion of the quartz monzonite porphyry dikes. The three varieties are (1) unzoned dikes which contain abundant phenocrystic quartz and biotite as well as hornblende; (2) zoned dikes whose interior is similar to, if not identical with, the unzoned dikes but whose margins or entire width, if narrow, contains very few quartz phenocrysts, very little biotite, and as much as 25 percent hornblende; and (3) zoned dikes which contain a few sparse porphyroblasts of orthoclase, a few phenocrysts of quartz, and biotite as well as hornblende. This last variety is not common, which is fortunate for mapping purposes, because it is not easily distinguishable in the field from the younger quartz monzonite porphyry dikes. The three types were not mapped separately, because their relative age has not been established. Type 1 dikes are tentatively considered the oldest, and type 3 dikes the youngest. In the Groundhog mine and at the surface near the Ivanhoe mine, type 3 dikes cut across type 2 dikes. The unzoned dikes (type 1) resemble the Santa Rita stock rock, and some may be apophyses; for this reason they are considered to be the oldest of the granodiorite dikes.

Distribution and structural relations

Granodiorite porphyry dikes are exposed within a northeast-trending zone 1½–2½ miles wide that extends for about 7 miles across the Santa Rita quadrangle, from the Vanadium area in the southwest corner to the north-central margin of the quadrangle (fig. 47*A*; pl. 1). Both the number of dikes and the complexity of their pattern decrease northward within this zone, from an intricately linked network in the Groundhog mine area to simple fissure fillings north of Hanover. Some dikes are exposed in mine workings but not at the surface. Commonly they intrude minor faults or fractures—some of them adjacent to major faults—rather than the major faults themselves. As Lasky noted (1936, p. 35), "some dikes cut across earlier fissures instead of following them, but the dike is likely to widen or jog at the fissure or to send a short tongue along it," and at some places where the dikes cut through sedimentary rocks they widen or narrow abruptly along a bedding plane, like a sill. Most of the granodiorite porphyry dikes are irregular in plan or section, or both, and detailed studies at the surface and underground show that they pinch, swell, change dip, end abruptly, and reappear in an en echelon position. Some dikes are short and stubby; some are long and slender. The longest dikes of granodiorite porphyry in the quadrangle extend northward for more than 3 miles from the north pit of the Chino mine. Individual dikes range in width from 1 to 400 feet, but most are less than 100 feet wide.

The walls and interiors of granodiorite dikes are commonly sheared, and these fractures serve as channelways for mineralizing fluids (fig. 28).

FIGURE 28.—Sheared walls along granodiorite porphyry dikes, gd, which here intrude the Syrena Formation, Ps. Zinc gossan, gos. Roadcut along State Highway 90, 1,200 feet south of Oswaldo 1 shaft.

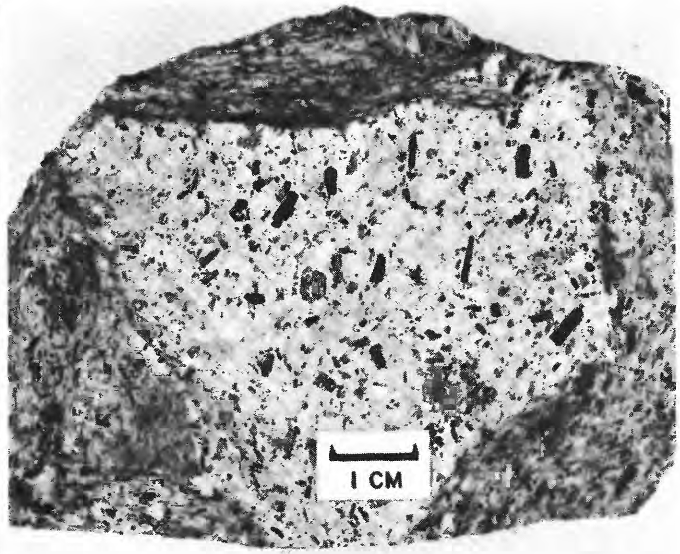
Petrography

The relatively fresh granodiorite porphyry is typically a medium-gray to dark-greenish-gray medium-grained rock in which white feldspar phenocrysts and dark mafic phenocrysts (either hornblende or biotite, or both) are conspicuous (fig. 29; see also Lasky, 1936, p. 26, pl. 6). Quartz phenocrysts are present in variable amounts, generally making up 1–6 percent of the rock. The major phenocrysts generally constitute about half the rock, but they range from one-third to almost two-thirds of volume; most of them are subhedral crystals of white feldspar which are 1–20 mm long and average about 7 mm. The content of mafic minerals is variable, even within the same dike, as are the proportions of hornblende and biotite; in a few specimens biotite exceeds hornblende, but in most, hornblende predominates, and in some it is the only mafic mineral. The groundmass is generally very fine grained to aphanitic and dark gray. Sphene, magnetite, apatite, and, rarely, allanite, in addition to the phenocrysts mentioned above, can be easily identified in hand specimens.

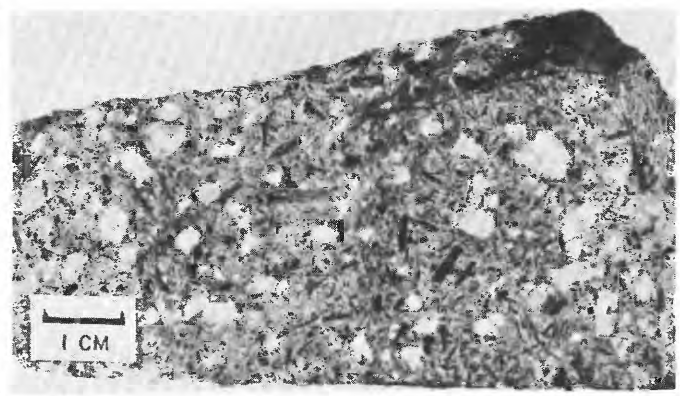
As stated, the granodiorite porphyry dikes can be divided into three types on the basis of abundance of certain phenocrysts. The differences are apparent from the modal analyses in table 12, in which modes are listed for five specimens of type 1, three of type 2, and two of type 3. The differences among the three types are more apparent in table 13. The ranges given should be considered only as indicative of the order of magnitude in differences among the types.

Microscopic examination of thin sections of granodiorite porphyry shows that the character of the phenocrysts in all the types is about the same. The plagioclase feldspar is dominantly andesine, the anorthite content ranging from 25 to 50 percent; most grains are fractured, euhedral to subhedral, weakly zoned, and twinned in the normal way. The andesine grains range widely in size, even within the same specimen, from less than 1 mm to 10 mm, but most are 4–7 mm long. The andesine is partly to completely altered to one or more of the following minerals: Albite, epidote, clinozoisite, sericite, montmorillonite, "illite," and kaolinite. A few phenocrysts of orthoclase are present in some slides examined, but they constitute less than 1 percent of the rock. Stain tests, however, show that orthoclase is abundant in the cryptocrystalline matrix. Orthoclase also occurs as irregular patches within plagioclase grains, according to Kerr (in Kerr and others, 1950, p. 296). Quartz grains 1–3 mm wide occur both as irregularly embayed anhedra and as well-formed dipyramids. Some grains contain inclusions; a few show marginal alteration rims, but otherwise the grains are generally unaltered. Green hornblende occurs both in the groundmass and as subhedral to euhedral phenocrysts ranging in length from less than 1 mm to 10 mm. The phenocrystic hornblende is in general partly to completely altered to chlorite, calcite, epidote, zoisite, and aggregates of secondary biotite. Hornblende is concentrated in the margins of the dikes north of Hanover, and the prismatic crystals are alined parallel to the walls of the dikes. Biotite forms euhedral phenocrysts, many of which are three to four times as long normal to cleavage as parallel to it. Thin books are not uncommon. Most biotite is altered, usually to chlorite, epidote, and minor leucoxene, sphene, and magnetite. Among the minor primary constituents are elongate apatite prisms and honey-colored wedge-shaped crystals of sphene, both as much as 5 mm long, and equant grains of magnetite and pyrite. Allanite was found in a granodiorite dike about 500 feet east of Cemetery No. 4, north of Santa Rita. The groundmass is generally too fine grained to permit identification of individual grains, even under high magnification. It appears darker and is therefore probably less felsic than the matrix of the stocks previously described.

The alteration of the granodiorite porphyry dikes is characterized more by such minerals as epidote, zoisite, clinozoisite, calcite, quartz, and chlorite than by argillic minerals or sericite, although not all these alteration minerals are likely to be present in any one specimen. Epidote and its related alteration suite pervade most of the dike rock but show a definite concentration near contacts and fractures. Some dikes in the Empire zinc mine, and one dike south of the Princess shaft, are completely altered to epidote-group minerals. Granodiorite porphyry dikes are the youngest dikes in the igneous series to have common epidote coatings on joint surfaces. Shear zones in the dikes are chloritized or epidotized. Epidote-group minerals occur also as irregular spots, masses, or bands replacing the phenocrysts and commonly the groundmass. At the Pewabic mine, Schmitt (1939a, p. 791) noted almost complete replacement of a granodiorite porphyry dike by thuringite, the iron-rich chlorite. Similar alteration was noted by the authors in dikes west of the Kearney mine and in dikes that extend northward from Santa Rita. Schmitt (1939a, p. 791) suggested that thuringite formed later than the epidote, at nearly the same time as sulfide emplacement. In rock in which the mafic minerals are altered to epidote and chlorite, the andesine may be flecked with sericite, epidote, montmorillonite, and "illite" (Kerr and others, 1950, p. 334). Not uncommonly, hornblende phenocrysts are converted entirely to finely crystalline biotite; and in one dike exposed in the northeast corner of the south Chino pit, the entire groundmass is also converted to biotite (table 12, norm of No. 4). In this dike the plagioclase phenocrysts are completely altered



A



B

FIGURE 29.—Granodiorite porphyry. *A*, Type 1, from dike 400 feet northeast of Sully school. Black phenocrysts are biotite and hornblende. Irregular light-gray patches are plagioclase. (Mode for specimen JC–2–57 given in table 12 (No. 7).) *B*, Type 2 granodiorite porphyry from narrow dike cutting Hanover lobe of Hanover-Fierro pluton. Black phenocrysts are hornblende; white phenocrysts are plagioclase. (Mode for specimen JC–17–52 given in table 12 (No.11).)

to clay and sericite. Other dikes in the pit contain fresh plagioclase phenocrysts, although the matrix is completely converted to biotite.

The epidote-chlorite alteration of granodiorite dikes is the counterpart of the pyrometasomatic aleration of carbonate rocks. The belt of altered limestone and dolomite includes most of the main zone of granodiorite porphyry dikes. In the general vicinity of the Santa Rita stock and along major fractures trending southwest toward the Groundhog mine, the alteration of the granodiorite dikes is characterized by the formation of

TABLE 12.—*Analyses, norms, and modes, in percent, of granodiorite porphyry dikes*

[nd, not determined; ng, not given; --, absent; A, abundant; C, common; Alt., altered beyond recognition; Tr., trace (<0.3)]

Chemical analyses

	1	2	3	4
SiO_2	64.15	56.68	64.63	61.47
Al_2O_3	16.45	16.18	15.68	16.03
Fe_2O_3	1.13	3.50	2.75	2.38
FeO	2.12	2.25	1.96	2.10
MgO	2.05	3.25	1.00	2.79
CaO	7.09	7.82	4.16	4.07
Na_2O	2.10	2.55	2.10	3.29
K_2O	1.66	1.92	2.73	3.14
H_2O+	1.40	1.15	1.51	2.03
H_2O-	.44	.60	.60	1.02
TiO_2	.48	.60	.31	.57
P_2O_5	.24	.48	.20	.25
MnO	.20	.21	1.25	.11
BaO	.25	--	.12	--
CO_2	.13	1.40	.98	.15
S	ng	1.18	ng	nd
Cl	nd	nd	nd	.02
F	nd	nd	nd	.05
Total	99.89	99.77	99.98	99.47
Less O	--	--	--	.02
	99.89	99.77	99.98	99.45
Specific gravity:				
Bulk	2.735	ng	ng	2.60
Powder	ng	ng	ng	2.68

Spectrographic analysis [1]

	4		4		4
Ba	0.15	La	0.005	V	0.015
Co	.007	Ni	.003	Y	.002
Cr	.0005	Pb	.002	Yb	.003
Cu	.002	Sc	.001	Zr	.01
Ga	.003	Sr	.1		

Norms

	1	2	3	4
Quartz	26.79	16.60	31.17	18.1
Orthoclase	11.12	11.68	16.12	18.4
Albite	17.82	22.53	20.44	27.8
Anorthite	30.02	27.80	13.90	18.1
Corundum	--	--	3.57	--
Diopside	2.94	6.80	--	--
Hypersthene	6.08	5.80	8.20	8.1
Magnetite	1.62	5.34	3.94	3.5
Ilmenite	.91	1.22	.61	1.1
Apatite	.34	1.34	.3	.7
Calcite	.27	--	2.2	.6

Modes

	5	6	7	8	9	1	10	11	12	13	14
Matrix	56	60	52	62	62	50?	58	52	66	54	75
Quartz	A	A	C	29?	Tr.	10?	C	20	10	C	C
Orthoclase	A	A	C	28?	C	30?	C	26	--	C	C
Hornblende	Tr.	Tr.	C	--	Tr.	5	C	5	--	C	C
Plagioclase	Tr.	C	C	--	C	5	C	Tr.	--	C	C
Specularite and pyrite	C	--	--	--	--	--	--	--	12	Tr.	--
Biotite-chlorite	C	--	Tr.	3	Tr.	--	--	--	43	Tr.	--
Epidote	C	--	Tr.	3	Tr.	--	--	--	--	Tr.	--
Major phenocrysts:											
Quartz	2.2	6	4.3	2.3	1.1	--	Tr.	.8	1	1.1	Tr.
Orthoclase	--	--	Tr.?	--	--	--	Tr.?	--	--	Tr.	Tr.
Plagioclase	36	[2] 32	29	27	23	40	28	17	12	23	18
Maximum An	An_{47}	nd	An_{45}	An_{37}	An_{45}	An_{50}	An_{37}	An_{37}	nd	An_{45}	An_{32}
Hornblende	Alt	--	9	3.6	[3] Alt	10	13	26	[4] 13	([5])	2.9
Biotite	Alt	6	2.8	4.0	Alt	--	Tr.	Tr.	1.5	([5])	2.0
Accessory minerals:											
Magnetite	1.5	2.5	--	Tr.	C	--	1.3	.4	Tr.	.6	--
Sphene	.5	Tr.	.1	.6	Tr.	<1	Tr.	Tr.	--	Tr.	Tr.
Apatite	Tr.	1	.4	.3	.4	<1	1	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	--	Tr.	Tr.	--	Tr.	Tr.
Alteration minerals:											
Epidote group	6	Tr.	2.6	[6] 2.5	C	5	.2	3.2	Tr.	2.9	Tr.
Calcite	--	4.6	--	C	C	--	--	--	--	3	Tr.
Sericite	C	A	--	--	Tr.	--	--	Tr.	--	Tr.	Tr.
Clay	C	A	C	Tr.	Tr.	--	Tr.	--	C	Tr.	Tr.
Albite	--	--	Tr.	Tr.	--	--	--	--	--	Tr.	Tr.
Chlorite	Tr.	--	Tr.	[7] 2.8	C	<1	[8] 1.5	[8] 1.2	Tr.	3	[8] 1.5
Leucoxene	--	Tr.	Tr.	--	--	--	--	Tr.	--	--	Tr.
Quartz	--	C	--	--	3.3	<1	Tr.	Tr.	9	Tr.	Tr.
Pyrite	Tr.	--	--	--	Tr.	--	--	--	Tr.	.6	1.3
Biotite	--	--	--	--	--	--	--	--	8	--	--

[1] Analyst, J. C. Hamilton. Looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ce, Hf, Hg, In, Li, Mo, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W. Zn. Figures reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1.

[2] Completely altered to sericite and clay.

[3] Total mafic silicates estimated to be 9 percent.

[4] Completely replaced by fine-grained biotite.

[5] Completely replaced by calcite, chlorite, and epidote.

[6] Replacement of plagioclase.

[7] Replacement of hornblende in matrix.

[8] Replacement of biotite.

SAMPLE DESCRIPTIONS

1. Field No. P-21. Pewabic mine area. (Hornblende quartz diorite.) Chemical analysis and norm by A. Willman (Schmitt, 1939a, p. 782); mode by H. A. Schmitt (1939a, p. 783).
2. Empire Zinc and Oswaldo 1 mines. Silve Kallmann, analyst (Kerr and others, 1950, p. 300). (Hornblende granodiorite.)
3. Groundhog mine, Vanadium area. L. Entwistle, analyst (Schmitt, 1954, p. 878.)
4. Field No. JC-261; lab. No. H-3478. 50 feet east of Hanover Creek, north of Groundhog mine. Least altered rock in area. C. L. Parker, analyst.

5–9. Quartzose granodiorite porphyry dikes:
- 5. Field No. HC-6-50 1,160 feet N. 45° E. of Bull Hill; 1,400-point count.
- 6. Field No. LC-13-46 900 level, Groundhog mine; specimen cut by calcite and quartz veinlets; 1,700-point count.
- 7. Field No. JC-2-57 400 feet northeast of Sully School; possible apophysis of Santa Rita stock; 2,500-point count. (See fig. 29*A*.)
- 8. Field No. JC-1-57 Outcrop east of Slate mine; 2,300-point count.
- 9. Field No. JC-3-57 West center sec. 6, T. 18 S., R. 12 W., north of Bayard, N. Mex.; 2,300-point count.

10–12. Hornblende-rich granodiorite porphyry dikes. (See also No. 1.)
- 10. Field No. JC-21-52 Narrow dike within Hanover-Fierro pluton, west of Pewabic mine; 2,000-point count.
- 11. Field No. JC-17-52 Narrow dike, 4,400 feet S. 75° E. of Humbolt Mountain; 2,200-point count. (See fig. 29*B*.)
- 12. Field No. JC-22-52 Narrow fine-grained dike; from east side of south Chino pit, 6600 bench; abundant secondary biotite; 1,500-point count.

13, 14. Granodiorite porphyry dikes containing sparse orthoclase porphyroblasts and quartz:
- 13. Field No. HC-19-51 "Star dike," 1800 level, Groundhog mine.
- 14. Field No. HC-14-50 From center of narrow dike, 2,450 feet S. 56° W. of Princess shaft.

TABLE 13.—*Major constituents, in volume percent, of three types of granodiorite porphyry dikes*

[Tr., trace, (<0.5 percent)]

Phenocrysts	Type 1		Type 2		Type 3	
	Range	Avg [1]	Range	Avg [2]	Range	Avg [3]
Quartz	1.1–6.4	3.3	Tr.–0.8	Tr.	1.2–1.4	1.3
Biotite	2.8–5.8	3.2	Tr.–1.5	Tr.	1.3–5.9	3.6
Hornblende	3.6–9.2	6.4	13.2–25.7	17.4	11.1–11.9	11.5
Orthoclase porphyroblasts	None	None	None	None	Tr.	Tr.
Plagioclase	23.2–36.0	29.3	12.3–37.7	19.0	23.6–26.1	24.9

[1] One thin section from each of five dikes.
[2] One thin section from each of three dikes.
[3] Two thin sections from Star dike in Groundhog mine.

various clay minerals, sericite, disseminated pyrite, and secondary quartz. This argillic-sericitic type of alteration obviously took place later than the epidote-chlorite pyrometasomatic type. The argillic-sericitic alteration in the granodiorite dikes is similar to the alteration in the Santa Rita stock rock. Locally, acid supergene waters have superimposed an argillic-alunitic alteration on all earlier types of alteration, as well as on previously unaltered rocks.

Chemical composition

Three chemical analyses of granodiorite porphyry dike rocks have been published and are reproduced in table 12 along with a new analysis (No. 4). The analysis given under sample 2 shows considerably less SiO_2 than do the other two analyses; the value is closest to that given by Nockolds (1954, p. 1019) for SiO_2 in average andesite. In the normative diagrams (figs. 13, 15) the plots generally indicate a typical granodiorite composition. The granodiorite dike from the Pewabic mine, however, falls within the quartz diorite field, though it is very close to the granodiorite field.

Because the granodiorite dikes are everywhere moderately to intensely altered, the original chemical composition of the dikes is in doubt. In most places, considerable amounts of calcium, magnesium, and iron were added during metasomatism, and much sodium and potassium were subtracted.

As the analyses indicate, sample 3 contains much less CaO, and an unusually large amount of MnO, which suggests that the dike sampled may be intensely altered.

Some dikes of this group, which preceded the mineralization and metalization episode in the district, are somewhat more mafic than the stock rock which preceded them. This reversion to a more mafic magma, commonly to one from which lamprophyric dikes crystallized, has been noted in many mining districts, and may be a significant factor in studies attempting to show the relationship between differentiation of a magma and the origin and timing of hypogene ore-depositing fluids (Hulin, 1929).

QUARTZ MONZONITE PORPHYRY DIKES

The quartz monzonite porphyry dikes were originally grouped with the earlier granodiorite porphyry dikes (Spencer and Paige, 1935; Lasky, 1936), although geologists of mining companies as well as of the U.S. Geological Survey recognized their distinctive character. Lasky was the first to map them separately, on a revised map of the Vanadium-Bayard area prepared in 1945–48. As stated earlier, Kerr (Kerr and others, 1950) and Leroy (1954) called them quartz granodiorite porphyry dikes, to distinguish them from earlier "hornblende granodiorite porphyry dikes." Distinction between these two similar dike swarms became important when it was realized that the main surge of mineralization in the district occurred after intrusion of the granodiorite porphyry dikes (of this report) and before intrusion of the quartz monzonite porphyry dikes. Separation of the two has also helped to pinpoint the time of maximum development of epidote, garnet, and other products of pyrometasomatic alteration. The presence of orthoclase porphyroblasts in the dikes of the younger swarm distinguishes these dikes from types 1 and 2 granodiorite dikes described in the preceding section of this report, but not from type 3 dikes, which also contain orthoclase porphyroblasts. The dikes of the younger swarm are distinguished from type 3 dikes by larger and more abundant orthoclase porphyroblasts and by more common phenocrystic quartz. Unfortunately, these criteria may not be applicable where the dikes are 10 feet wide or less.

Distribution

Most dikes of quartz monzonite porphyry are exposed within a northerly trending zone about 5½ miles long and generally less than 1 mile wide extending from the Groundhog mine on the south to the Barringer fault on the north (fig. 47*B*). The volume of quartz monzonite porphyry exposed decreases northward. The thickest dikes are exposed between the Princess and the Groundhog mines. North of Union Hill the quartz monzonite porphyry fills a narrow belt of en echelon fractures in the Hanover-Fierro pluton. This belt lies just west of Fierro and ends at the Barringer fault. A small mass of quartz monzonite porphyry crops out 1,000–1,500 feet east of the Nigger Shack mine (SE¼ sec. 5, T. 17 S., R. 12 W.), and irregular blocks of the porphyry are included in the coarsely brecciated Colorado Formation farther east.

Individual dikes within the zone have various trends. Within the wider southern part of the zone, individual dikes of the swarm trend north-northeast, generally paralleling but locally intruding the earlier granodiorite porphyry dikes. In the northern part of the zone, between Hanover and Union Hill, some dikes trend nearly due north, and some trend just west of north. South of State Highway 90, in the area from Wimsattville to the south Chino pit, several dikes of the swarm trend northwest.

Geologic relations

The dikes of quartz monzonite porphyry show all the detailed features of shape, size, lateral and vertical continuity, and outcrop pattern of the earlier granodiorite porphyry dikes. Exposures in the south pit of the Chino mine show typical irregularities—abrupt swellings and terminations—along both strike and dip.

The intrusions of quartz monzonite porphyry had little effect on their host rock other than a slight coarsening of grain of limestone and a slight hardening of shale. The maximum contact alteration related to the dikes was observed on the south flank of Humbolt Mountain, where limestone is garnetized in a zone about an inch thick that follows the contact of a dike and its apophyses; the dike itself is strongly epidotized for about an inch from the contact.

All dikes of quartz monzonite porphyry show a textural and mineralogical change close to their walls. In their margins they contain more hornblende and less biotite and quartz, and the hornblende blades are alined. This alinement of the hornblende blades gives the outcrop a banded appearance.

Petrography

The quartz monzonite porphyry is generally consistent in appearance throughout the quadrangle. Because the distinction between this rock and others in the quadrangle is based on the petrographic character of the internal facies, only that facies will be described in detail. The internal facies is light greenish gray on fresh fracture but commonly weathers brown or reddish brown; it is fine to medium grained, and porphyritic (fig. 30). Phenocrysts constitute about 47 percent of relatively fresh specimens of the internal facies of the dikes for which modal analyses are available. Major phenocrysts include andesine, quartz, orthoclase, biotite, and hornblende; minor accessory phenocrysts are magnetite, sphene, apatite, zircon, and allanite. Epidote, chlorite, pyrite, sericite, clay, and secondary orthoclase constitute the chief alteration products, and one or more of these is present in all specimens so far examined. The groundmass is largely a very finely crystalline aggregate of potassic feldspar and quartz. Modal analyses of 10 dikes are given in table 14.

TABLE 14.—*Analyses, norms, and modes, in percent, of quartz monzonite porphyry dikes*

[ng, not given; nd, not determined; Tr., trace (<0.3); ---, absent; A, abundant; C, common]

Chemical analyses

	1 [1]	2		1 [1]	2
SiO_2	66.16	65.88	P_2O_5	0.21	0.26
Al_2O_3	15.70	15.07	MnO	.17	.08
Fe_2O_3	1.30	1.74	BaO	.11	ng
FeO	1.62	2.73	CO_2	.21	ng
MgO	1.20	1.38			
CaO	3.66	3.36	Total	99.77	100
Na_2O	3.46	3.53			
K_2O	3.58	4.64	Specific gravity:		
H_2O+	1.62	.52	Bulk	2.58	ng
H_2O-	.40	ng	Powder	ng	ng
TiO_2	.37	.81			

Spectrographic analyses (parts per millon) [2]

	3	4		3	4
Pb	30	50	Be	1	1
Mn	200	1,000	Ag	1	1
Cu	500	30	B	10	10
Zn	200	200	La	50	50
Zr	150	150	Sc	10	10
Ni	15	10	Cr	20	10
Co	15	15	Ba	1,500	1,000
V	70	100	Sr	300	700
Mo	7	5	Ti	2,000	2,000
Y	10	15			

Norms

	1	2		1	2
Quartz	23.52	18.8	Diopside	---	1.4
Orthoclase	21.13	27.2	Hypersthene	4.79	6.4
Albite	29.34	29.9	Magnetite	1.86	2.6
Anorthite	14.73	11.7	Ilmenite	.76	1.5
Corundum	.71	ng	Apatite	.34	.6

See footnotes at end of table.

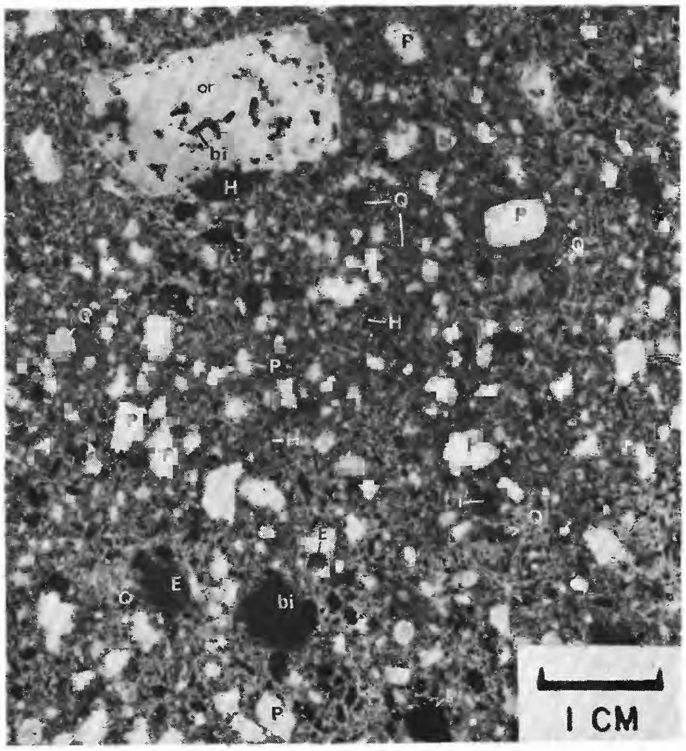


FIGURE 30.—Quartz monzonite porphyry from dike. Quartz, Q; biotite, bi; epidote, E; hornblende, H; poikilitic orthoclase porphyroblast, or; plagioclase, P.

TABLE 14.—*Analyses, norms, and modes, in percent, of quartz monzonite porphyry dikes*—Continued

[ng, not given; nd, not determined; Tr., trace (>0.3); ----, absent; A, abundant; C, common]

Modes

	1	5	6	7	8	9	10	11	12	13	Avg. 1, 5–13
Matrix	42	53	51	55	52	72	55	60	58	52	55
Quartz	21?	A	A	A	A	A	A	A	A	A	----
Orthoclase	19?	A	A	(3)	A	A	A	A	A	A	----
Chlorite	2.4	C	1.3	----	C	A	C	Tr.	Tr.	C	----
Sericite	----	Tr.	----	C	C	A	C	C	Tr.	C	----
Kaolinite	----	----	----	A	C	----	Tr.	----	Tr.	C	----
Major phenocrysts:											
Quartz	Tr.	2.1	1.1	2.4	10	5	6	4.7	Tr.	2.1	3.3
Orthoclase	9	9	1.4	(3)	1.9	Tr.	1.2	1.7	----	.7	nd
Plagioclase	43	25	39	[4] 38	23	[5] 18	27	29	29	38	31
Maximum An	nd	An_{32}	An_{45}	nd	nd	nd	nd	An_{32}	An_{37}	An_{40}	nd
Hornblende	.5	[6] 2.0	[6] 1.7	[6] Tr.	1.7	.8	.7	Tr.	3.7	4.8	1.6
Biotite	2.8	[6] 3.7	[6] 3.7	[3] .8	4.0	1.0	2.1	Tr.	2.2	1.0	2.2
Accessory minerals:											
Magnetite	.5	.8	.3	.7	.6	----	Tr.	Tr.	Tr.	.6	Tr.
Sphene	Tr.	.4	Tr.	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Apatite	Tr.	.3	.3	nd	Tr.	Tr.	----	Tr.	Tr.	1.0	Tr.
Allanite	Tr.	Tr.	Tr.	----	----	Tr.	----	Tr.	----	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	----	----	Tr.	Tr.	Tr.	Tr.	----	Tr.
Alteration minerals:											
Epidote group	1.9	[7] 1.0	[7] .5	----	5	----	6	Tr.	2.9	C	----
Calcite	Tr.	.3	Tr.	----	----	----	A	C	C	2.5	----
Sericite	----	----	----	A	A	A	A	C	C	A	----
Clay	Tr.	----	Tr.	A	C	----	Tr.	Tr.	----	Tr.	----
Albite	Tr.	----	Tr.	----	----	----	----	Tr.	C	Tr.	----
Chlorite	2.4	[7] 1.7	[7] .3	----	2.3	C	2.1	C	Tr.	1.0	----
Leucoxene	Tr.	----	----	Tr.	----	Tr.	----	Tr.	Tr.	Tr.	----
Quartz	Tr.	----	Tr.	----	C	C	C	Tr.	2.6	Tr.	----
Pyrite	----	----	----	C	C	2.9	.5	C	Tr.	----	----
Limonite	C	----	----	C	C	----	----	Tr.	Tr.	----	----
Orthoclase	----	----	Tr.	----	C	(5)	C	Tr.	.5	----	----

[1] Analysis by L. D. Trumbull.
[2] Analyses by E. F. Cooley. Sn <10, Ge <20, Ga <5, As <1,000, In <10, Cd <50, Bi <10, Tl <100, Sb <200, W <100, Nb <50, Ta <50.
[3] Completely altered to kaolinite.
[4] Completely altered; 28 percent sericite; 10 percent kaolinite and illite.
[5] Orthoclase replaces plagioclase phenocrysts.
[6] Altered completely to epidote, chlorite, and calcite.
[7] In addition to amounts in altered biotite and hornblende.

SAMPLE DESCRIPTION

1. Field No. I-PQM; lab. No. 53-1982CD. 1634 footwall drift, 1600 level, Groundhog mine; 1,560-point count.
2. Average hornblende-biotite adamellite (Nockolds, 1954, p. 1014).
3. Field No. 58-As-116; lab. No. 59-80S. Dike in Santa Rita stock.
4. Field No. 58-As-119; lab. No. 59-84S. Same as No. 3.
5. Field No. HC-9-50. 17 footwall drift, 1800 level, Groundhog mine; 2,200-point count.
6. Field No. HC-7-57. 1634 drift, diamond-drill hole 1048, along 4600 section, Groundhog mine; 2,400-point count.
7. Field No. HC-17-50. 400 feet N. 21° E. of top of Lee Hill, near Chino pit; 1,550-point count.
8. Field No. HC-18-50. 900 feet S. 60° W. of engineering-office site on island, as of 1953; 2,400-point count.
9. Field No. HC-18-51. In Chino pit, 5900 bench; contains pyrite and chalcopyrite.
10. Field No. JC-9-57. In southwest corner of south Chino pit, deepest level; 1,900-point count.
11. Field No. HC-12-49. Thin dike in Hanover Creek, 1,820 feet S. 22½° W. of Hanover Schoolhouse; 1,650-point count.
12. Field No. HC-10-50. 1,700 feet S. 23° E. of top of Humbolt Mountain; 1,850-point count.
13. Field No. JC-5-52. 30-foot-wide dike, 5,600 feet S. 4° W. of Hanover Mountain.

Euhedral to subhedral andesine (An_{26-45}) constitutes on the average about 30 percent of the rock, and it ranges from 23 to 43 percent of volume in the 10 sections analyzed; the crystals as a whole probably have the composition of sodic andesine. These phenocrysts range in maximum dimension from a fraction of a millimeter to about 8 mm, but most are about 2–4 mm long.

The percentage of quartz phenocrysts and orthoclase porphyroblasts given in modal analyses is too variable to be representative of large volumes of the rock. The variability is attributable to the relatively large size and the sparse distribution of the crystals, and to a tendency for quartz to occur in clusters. In spite of the small amount of quartz in certain thin sections, it forms conspicuous phenocrysts in hand specimens and probably makes up, on the average, about 5 percent of the rock. The quartz phenocrysts are as much as 7 mm in diameter; some are rounded and embayed, but well-formed dipyramids are common and tend to occur in clusters. Overgrowths of secondary quartz are evident in many thin sections. In contrast to the estimated amount of quartz, orthoclase porphyroblasts constitute probably less than 1 percent of the rock; the greater amount in some thin sections is due to the size of the porphyroblasts, which may be as much as 20 mm long. The porphyroblasts poikilitically enclose other phenocrysts, some of which are still unaltered, although those outside the porphyroblasts are completely altered. The orthoclase porphyroblasts are difficult to detect on weathered surfaces because they blend in with the groundmass. Biotite and hornblende phenocrysts together constitute about 3–6 percent of the average fresh rock.

Biotite is more abundant than hornblende in most specimens, but the reverse is probably true locally and is unquestionably true in marginal facies; the ratio of the two is therefore not considered diagnostic of the rock. In most sections both biotite and hornblende are completely altered, principally to chlorite, and many primary mafic minerals have undoubtedly been destroyed where alteration has been exceptionally severe. The biotite crystals are generally 1–2 mm in diameter, and their shapes range from barrels to books to plates, depending on the dimension normal to cleavage, which may be as great as 8 mm or as little as a fraction of a millimeter. Hornblende occurs as both stubby and acicular crystals; the stubby ones are generally 4–5 mm long and 1 mm across, and the acicular ones are commonly as much as 7 mm long and 1–2 mm across, though most occur as very small needles. Slender prisms of allanite and apatite and wedge-shaped crystals of sphene, all as much as 4 mm in length, are common. Magnetite or pyrite is usually disseminated throughout the rock.

The alteration of the various quartz monzonite porphyry dikes is similar to that of the older rocks. Biotite and hornblende were the most susceptible to alteration fluids, and even in rock in which plagioclase is nearly fresh these mafic minerals are pseudomorphically replaced by chlorite and epidote or zoisite, and less commonly by calcite and orthoclase. Fresh hornblende or biotite occurs rarely except within feldspar porphyroblasts; hence, chloritization of the mafic minerals followed the growth of the porphyroblasts. In some altered rock the chlorite-epidote pseudomorphs after biotite are converted to a white mica with segregations of iron oxide and leucoxene. In a specimen from a dike near Humbolt Mountain, much of the hornblende is unaltered, some is chloritized, and some has been partly converted directly to clay. In the same rock, biotite has been converted to chlorite and epidote, and plagioclase is clouded with clay; all other phenocrysts are relatively fresh, and the rock contains disseminated pyrite. Secondary biotite, pseudomorphic after hornblende, is rare in these dikes. Also these dikes are nowhere pervasively epidotized or chloritized, as are the granodiorite porphyry dikes in areas where carbonate rocks were silicated. Either large-scale silication and related metalization preceded the intrusion of the quartz monzonite porphyry dikes, or the dikes were not sheared at the contacts nor internally ruptured, as were the older rocks, and hence did not provide channelways for the earliest hypogene solutions.

In the Santa Rita area, however, the quartz monzonite porphyry dikes were fractured and cut by fissures, but the alteration consisted of bleaching and of formation of pyrite and some chalcopyrite. Plagioclase phenocrysts are altered to various clay minerals, sericite and calcite, and, rarely, orthoclase and chlorite. The interior of the quartz monzonite dikes cutting the Santa Rita stock is generally much less altered than the stock rock. The margins of the dikes, however, are bleached and argillized, presumably by supergene acid solutions. Sparse seams of quartz, pyrite, sphalerite, and galena occur in these dikes in the Ivanhoe, Groundhog, and Kearney mines.

In one dike in the Lee Hill area the orthoclase phenocrysts and the orthoclase of the matrix are completely altered to kaolinite, presumably directly, whereas the plagioclase phenocrysts are still largely sericite and quartz and are only partly altered to illite and kaolinite.

Chemical composition

A chemical analysis of quartz monzonite porphyry is given in table 14 along with the average chemical composition of 41 hornblende-biotite adamellites by Nockolds (1954, p. 1014). In the two normative diagrams (fig. 13, point 13; fig. 15, line 10), the plots indicate a granodioritic rather than a typical quartz monzonitic composition. Actually, the rock seems to be intermediate between these two standard types.

Classification of the dikes as quartz monzonite rather than granodiorite is based on the estimated mode but is somewhat arbitrary. Staining of hand specimens and thin sections shows that much of the matrix, which averages 53 percent of the rock volume, is potassic feldspar; therefore, the total amount of potassic feldspar in the rock is probably about equal to the average plagioclase content (30 percent), and the rock is therefore classified as quartz monzonite. Furthermore, the dikes appear more felsic than most of the granodiorite porphyry dikes, and a clear distinction in name between the two dike swarms is desirable.

QUARTZ LATITE PORPHYRY DIKES

GENERAL FEATURES

Emplacement of the quartz monzonite porphyry dikes was followed by injection of quartz latite porphyry, forming dikes and irregular plugs within a radius of 1.5 miles of Bull Hill, near Hanover. The irregular plugs are exposed at the southeast margin of the Hanover Hole, partly within its margins and partly in the surrounding rock. Two north- to northeast-trending dike swarms include most of the dikes of the group (fig. 47*C*); one swarm lies within half a mile of the northwest margin of the hole, and the other passes through the south lobe of the Hanover-Fierro pluton.

In general, the outcrop pattern of the individual dikes is not as complex as that of the dikes in the two older groups. However, the younger dikes also change course abruptly along strike and presumably down dip, and some end abruptly and then continue en echelon. Some dikes have sill-like shelves projecting into the sedimentary host rock. The wallrock and the marginal parts of the dikes are commonly brecciated, the breccia fragments consisting of both dike rock and host rock.

The larger masses of quartz latite porphyry, and a few of the dikes, are largely homogeneous from wall to wall, but in most dikes the interior is distinctively different from the margins in texture and in mineral composition. The transition between the two facies is gradational in most dikes, but is sharply delineated in a few. Some of the sharply delineated dikes are known to cut those showing the gradational change, in sec. 15, T. 17 S., R. 12 W., west of the Copper Queen shaft. In some dikes having well-defined marginal zones, the internal facies has in places stoped or intruded the marginal facies. As the internal facies does not continue laterally beyond the dark borders, and as the borders are in general symmetrically disposed with respect to the internal facies, no appreciable length of time intervened between the consolidation of the two facies.

The rock of the internal facies is typically a light-colored fine- to medium-grained andesine-biotite-quartz latite porphyry which has a very fine grained felsic matrix, whereas the rock of the marginal facies is a gray to black fine-grained hornblende-andesine porphyry which has a cryptofelsitic or glassy matrix. (See fig. 31.)

The matrix constitutes 50–70 percent of the internal facies and 60 to almost 90 percent of the border facies.

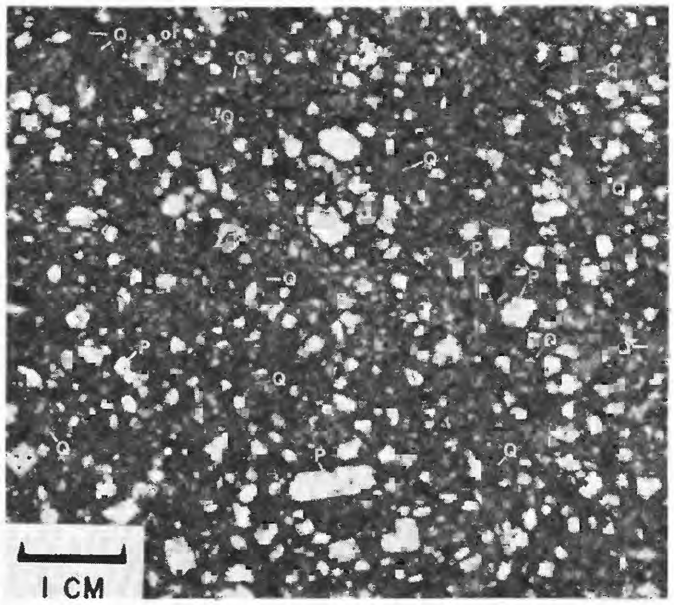
The major phenocrysts and their range in abundance in the internal facies are:

	Volume percent
Andesine (An_{30-47})	20–42.
Quartz	3–13; average about 9.
Orthoclase	$<$1–3.
Biotite	1–5.
Hornblende	$<$1–3; average $<$1.

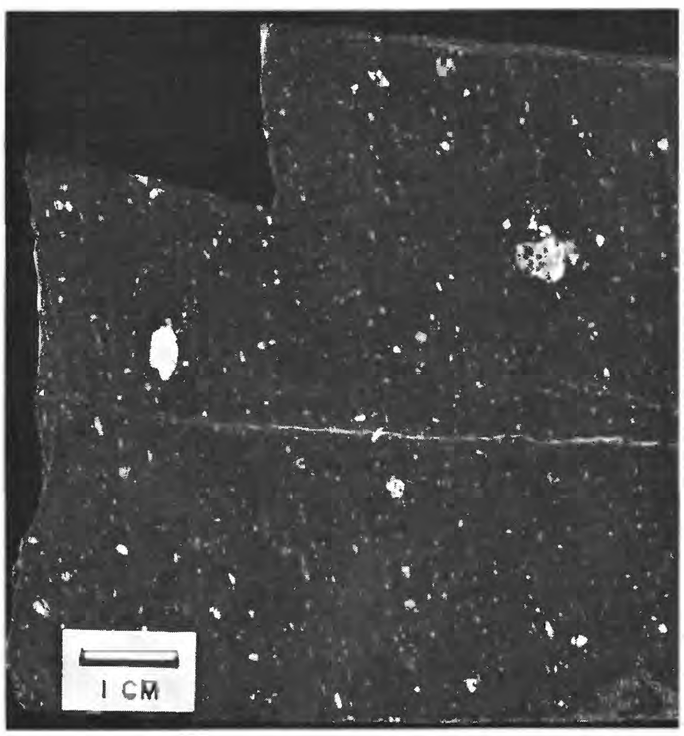
Apatite, magnetite, and sphene are present as megaphenocrysts, but none of them constitute more than a fraction of 1 percent. Microphenocrysts include zircon, sphene, and allanite; sphene and allanite are recognized in only a few dikes.

The phenocrysts range in size from 0.1 mm to about 10 mm, except for poikilitic orthoclase porphyroblasts, which are commonly 2 cm long. The average grain size of the rock is about 1–2 mm.

Quartz phenocrysts occur as small dipyramids, wedge-shaped slivers, and deeply embayed grains or partly absorbed rounded grains. All forms commonly contain many inclusions, some of which are probably rutile. Andesine is present as subhedral to euhedral grains showing zoning and albite twinning. Hornblende is sparse; it occurs as needles or stubby euhedra. Biotite forms small and large flakes, thin books, or thick books whose ratio of thickness to diameter is commonly 3 : 2 or, rarely, 2 : 1.



A



B

FIGURE 31.—Quartz latite porphyry dike 1 mile north of Pewabic mine. *A*, Internal facies. Quartz, Q; plagioclase, P; orthoclase, or; most black phenocrysts are biotite. *B*, Marginal facies. White phenocrysts are plagioclase; dark matrix is largely hornblende alined normal to surface of specimen.

The border facies consists predominantly of gray fine-grained to aphanitic rock in which andesine and acicular hornblende predominate. Crystals of quartz and biotite are sparse in the border facies of most dikes, but apatite is as abundant in the border facies as in the internal facies.

None of the quartz latite porphyry intrusions have had any obvious metamorphic effect on the wallrock (fig. 10), but the intrusions themselves are in general pervasively altered and contain much disseminated pyrite or magnetite. The absence of megascopic epidote in these rocks helps to distinguish them from older intrusions; however, some epidote has been identified microscopically in the marginal facies of two of the dikes, and field relations indicate that these two dikes are the oldest of the quartz latite group.

In general, the rocks are extensively altered; the more severe alteration appears to be coextensive with remnants of abundant disseminated pyrite. As much of the pyrite oxidized to limonite, acid solutions formed and percolated downward and reacted with the rock previously altered by late magmatic or hypogene hydrothermal fluids. In some dikes the supergene acids leached calcite, formed during the earlier hydrothermal alteration, and at the same time converted sericite to illite, and the latter, in turn, to kaolinite.

The earlier, hypogene hydrothermal alteration also resulted in bleaching and was characterized by the formation of copious calcite, sericite, pyrite, and quartz. Biotite and hornblende were almost completely altered to chlorite and white mica. Pseudomorphs of finely crystalline biotite after hornblende or biotite phenocrysts have been recognized in a few dikes.

In spite of crosscutting relations in several places, the relative ages of the numerous dikes and plugs within the quartz latite porphyry group are imperfectly known. Two dikes predate the formation of the Hanover Hole; others may, but this cannot be proved because they do not intersect the margin of the hole. These two older dikes will be described separately; the southern dike is referred to as the Turnerville dike system, and the northern dike as the Republic dike system. The general nature of the remaining dikes, most of which are probably younger than the Hanover Hole, has been described, and the specific nature of many of the dikes is given in table 15. The plugs and apophysal dikes that intrude the hole at its southeast margin are described on pages 91–92).

REPUBLIC DIKE SYSTEM

Extent

The five en echelon dikes that extend eastward from near Hanover to the foot of Topknot Hill, a distance of about 7,000 feet, constitute the Republic dike system. Individual dikes are, in general, about 50 feet wide, but one swells to 140 feet wide at its west end before ending abruptly against the Hanover Hole. Its continuation beyond the hole is in doubt. West of the hole are several dikes of quartz latite porphyry, and if one of these is to be interpreted as an extension of the Republic dike system the most logical choice is the one that extends a short distance west-southwest from the hole and then turns southwestward across Gooseneck Hill. If this dike is a true extension of the Republic dike system, the overall length of the system was originally 12,800 feet.

Petrography

The rock of the Republic dike system and of its possible extension in Gooseneck Hill is zoned parallel to the contacts. The marginal zones are about 30 inches thick, and the transition to the internal zone is gradational. The marginal zones are gray where fresh, in contrast to the rusty or creamy-white internal zones; also, they are finer grained and contain fewer phenocrysts, most of which are plagioclase and acicular hornblende. Marginal zones contain inclusions of wallrock and show strong fluxion banding. In this dike system the marginal zones contrast so strikingly with the interior that they appear at first glance to be later intrusions.

The internal facies of the Republic dike system is a creamy-white andesine-biotite-quartz latite. The essential phenocrysts, which constitute a little less than half the rock volume, are andesine (An_{40}), quartz, orthoclase, and biotite; biotite, though, is little more than an accessory mineral in many specimens. Apatite, zircon, and rutile are the only accessory minerals recognized. Secondary minerals are calcite, chlorite, sericite, hydromica, secondary green biotite, leucoxene, clay, and pyrite; the pyrite forms abundant minute cubes but is largely altered to limonite. The matrix, which is light colored and cryptocrystalline, consists largely of potassic feldspar and contains minor quartz. (Mode is given in table 15 (No. 1).)

The andesine phenocrysts are euhedral to subhedral and as much as 3 mm long; most, however, are 1–2 mm long. Several of the larger grains poikilitically enclose rounded grains of quartz and fresh biotite. Most andesine grains are completely altered to aggregates of plumose sericite and patches of calcite.

Quartz is present as small dipyramids, deeply embayed grains, and wedge-shaped fragments. The grains range in diameter from 0.1 to 8 mm; most are less than 0.5 mm. Quartz is not altered, and some grains contain a few thin rods of rutile(?).

TABLE 15.—*Modes, in volume percent, of quartz latite porphyry dikes and plugs*

[nd, not determined; Tr., trace (<0.3); ----, absent in thin section; C, common; A, abundant]

	1	2	3	4	5		6	7	
	HC-19-50	HC-19a-50	HC-15-50	HC-3-51	HC-13-49	Avg 3-5	HC-8-50	HC-3-49	Avg 6, 7
Matrix	53	87	53	48	52	51	68	58	63
Major phenocrysts:									
Quartz	9	Tr.	13	12	9	11	2.4	.8	1.6
Orthoclase	2.3	----	1.0	3.9	1.8	2.2	----	----	----
Plagioclase	32	6	31	31	34	32	30	36	33
Maximum anorthite	An_{40}	[2] nd	nd	An_{38}	nd	nd	nd	nd	nd
Hornblende	.6	4.6	----	Tr.	----	Tr.	(2)	.7	Tr.
Biotite	2.0	.3	1.2	2.7	2.5	2.1	(2)	4.8	Tr.
Accessory minerals:									
Magnetite	----	----	----	----	----	----	----	Tr.	Tr.
Sphene	----	----	----	----	----	----	----	Tr.	Tr.
Apatite	Tr.	Tr.	Tr.	Tr.	----	Tr.	----	----	----
Zircon	Tr.	----	----	----	----	----	----	----	----
Rutile	Tr.	----	Tr.	Tr.	----	Tr.	----	----	----
Alteration minerals:									
Epidote group	----	.8	----	----	----	----	----	----	----
Calcite	A	----	A	----	----	C	----	----	----
Sericite	A	Tr.	A	A	C	A	Tr.	C	Tr.
Illite	C	A	A	C	A	A	A	A	A
Clay-alunite	Tr.	C	C	C	C	C	A	C	C
Albite	----	----	----	----	----	----	----	----	----
Chlorite	Tr.	Tr.	----	Tr.	----	Tr.	----	----	----
Biotite	Tr.	----	----	Tr.	----	Tr.	----	----	----
Magnetite	Tr.	----	Tr.	C	Tr.	Tr.	Tr.	Tr.	Tr.
Leucoxene	Tr.	C	Tr.	C	C	C	----	C	Tr.
Sphene	----	----	----	----	----	----	----	----	----
Quartz	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Pyrite	1.4	1.1	Tr.	.9	.6	C	----	Tr.	Tr.
Limonite	Tr.	C	C	C	C	C	----	----	----
Jarosite	----	----	----	----	----	----	C	Tr.	Tr.

	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	HC-5-51	HC-6-51	HC-4a-51	HC-5-49	HC-4-51	HC-11-49	HC-1-49	HC-4-50	HC-8-51	HC-11-50	HC-11a-50	HC-17-51	JC-10-57	HC-12-51	HC-12a-51	HC-9-51	HC-9a-51
Matrix	60	62	64	65	62	50	49	44	84	57	61	63	57	66	75	63	66
Major phenocrysts:																	
Quartz	3.0	4.1	9	3.2	8	12	8	9	Tr.	12	11	[1] 1.8	13	5	2.3	4.7	3.3
Orthoclase	----	----	2.0	----	2.6	1.8	Tr.	.6	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Plagioclase	32	23	20	25	23	34	36	42	10	25	25	27	28	22	10	27	28
Maximum anorthite	nd	An_{42}	An_{40}	An.,	An_{40}	An_{40}	An_{40}	nd	nd	An_{40}	An_{37}	An_{47}	An_{37}	An_{44}	nd	An_{40}	nd
Hornblende	1.3	.6	.5	1.3	(2)	.4	.6	Tr.	7	.1	----	[3] 2.7	----	Tr.	3.9	[4] Tr.	Tr.
Biotite	2.0	2.5	1.8	2.9	3.2	2.5	2.8	1.6	.2	3.6	1.9	3.8	1.7	4.0	7.5	3.4	1.6
Accessory minerals:																	
Magnetite	.4	.6	Tr.	Tr.	Tr.	.3	Tr.	----	----	----	----	.4	----	----	----	.4	.6
Sphene	Tr.	----	Tr.	Tr.	----	Tr.	Tr.	Tr.	----	Tr.	----	Tr.	Tr.	Tr.	Tr.	Tr.	----
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	.5	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Zircon	----	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	----	Tr.	Tr.
Rutile	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	----	Tr.	Tr.	Tr.	----	Tr.	----	----	Tr.
Alteration minerals:																	
Epidote group	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Calcite	A	4.9	2.0	Tr.	A	A	1.8	1.3	C	2.3	1.1	.7	Tr.	2.1	----	----	----
Sericite	A	A	C	C	A	A	A	Tr.	C	A	C	C	----	A	----	.4	A
Illite	C	C	A	A	Tr.	Tr.	Tr.	C	C	C	Tr.	A	Tr.	Tr.	C	----	C
Clay-alunite	Tr.	Tr.	C	A	Tr.	Tr.	----	A	C	Tr.	Tr.	C	----	Tr.	A	Tr.	C
Albite	Tr.	----	C	Tr.	----	----	Tr.	----	----	----	----	A	A	C	----	----	----
Chlorite	Tr.	Tr.	----	----	Tr.	Tr.	Tr.	Tr.	C	----	----	Tr.	Tr.	C	A	----	----
Biotite	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1.6	Tr.
Magnetite	Tr.	Tr.	Tr.	----	Tr.	----	Tr.	----	----	----	----	Tr.	----	----	----	Tr.	----
Leucoxene	C	C	Tr.	C	C	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	C	Tr.	Tr.
Sphene	Tr.	----	----	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	----	Tr.	----	Tr.	----
Quartz	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1.8	Tr.	.3	1.0	Tr.	.4	.6	.9	Tr.	----
Pyrite	----	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Limonite	Tr.	----	Tr.	A	Tr.	Tr.	Tr.	----	----	Tr.	Tr.	Tr.	C	C	C	----	C
Jarosite	Tr.	----	Tr.	----	----	----	----	----	----	Tr.	Tr.	Tr.	Tr.	----	Tr.	----	----

[1] Rock actually contains about 5 percent.
[2] Too altered for determination.
[3] Completely altered to kaolinite.
[4] Blocky hornblende replaced by biotite.

SAMPLE DESCRIPTION

1, 2. Republic dike system:
1. 1,200 feet N. 50° E. of top of Bull Hill; internal facies.
2. Same location as No. 1; border facies.

3-7. Turnerville dike system:
3. From dump of prospect pit, just southeast of Turnerville.
4. 80 feet NNW. of Turnerville; internal facies.
5. 1,500 feet S. 40° E. of southwest corner of cemetery at Turnerville.
6. 500 feet S. 31° E. of top of Lee Hill.
7. 430 feet N. 31° E. of Treasure Vault shaft.

8-24. Trevarrow plug:
8. Roadcut 1,000 feet east of crossroads at Wimsattville.
9. From depth of 693 feet in diamond-drill hole 48, U.S. Smelting and Refining Co.
10. Small plug in northeast side of Hanover Hole; internal facies.
11. Same plug as No. 10, 1,000 feet S. 20° W. of Oswaldo 1 shaft.

Trevarrow plug—Continued
12. Same plug as No. 11; border facies.
13. Dike 800 feet S. 14° E. of Oswaldo 1 shaft. Apophysis of Trevarrow plug.
14. Dike 400 feet south of Turnerville dike crossing.
15. Dike 1 mile S. 72° W. of Bull Hill; internal facies.
16. Same dike as No. 15; marginal facies.
17. Dike 4,650 feet due west of Bull Hill; internal facies.
18. Same dike as No. 17; marginal facies.
19. Dike in Buckhorn Gulch west of Empire Zinc Co. office; internal facies.
20. Dike in Hanover Creek north of Pewabic tramline; altered, internal facies.
21. Northeast-trending dike just east of Thunderbolt opencut; internal facies.
22. Same dike as No. 21; border facies.
23. Dike 1,900 feet S. 20° E. of Princess shaft; internal facies.
24. Same dike as No. 23; border facies.

Orthoclase is present as phenocrysts of two sizes: some are the same size as most of the andesine grains (1–2 mm long), and others are noticeably larger (as much as 3 cm long); most of the larger phenocrysts are poikilitic. One poikilitic crystal was observed in which a euhedral grain of hornblende, pseudomorphically replaced by finely crystalline biotite, was preserved. Orthoclase is generally fresh, but some grains show alteration to clay and calcite.

The biotite phenocrysts range in diameter from a fraction of a millimeter to 5 mm, and in thickness from thin plates, commonly bent, to books twice as long normal to cleavage as parallel to it. The biotite is commonly replaced pseudomorphically by chlorite.

The few phenocrysts of hornblende seen in the internal facies are all pseudomorphically replaced by secondary biotite or by chlorite.

Fresh apatite is present in considerable abundance both as small euhedral rods in the matrix and as large fragments of phenocrysts.

Pyrite cubes, generally less than 0.5 mm across, are disseminated throughout the rock and constitute about 1.5 percent of its volume.

In general, the rock has undergone a bleaching-type alteration, although the small volume of mafic constituents would suggest that it could never have been very dark. Epidote has not been recognized in the internal facies, but it is seen as a replacement of plagioclase phenocrysts in the marginal facies; it amounts to 0.8 percent of the area in the one section examined.

The marginal facies of the Republic dike system is darker than the internal facies; where unaltered it is gray, but it is generally altered to tan. It contains the same type of phenocrysts as does the internal facies, but the abundance of each type and the total abundance of phenocrysts differ markedly (table 15, sample 2); it is virtually a hornblende syenite. Biotite and quartz phenocrysts are rare, and the major phenocrysts, plagioclase and hornblende, constitute only 6.3 and 4.6 percent of rock volume, respectively. Apatite is the only accessory mineral. Secondary minerals include chlorite, calcite, sericite, illite, quartz, and epidote. The matrix is a fine-grained crystalline aggregate consisting largely of equant grains of potassic feldspar and some quartz.

Pyrite cubes, largely converted to limonite, are disseminated throughout the rock but are noticeably smaller—0.1 mm in diameter or less—than those in the internal facies.

The hornblende is altered, as in the internal facies. The plagioclase was too altered to permit optical determination of the anorthite content; the alteration products are sericite, illite, calcite, and minor amounts of epidote. The epidote is generally found at the margins of the hornblende grains, but it is also disseminated throughout the matrix.

TURNERVILLE DIKE SYSTEM

Extent and geologic relations

A composite dike which extends from near the settlement of Turnerville southeastward to near the northwest corner of the south Chino pit is here named the "Turnerville dike system." It is about 4,100 feet long and is about 500 feet wide in the northwestern half and 50–200 feet wide in the southeastern half.

The Turnerville dike was not distinguished by earlier workers. The so-called "Lucky Boy Intrusive" as outlined by Kerr, Kulp, Patterson, and Wright (1950, pl. 11) includes part of the dike's wide western segment as well as an assortment of older sills, dikes, and sedimentary rocks. The dike traverses an area in which all the sedimentary rocks and included sills are thoroughly brecciated and altered; hence, any alteration in its wallrocks due to the Turnerville dike is not distinguishable.

Petrography

The rock of the wide northwestern part of the Turnerville dike is so unlike the rock of the narrow southeastern part that the two facies are differentiated on the map and will be described separately. Neither the wide nor the narrow part has chilled margins, nor is there a noticeable change in mineral content or abundance toward the contact.

The rock in the wide part is a light-creamy-gray fine-grained quartz latite which has a granular aspect in hand specimen. When viewed through a microscope, however, the rock's decidedly porphyritic texture is apparent. In a typical thin section, phenocrysts of oligoclase-andesine, quartz, orthoclase, and biotite constitute about 50 percent of volume and are set in a cryptocrystalline matrix which stain tests indicate is largely potassium feldspar. Accessory minerals include apatite, magnetite converted mainly to pyrite, possibly sphene as small irregular grains, rutile(?) largely within phenocrystic quartz, zircon, and sparse stubby phenocrysts of hornblende. Secondary minerals, common in even the least altered specimen, include pyrite, calcite, orthoclase, sericite, hydromica, clay, chlorite, biotite, leucoxene, limonite, and jarosite. Several grains of epidote were identified in one specimen, but in general epidote is absent from thin sections and surface exposures.

Oligoclase-andesine phenocrysts constitute about a third of the rock (table 15, samples 3, 4, 5). They are euhedral to subhedral and range in length from a fraction of a millimeter to 3 mm; most are 1–2 mm long. The maximum anorthite content ranges from 35 to 38 percent and is as low as 10 percent in parts of some grains; however, in some specimens the composition could not be determined because the specimens were completely altered.

Quartz phenocrysts, which are second in abundance, constitute 8–13 percent of the rock and are present as small dipyramids (< 0.4 mm across), as irregular embayed grains, and as wedge-shaped fragments. The grains range in maximum dimension from 0.1 to 3 mm; most are less than 1 mm. Most grains contain a few elongate needles of rutile and minute stubby crystals believed to be zircon.

Orthoclase is present as euhedral grains 1–2 mm long and as poikilitic porphyroblasts measuring 2 cm by 1.5 cm. This orthoclase probably does not constitute more than 4 percent of the rock, but stain tests and examination of thin sections under high magnification indicate that about two-thirds of the matrix is potassic feldspar; the total content thus equals or exceeds the plagioclase content.

Biotite, as thin plates and thick books as much as two times longer normal to cleavage than parallel to it, is present in amounts ranging from about 1 to 3 percent of the rock. Most of the biotite crystals are 1 mm in diameter or less, but a few are 5 mm, and barrel-shaped grains commonly measure 3 mm by 1.5 mm. Many flat plates of biotite are bent or broken. In all but one section examined, the biotite was completely altered, generally to chlorite and white mica containing interleaved minute grains of opaque to semiopaque material—magnetite, sphene, or leucoxene. Biotite is partly recrystallized to finely crystalline biotite in specimens showing mild alteration.

Hornblende was noted in hand specimens and outcrops as stubby grains measuring about 2 mm by 4 mm. Microscopic examination of these grains revealed that they are pseudomorphically replaced by two or more minerals, one of which is probably diabantite, a type of chlorite, and the other hydromica.

The rock is typically affected by the bleaching type alteration characterized by the formation of various clay minerals, sericite, secondary quartz, and disseminated cubic pyrite. Plagioclase phenocrysts are typically clouded with clay and flecked by wisps of tan to white mica, some of which is true sericite but much of which lacks the high birefringence and wide optic angle of sericite.

Irregular grains of quartz form an aggregate with the tan and white mica; the aggregate commonly has the sharp outline of the original plagioclase crystal. In one of the least altered sections of rock (table 15, sample 4), finely crystalline biotite pseudomorphically has replaced hornblende and parts of primary biotite phenocrysts as well. The orthoclase phenocrysts are altered very little, except for a slight dusting of clay. Calcite seems to be less abundant in the Turnerville dike than in many altered rocks both younger and older.

The narrow part of the dike is intensely altered; that the alteration was partly caused by acid supergene waters is indicated by the local destruction of pyrite, which normally forms with the argillic-sericitic alteration, and by the abundance of yellow jarosite, which occurs as films on joints and as disseminated aggregates. Veinlets of quartz, quartz-alunite, and quartz-chalcopyrite-pyrite in which the sulfides are generally oxidized are found locally. The rock of the narrow southeastern segment contains abundant small white pseudomorphs of feldspar, sparse tan pseudomorphs of biotite, and, in contrast with the northwest segment, relatively few quartz phenocrysts. (See table 15, samples 6, 7.)

Modal analyses of two specimens show that phenocrysts, which appear to be so abundant megascopically, constitute only about 37 percent of the rock. Sericite-clay pseudomorphs after feldspar predominate, constituting 30–36 percent of the rock; the feldspar was presumably a plagioclase, but no unaltered grains were seen. Argillic pseudomorphs after biotite amounted to nearly 5 percent of volume in one specimen but were absent from a thin section of a more intensely altered specimen. Quartz phenocrysts in the two thin sections averaged 1.6 percent of volume, and this amount agrees with estimates based on inspection of several hand specimens. The matrix seems to consist mainly of interlocking quartz grains which contain much yellow crystalline material, either jarosite or alunite. The matrix is much coarser grained than that of the wide part of the dike.

Rock from the southeastern part of the Turnerville dike is largely altered to a degree corresponding to that of advanced argillic alteration of the Santa Rita stock. The specimens studied were collected from surface exposures, and they show the effects of both hypogene and supergene alteration. A churn-drill hole whose collar is within the dike on Lee Hill and that apparently continues in the dike penetrated disseminated chalcocite that may have been derived by supergene alteration of chalcopyrite in higher parts of the dike and in other rocks.

CONGLOMERATE OF EARLY TERTIARY AGE WEST OF WIMSATTVILLE

The shallow topographic basin lying just south of Hanover, N. Mex., coincides with an elliptical caldera-like hole of uncertain origin which is about 1 mile long and half a mile wide. This hole, here termed the "Hanover Hole," formed and was filled after the main episode of metalization and during the time of intrusion of the quartz latite porphyry dikes. The origin of the Hanover Hole is discussed in the section "Structure." In this section the lithologic character of the material that fills the hole is described.

The exposed clastic material that fills the hole does not contain pyroclastic or other type of volcanic rock. The filling within 100–300 feet of the periphery of the hole is characterized by complete lack of bedding and little, if any, sorting; it includes angular and subangular fragments and massive blocks of rock whose lithology depends on the type of wallrock nearby. The margin of the hole is sharply delineated in some places, but in others, sections of the wallrock have slumped into the hole. This marginal facies of the filling is an accumulation of blocks and fragments derived from scaling of the steep walls of the hole.

The internal facies now exposed was deposited in a sumplike hole by runoff from the surrounding drainage area. The rocks have good to crude bedding, local cross bedding, abrupt changes in size of material from bed to bed, and crude to fair sorting within individual beds (fig. 32); grains and pebbles are well rounded. Dips and strikes were measured where possible but could not be determined in some thick beds of unsorted material. The sedimentary rocks are chiefly arkosic sandstone, conglomerate, and graywacke. Pebbles derived from the Paleozoic and Cretaceous formations and from igneous rock as young as certain quartz latite dikes were identified. In addition, there are pebbles of skarn and tactite, magnetite, altered pyritic rocks, quartz, and pyrite. The matrix of the conglomerate and the sandstone contains smaller fragments of the same material, but the finer grained material seems to be more arkosic. Microscopic examination of a few thin sections of rocks exposed at the surface did not reveal any glassy or tuffaceous grains. If pyroclastic material was deposited around the rim of the hole, it must have been eroded and carried into the deepest part of the hole, or away from the rim. The depth of the sedimentary filling is unknown, but it is at least 1,100 feet in a deep drill hole just north of the Princess mine. Elevations measured at the surface indicate that the layers form an asymmetrical syncline whose axis trends northwest, parallel to but a few hundred feet south of the long axis of the elliptical hole. Strikes in the bedded facies roughly parallel the nearest margin of the hole, but there are many exceptions near the east and west margins. Layers within the wide north flank of the syncline dip 40°–55° S. in many places, but locally they dip only as much as 30° S. At the east margin of the fill the dips are nearly vertical.

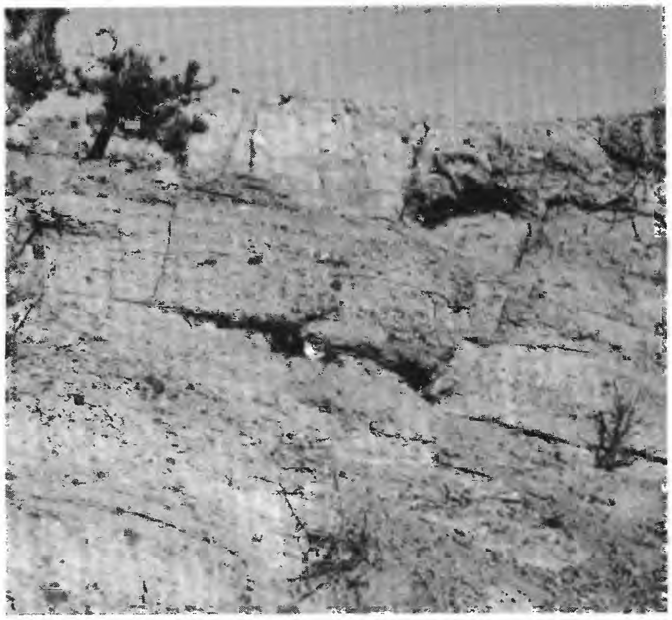


FIGURE 32.—Crudely sorted conglomerate in Hanover Hole, east bank of railroad cut, 1,300 feet southeast of Bull Hill. Compass shown for scale.

Layering in the west half of the syncline's south flank dips 55°–70° N.; the east half of its south flank is largely covered with alluvium, and attitudes cannot be seen. Although compaction of the layers may account for part of the downwarp in the basin fill, the authors believe that the basal support of the sedimentary column must have withdrawn, perhaps while the sedimentary filling was still saturated with water.

The sedimentary rock that fills the Hanover Hole is more easily eroded than are the adjacent Paleozoic and Mesozoic sedimentary rocks, and consequently the hole is marked by a topographic basin.

Relative age

The filling does not contain fossils, and its geologic age is known only in relation to the sequence of igneous intrusions. The exposed beds are almost certainly younger than the two Tertiary dikes — the Turnerville and Republic dikes (pl. 1) — though beds older than these intrusives could exist far below the surface. After the sediments were consolidated to such a degree that through-going fractures could be formed, the filling was invaded by dikes and plugs of the quartz latite and rhyodacite groups. The plugs crop out near the walls of the basin, and the dikes cross the basin generally parallel to its short axis.

Pebbles of mineralized material are strong evidence that the main episode of mineralization preceded deposition of the exposed part of the filling. The filling is, however, somewhat altered in places, particularly north of the Blackhawk (Combination) mine. A few joints in specimens of dump rock taken from a drift of the Blackhawk mine are thinly coated with pyrite, and one specimen contains a little sphalerite and galena. A few thin slabs of amethystine quartz from narrow veins were found in the mildly altered western part of the fill. This type of later noncommercial mineralized rock is also known along the dike system a mile west of the Hanover Hole.

The Hanover Hole formed near the west margin of a large brecciated and mineralized area. (See fig. 43.) This mineralized breccia adjacent to the hole should not be confused with the talus breccia that makes up the marginal facies within the hole.

The general aspect of the layered rocks has led some previous geologists to correlate them with the gravel, sand, and tuff of the Sugarlump Tuff, which underlies the massive rhyolitic tuffs in the southern part of the quadrangle. The Sugarlump Tuff, however, has many glass-bearing tuffaceous beds, including beds of pumice; the exposed part of the filling in the Hanover Hole, in contrast, does not contain pumice or, apparently, any type of glass. The conglomeratic filling is more like the detrital beds of the Rubio Peak Formation; however, it is cut by numerous Tertiary intrusives which are conspicuously absent from the Rubio Peak Formation and from the Sugarlump Tuff. These facts indicate that the filling in the Hanover Hole predates the Miocene(?) volcanism.

DIKE SWARMS AND PLUGS OF EARLY TERTIARY AGE

TREVARROW PLUG AND APOPHYSES

Introduction

The plug of quartz latite porphyry with a tear-shaped outline (disregarding the alluvial cover) which lies just east of Wimsattville is called the Trevarrow plug. Its outcrop measures 2,000 feet in a north-northwesterly direction, and its maximum width near the southern end is about 1,000 feet. Three irregular dikes appear to radiate from the plug and extend north, northeast, and south-southwest for about 4,000, 2,000, and 3,000 feet, respectively. The small plug just northeast of the junction of the Wimsattville road and State Highway 90 is apparently identical with the Trevarrow and may be connected with it at depth.

The plugs and apophyses are in general deeply weathered and mantled with soil except where erosion has been relatively rapid. Their outcrops are in most places eroded below the level of the surrounding rock.

Flow structures well within the Trevarrow plug and fluxion banding and highly irregular contacts against the host rock in the darker chilled margins of the dikes have been noted.

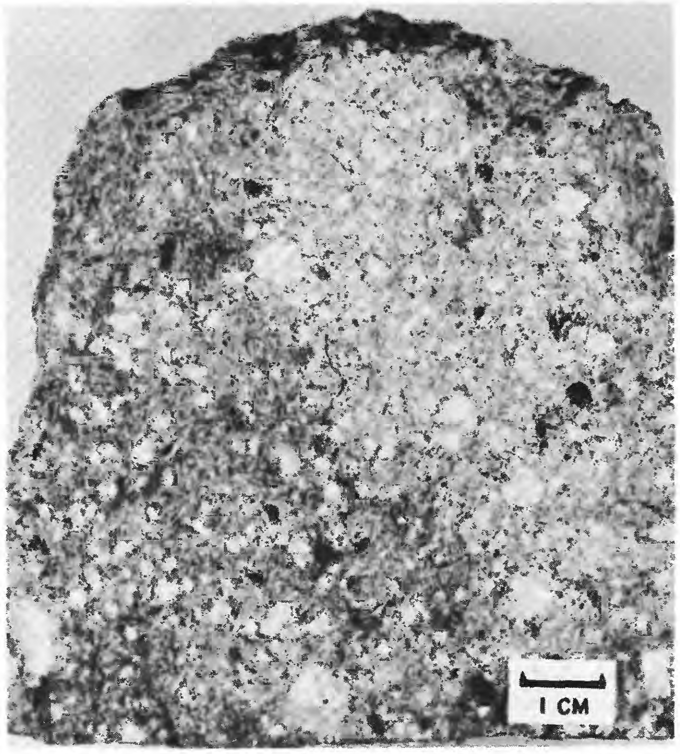


FIGURE 33.—Quartz latite porphyry from Trevarrow plug. Dark phenocrysts are chloritized hornblende and biotite. White phenocrysts are altered plagioclase. (See mode of sample 8, table 15.)

Petrography

The rock of the Trevarrow plug and its apophyses is a fine- to medium-grained andesine-biotite-quartz latite porphyry. (See fig. 33.) About 35–50 percent of the rock consists of phenocrysts of andesine, quartz, biotite, orthoclase, hornblende, magnetite or pyrite, and apatite, named in order of decreasing abundance. These phenocrysts are set in a fine-grained holocrystalline matrix of orthoclase and quartz. Microphenocrysts include apatite, zircon, sphene, and rutile. Differences in abundance of the constitutents in the main plug, its apophyses, and the small plug south of the Oswaldo 1 shaft are apparent from the modal analyses given in table 15, (samples 8–14), which are based on point counts of two slides from each body. The main differences summarized below seem to be in the total percentage of phenocrysts and in the relative percentages of quartz and andesine phenocrysts. No differences are revealed in the total mafic content; biotite is consistently about six times as abundant as hornblende.

	Total percent phenocrysts	*Percent quartz (1–8 mm)*	*Percent anaesine (1–10 mm)*	*Percent major mafic silicates (chiefly biotite) (1–5 mm)*
Trevarrow plug	39	4	28	3
Small plug	36	7	24	3
Dike apophyses	51	11	35	3

The white andesine phenocrysts range in maximum dimension from a fraction of a millimeter to 10 mm; most are about 1 mm long, many are 5 mm long, and very few are 10 mm long. The porphyritic aspect of the rock is due to the contrast of the phenocrystic andesine with the greenish-tan nearly aphanitic matrix.

The alteration of the rock and its constituents is identical with that in the internal facies of the Republic dike system described on preceding pages. Numerous tiny spots of epidote were noted in the chilled margins of the Trevarrow plug in the roadcut on State Highway 90, but this is the only locality at which epidote was found.

OTHER QUARTZ LATITE PORPHYRY DIKES

The general nature of other quartz latite porphyry dikes shown on the geologic map is given on preceding pages (p. 84–86). Modal analysis of six dikes are given in table 15 (samples 15–24). For four of the dikes, modes are given of both the internal and marginal facies, and these modes illustrate two types of dikes: one in which the mineral composition of the border is distinctly different from that of the interior (compare sample 16 with sample 15, table 15); the other in which the border is not greatly different (compare sample 13 with sample 24, table 15). The dike represented by samples 17 and 18 resembles the western part of the Turnerville dike in that it has an unusual abundance of phenocrystic quartz and very little hornblende even in its margins. The dike represented by samples 15 and 16 resembles the Republic dike and may be its southwest extension, as previously mentioned. Sample 21 represents a dike which, because of its milder alteration and crosscutting relations, may be the youngest of this group. Sample 19 is from a dike that might be classified with the next younger group, rhyodacite porphyry, except that hand specimens contain considerably more phenocrystic quartz.

RHYODACITE PORPHYRY PLUG AND DIKES

Distribution and general features

Rhyodacite porphyry dikes are found within a wide belt which trends northeast from near the town of Vanadium to the Mimbres fault (fig. 47*D*). None are known to occur in the northwest and southeast corners of the Santa Rita quadrangle—that is, north of the Barringer fault or south of the Hornet fault located east of Santa Rita. Their absence from the areas covered by tuffs and flows of Miocene(?) age suggests that they are older and were emplaced prior to this volcanic episode. Many of them are too small to map at the scale used. The dikes range in length from a few tens of feet to about 2 miles, and in width from 1 foot to 200 feet. Some dikes have sill-like apophyses extending into the wallrock for short distances. The only plug-shaped mass is a body of rhyodacite about 2,000 feet long and 400 feet in maximum diameter that intrudes the sedimentary rocks in the Hanover Hole and forms Bull Hill.

Weathered outcrops of relatively unaltered dikes are friable and are commonly marked by shallow trenchlike depressions. The rhyodacite plug at Bull Hill is partly silicified and forms a conical hill.

The rhyodacite dikes, like those of the next older group, occur as zoned and unzoned dikes. The marginal facies of some of the zoned dikes is sharply delineated from the internal facies; in others the transition is gradational. Fluxion banding, largely the result of an alinement and concentration of acicular hornblende, is conspicuous in many dikes. The contacts with the wallrock are commonly irregular in detail, and the wallrock is commonly brecciated, presumably as a result of the forceful intrusion of magma. No evidence of thermal metamorphism or metasomatic alteration has been detected in the wallrock adjacent to any of the rhyodacite dikes or to the plug, although the plug itself is severely altered.

Petrography

In general, the rhydocite-dike rock is light to dark gray and fine to medium grained and includes phenocrysts of plagioclase, hornblende, and biotite set in an aphanitic groundmass. (See fig. 34.) The groundmass constitutes 58–85 percent of the rock, and averages about 70 percent (table 16). Dikes in which the phenocrysts average about 1 mm in diameter appear granular, and their porphyritic aspect is revealed only by microscopic examination. Phenocrystic quartz generally makes up less than 2 percent of the rock, although in one dike it constitutes 3.7 percent and in another 2.5 percent. Poikilitic orthoclase porphyroblasts are sparse in some dikes, absent from others. Accessory minerals include sphene, apatite, allanite, zircon, magnetite, and rutile. Sphene is perhaps more abundant in this group of rocks than in any of the older groups, although it is not always visible to the naked eye.

Strongly zoned subhedral to euhedral plagioclase (An_{20-48}) constitutes 10–30 percent of the rock and averages about 20 percent. In most specimens these phenocrysts average about 1 mm in maximum dimension; but the fabric is seriate, and the phenocrysts range from a fraction of a millimeter to more than 3 mm in maximum dimension. Large grains are sparse.

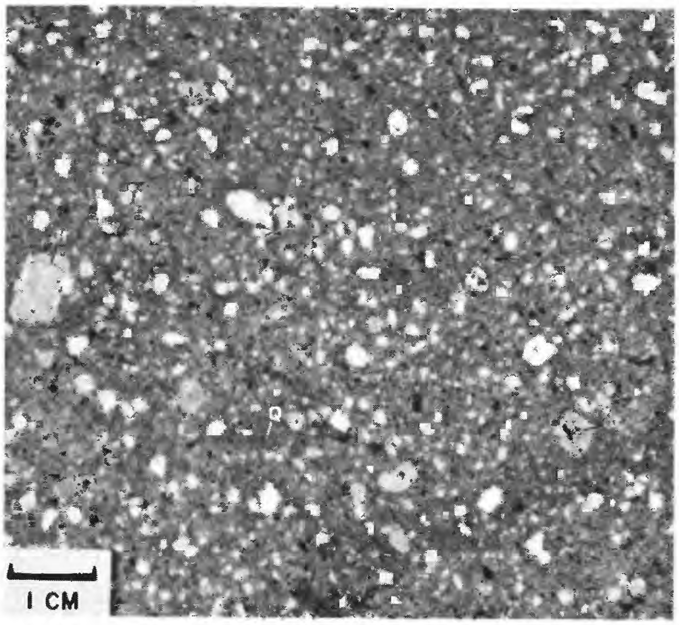


FIGURE 34.—Rhyodacite porphyry dike 1,300 feet southeast of Bull Hill. White phenocrysts are plagioclase; orthoclase, or; quartz, Q; black phenocrysts are largely biotite; gray matrix contains abundant light-green needle-shaped phenocrysts of hornblende.

Biotite occurs as small flakes 1 mm in diameter or less and as thin books, but in a few dikes it occurs as larger flakes and as sparse books whose ratio of thickness to diameter is commonly 3:2, rarely 2:1. The biotite flakes are commonly bent or shredded, and they have irregular terminations in the direction of cleavage.

Hornblende is present in all the dikes of this group, especially in their margins, where it may be the only mafic mineral and may constitute more than 10 percent of the rock. It generally occurs as thin prisms as much as 4 mm long, but in some dikes it occurs as large stubby prisms.

The matrix is composed principally of potassium feldspar and contains some quartz and plagioclase; in chilled margins the amount of plagioclase may equal the amount of potassium feldspar. In some dikes the matrix is cryptocrystalline, possibly in part glass, and in others microlites are abundant. In one dike amygdules of quartz, calcite, and apatite are common.

The rhyodacite of the plug at Bull Hill is coarser grained than that of most of the dikes. Andesine phenocrysts 3–5 mm long are either chalk white or greenish gray, the color depending on the type of alteration. Where the phenocrysts are white, the mafic minerals are largely destroyed and the matrix is light tan and aphanitic. Where they are greenish gray, the altered mafic constituents are barely discernible and the matrix is dark gray and aphanitic. A modal analysis of the dark variety of plug rock is given in table 16 (sample 1). Plagioclase is zoned inward from oligoclase to andesine (An_{20-45}); biotite, pseudomorphically replaced by aggregates of clay, chlorite, and calcite, is in moderately thick books; hornblende, similarly altered, is abundant as small slender prisms and as stubbier prisms as much as 5 mm long; and quartz phenocrysts are corroded. Patchy aggregates of small quartz crystals make up 7 percent of the rock, but this quartz was introduced during alteration or was recrystallized from inclusions. Accessory minerals are apatite, magnetite, zircon, and sphene.

The light-colored but commonly iron-stained part of the plug is converted mainly to various clay minerals, probably of the kaolin group, and silica, with some alunite (Spencer and Paige, 1935, p. 59). Veinlets of alunite are conspicuous along the west slope of Bull Hill. A little dusty pyrite was noted on some fractures in least weathered outcrops along Hanover Creek.

The dikes are variously altered; some, unlike most of the older rocks of the intrusive series, are virtually fresh and contain fresh biotite and hornblende. More commonly, the hornblende is pseudomorphically replaced by clay, calcite, chlorite, or secondary biotite, and the biotite phenocrysts are shiny black spangles. In some dikes the reverse is noted; the hornblende is black and shiny, and the biotite is altered to sericite, chlorite, hydromica, or clay. Plagioclase is commonly replaced by clay or calcite, less commonly by sericite or hydromica. In some dikes the plagioclase is complexly mottled, presumably owing to the formation of albite where calcium has been removed to form calcite. In the dike crossing the "island" between the north and south Chino pits, both the plagioclase and the matrix are partly replaced by yellow crystals of alunite.

Disseminated pyrite and sericite are much less common as products of alteration in the rhyodacite group. No megascopic epidote has been reported in any of the rhyodacite dikes, but a few grains have been doubtfully identified during microscopic study of thin sections from a few dikes. Some minute grains of sphene may be partly altered to epidote, for they show the birefringence of epidote rather than of sphene. For additional petrographic information on this group of dikes the reader is referred to descriptions by Kerr (in Kerr and others, 1950, p. 298, 299) and by Lasky (1936, p. 42–44).

TABLE 16.—*Analyses, norms, and modes, in percent, of rhyodacite porphyry plug and dikes*

[nd, not determined; ng, not given; Tr., trace; ---, absent; A, abundant; C, common]

Chemical analyses

	[1] 1	[2] 2	3
SiO_2	64.53	63.75	66.27
Al_2O_3	16.11	15.23	15.39
Fe_2O_3	1.50	2.63	2.14
FeO	1.56	.59	2.23
MgO	1.39	1.01	1.57
CaO	2.81	3.08	3.68
Na_2O	4.17	3.40	4.13
K_2O	3.21	3.86	3.01
H_2O+	1.53	2.01	.68
H_2O-	1.55	1.66	ng
TiO_2	.46	.50	.66
P_2O_5	.24	.30	.17
MnO	.08	.10	.07
BaO	ng	---	ng
CO_2	.83	1.64	ng
Cl	nd	.01	ng
F	nd	.05	ng
Total	99.97	99.82	100
Less O	---	.02	---
	99.97	99.80	100

Semiquantitative spectrographic analysis [3]

	2		2
Ba	0.3	Pb	0.001
Co	.0005	Sc	.0005
Cr	.00015	Sr	.1
Cu	.0015	V	.007
Ga	.002	Y	.002
La	.005	Yb	.0002
Ni	.0005	Zr	.01

Norms

	[4] 1	2	3
Quartz	20.84	24.90	20.8
Orthoclase	19.46	22.80	17.8
Albite	36.15	28.82	35.1
Anorthite	12.23	13.34	14.5
Corundum	1.43	4.18	---
Hypersthene	5.09	2.50	5.5
Magnetite	2.32	.70	3.0
Hematite	---	2.08	---
Ilmenite	.91	.91	1.4
Apatite	.67	.67	.3

Modes

[Volume percent]

	4	5	6	7	8	9	10	11	12	13	[5] 1	Avg 4–13
Matrix	58	70	71	81	74	74	85	66	62	66	65	71
Major phenocrysts:												
Quartz	1.6	2.5	.6	---	1.1	Tr.	.8	3.7	Tr.	Tr.	<1	1
Orthoclase	Tr.	1.6	Tr.	---	---	---	Tr.	Tr.	---	Tr.	5	Tr.
Plagioclase	22	21	16	13	14	20	10	24	30	27	25	20
Maximum An	An_{45}	An_{30}	nd	An_{48}	An_{30}	An_{40}	An_{40}	An_{40}	An_{37}	nd	An_{30}	nd
Hornblende	[6] nd	1.0	9	4.7	8	2.4	A	2.2	1.6	3.0	3	4
Biotite	[6] nd	2.2	.8	Tr.	2	1.2	Tr.	1.7	4.9	3.2	2	2
Accessory minerals:												
Magnetite	Tr.	Tr.	C	.8	C	.7	Tr.	Tr.	.6	Tr.	1	Tr.
Sphene	Tr.	---	Tr.	---	---	.6	Tr.	Tr.	Tr.	Tr.	<1	Tr.
Apatite	Tr.	Tr.	.8	Tr.	---	.3	Tr.	Tr.	Tr.	Tr.	<1	Tr.
Allanite	---	---	Tr.	---	---	---	---	---	---	---	---	---
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	---	Tr.
Rutile	---	---	---	---	---	Tr.	---	Tr.	Tr.	---	---	Tr.
Alteration minerals:												
Calcite	5	A	Tr.	C	.9	.3	---	A	---	A	Tr.	---
Sericite-illite	Tr.	A	Tr.	Tr.	C	Tr.	Tr.	C	Tr.	Tr.	---	---
Clay-alunite	C	A	Tr.	---	C	C	Tr.	C	A	C	Tr.	---
Albite	---	A	A	---	---	---	---	---	---	C	---	---
Chlorite	A	Tr.	---	---	C	Tr.	A	C	Tr.	C	Tr.	---
Biotite	---	---	---	---	---	Tr.	---	---	Tr.	---	---	---
Zeolite group	---	---	.7	---	---	---	---	---	---	---	---	---
Leucoxene	C	Tr.	Tr.	---	Tr.	Tr.	C	Tr.	---	Tr.	---	---
Sphene	Tr.	---	---	---	Tr.	---	Tr.	---	---	---	---	---
Quartz	7	---	---	Tr.	Tr.	---	Tr.	---	---	---	---	---
Pyrite	Tr.	Tr.	1.0	---	---	Tr.	---	---	Tr.	.4	---	---
Jarosite	Tr.	Tr.	---	---	---	Tr.	---	---	---	---	---	---

[1] Analyst: A. Willman.
[2] Analysis, standard rock, by C. L. Parker. CaO equivalent to CO_2 content was assigned to normative anorthite rather than to calcite.
[3] Analyst: J. C. Hamilton. Looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Ge, Hf, Hg, In, Li, Mo, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn.
[4] After H_2O- and CO_2 were excluded and the analysis was recalculated to 100.
[5] Determined by H. A. Schmitt (1939a).
[6] Altered beyond positive identification of host mineral.

SAMPLE DESCRIPTION

1. Field No. P-22. Dike in Pewabic mine (Schmitt, 1939a).
2. Field No. JC-15-62; lab. No. I-4032. Dike (latite dike of Lasky, 1936), somewhat weathered, cropping out in NW¼ sec. 6, T. 18 S., R. 12 W.
3. Average rhyodacite plus rhyodacite-obsidian (Nockolds, 1954, p. 1014).
4. Field No. HC-2-49. Plug underlying Bull Hill, 550 feet S. 70° E. of top of hill.
5. Field No. LC-247. Dike at intersection of Hanover Creek and State Highway 90.
6. Field No. HC-7-49. Dike 1,400 feet N. 10° E. of Princess shaft.
7. Field No. HC-5-50. Dike 5,200 feet S. 71° W. of top of Bull Hill.
8. Field No. HC-12-50. Dike 2,540 feet S. 81° W. of top of Bull Hill.
9. Field No. HC-14-51. Dike in roadcut on Gooseneck Hill; cuts quartz latite porphyry dike.
10. Field No. JC-26-52. Narrow dike in NE¼ sec. 16, T. 17 S., R. 12 W., in northwestern part of Union Hill.
11. Field No. JC-8-57. East-trending dike in Chino mine, between north and south pits.
12. Field No. JC-24-52. Dike in middle of east wall of south Chino pit, upper benches.
13. Field No. MC-241-51. Dike, 40 feet wide, 3,000 feet S. 85° E. of Grant County mine shaft.

The postore dike in the Pewabic mine is classified on chemical and textural bases as rhyodacite. The internal facies of many zoned dikes, however, which have been mapped and included in this group may be quartz monzonite or quartz latite. The abundance of quartz in the matrix of this group of dikes cannot be visually estimated, but it seems unlikely that it would be less than 10 percent, as suggested by the norms of the analysis. Earlier geologists called the group "latite," presumably because of the sparsity of quartz phenocrysts in most dikes. The dark aphanitic margins of some dikes, and the dikes so thin as to have no internal facies, may be hornblende latite or trachyandesite.

Chemical composition and classification

Two chemical analyses of rhyodacite (or latite) are available; one, published by Schmitt (1939a, p. 782, sample P–22), is of a specimen from a dike in the Pewabic mine area, the other is of a specimen from near the Slate mine. Judged by its mode (Schmitt, 1939a, p. 783; table 16, sample 2), the dike in the Pewabic mine area is typical of many mapped by the authors elsewhere in the quadrangle. Nockolds' average norm of 115 rhyodacites and rhyodacite obsidians (1954, p. 1014) is listed for comparison (table 16, sample 3). The norm of the specimen from the Pewabic mine area agrees closely with the average norm of Nockolds. The excessive normative corundum in the other dike indicates that the rock was severely weathered and kaolinized.

EVIDENCE OF RELATIVE AGES OF INTRUSIVE ROCKS

The evidence of relative ages of intrusive rocks is set forth in the following paragraphs, and the conclusions are shown graphically in the explanation of the geologic map (pl. 1).

The hornblende-augite syenodiorite porphyry is probably the oldest igneous post-Precambrian rock in the quadrangle. Fragments of it are found in the andesite breccia which rests unconformably on the northwest margin of the mass that underlies Hermosa Mountain. The syenodiorite magma was intruded, cooled and crystallized, intruded by numerous mafic dikes, and exposed by erosion of its roof rocks before the andesite breccia was deposited. Later, mafic dikes cut through the syenodiorite porphyry and the andesite breccia. The mass of syenodiorite west of Union Hill is cut by apophyses of the Hanover-Fierro pluton, and dikes resembling the hornblende quartz diorite cut the Hermosa Mountain mass. The relative age of the syenodiorite porphyry with respect to the age of the quartz diorite porphyry cannot be deduced because the porphyries are nowhere in contact with each other.

The age of the augite-hornblende andesite near Georgetown is known only in relation to the postore rhyodacite dikes which cut the andesite. The presence of augite as well as hornblende, however, suggests that this rock may be related to the hornblende-augite syenodiorite porphyry. The only difference between the two types of rock is the color of the hornblende; hornblende in the mass near Union Hill is the common green variety, whereas that in the sills near Georgetown is brown. The color of hornblende may not be significant, however, because the Georgetown area is far removed from the area of intense alteration. Because of its sill-like form, the augite-hornblende andesite is tentatively and arbitrarily grouped with other sills and is assigned an early age in the intrusive sequence.

The rhyolite porphyry is older than the granodiorite porphyry dikes. In the Groundhog mine, it apparently is older than the Marker sill of hornblende quartz diorite. An irregular lens of rhyolite porphyry is found locally at the horizon of the Marker sill. The sill is missing where the rhyolite porphyry is present. As the rhyolite porphyry did not stope or assimilate host rock during its intrusion, the Marker sill was probably intruded later than the rhyolite porphyry and was limited in its distribution by that rock. Age relations between the rhyolite porphyry and the quartz diorite porphyry have not been observed; the rhyolite porphyry may be either younger or older and is tentatively considered older.

The relative age of the quartz diorite porphyry is fairly well established by crosscutting relations. There is no question but that it is older than the Santa Rita stock, which intrudes it in the Chino mine area. Also, it is older than the hornblende quartz diorite, dikes of which cut sills of quartz diorite porphyry east-northeast of Kneeling Nun, southwest of the Chino pit, and at one place in the Allie Canyon quadrangle. The age of the quartz diorite porphyry relative to that of the syenodiorite porphyry or the rhyolite porphyry is not known.

Hornblende quartz diorite intrudes quartz diorite porphyry and is therefore younger. Also, dikes resembling the hornblende quartz diorite cut the syenodiorite at Hermosa Mountain, which indicates that the main masses of hornblende quartz diorite may be younger than the syenodiorite. The evidence here presented suggests that the hornblende quartz diorite is younger than the rhyolite porphyry. Hornblende quartz diorite is intruded by the stocks of granodiorite or quartz monzonite porphyry and by the dikes which intrude the stocks. North of Hanover Mountain the thin sills identified as hornblende quartz diorite are cut by mafic dikes that are probably equivalent to the swarm of mafic dikes in North Star Basin. Thus, the hornblende quartz diorite was emplaced after the syenodiorite and quartz diorite porphyry, and probably after the rhyolite porphyry, and was succeeded by trachyte porphyry and a series of discordant intrusions.

The trachyte porphyry intruded and was chilled against faulted segments of both the quartz diorite porphyry and the hornblende quartz diorite, and was intruded by a postore rhyodacite dike. Its age relative to that of the granodiorite and quartz monzonite stocks and dikes cannot be deduced, for nowhere is it in contact with any of them. The abundance of epidote and related alteration minerals favors a preore age, because these alteration minerals are very rare or are absent in postore intrusions. The location of the trachyte porphyry in exposures along the trend of the Mimbres fault and the fact that the porphyry is intruded along related northeast- and northwest-trending faults suggest that the porphyry is younger than the ancestral Mimbres fault. The trachyte porphyry, of course, predates the latest movement along the Mimbres fault which displaced upper Cenozoic gravels. The porphyry was emplaced immediately after the hornblende quartz diorite and before the formation of the Mimbres fault.

Crosscutting relations show that the age of the granodiorite of the Hanover-Fierro pluton is intermediate between that of the hornblende quartz diorite sills and that of the granodiorite porphyry dikes. There are no data relating the age of the Hanover-Fierro pluton to that of the Santa Rita stock; because both cut sills of hornblende quartz diorite and are cut by quartz monzonite porphyry dikes, we can only assume that they were intruded at about the same time. The equigranular facies cuts hornblende quartz diorite and syenodiorite porphyry sills at the south end of Union Hill. In the south bank of a wash in the SW¼ sec. 16, T. 17 S., R. 12 W., a 6-inch-thick dike of granodiorite porphyry resembling the porphyritic rock of the main mass cuts the equigranular facies. This rock may, however, belong to the swarm of granodiorite porphyry dikes that postdates the Hanover-Fierro pluton. However, other granodiorite dikes in the same area have wide chilled margins, and this small dike does not. In the central part of the south lobe, prongs of the main mass seem to extend well into the equigranular facies. Northwest of the Pewabic mine, however, the contact between the two facies is locally gradational. The equigranular facies is cut by aplite dikes related to the Hanover-Fierro pluton, and by granodiorite porphyry dikes, quartz monzonite porphyry dikes, and many types of postore dikes. As stated, the porphyritic facies apparently solidified somewhat later than the equigranular facies. It is also cut by the granodiorite porphyry dike swarm and by the younger postore dikes.

The position of the quartz monzonite porphyry of the Santa Rita stock is clearly established in the igneous sequence by crosscutting relationships. The quartz monzonite porphyry intrudes the quartz diorite porphyry sill and the hornblende quartz diorite sill and is extensively intruded by a narrow swarm of quartz monzonite porphyry dikes and by still younger postore dikes. Although the stock is cut by a few thin dikes grouped with the granodiorite porphyry swarm, it is not cut by the typical granodiorite dikes. This fact may be entirely fortuitous; more likely, some of the granodiorite dikes were emplaced contemporaneously with one of the earlier facies of the composite stock. The magma that formed the stock intruded and stoped several major faults, but later the stock itself was extensively faulted and fractured. The age relations of the Santa Rita and Copper Flat stocks and Hanover-Fierro pluton are not known.

Age relations of the composite pluton at Copper Flat with other intrusives of the quadrangle are undetermined; however, we do know that the pluton cuts a thick sill of hornblende quartz diorite (pl. 2, section *B–B′*). The pyrometasomatic metamorphism of the host rock, the presence of epidote in the alteration mineral suite, and the associated iron and zinc deposits all point to approximate equivalence in age of the composite pluton at Copper Flat and the other plutons.

The relative age of the granodiorite porphyry dikes is well established by crosscutting relations with other igneous rocks of the quadrangle. The dikes cut the various sills: hornblende-augite syenodiorite, quartz diorite, hornblende quartz diorite, and rhyolite porphyry. The hornblende-rich dikes (type 2) cut the Hanover-Fierro pluton; others that contain prominent quartz phenocrysts may be apophyses of one facies of the Santa Rita stock; still others seem to have formed when late surges of the magma were injected into the cracked hood of the Santa Rita stock. The dikes of all varieties of granodiorite porphyry are in many places cut by masses of younger igneous rock, including the next younger dikes of quartz monzonite porphyry.

The relative age of the quartz monzonite porphyry dikes is firmly established by numerous crosscutting relationships in the area. These dikes cut granodiorite porphyry dikes, the Santa Rita stock, the Hanover-Fierro pluton, and all the sills. In turn, they are cut by the Turnerville dike near the Turnerville townsite and by the Republic dike in the Hanover area.

Certain members of the quartz latite porphyry group are cut by rhyodacite dikes of the next younger group. As crosscutting relationships do not exist for all dikes of the two groups, it is presumptuous to state that all quartz latite porphyry dikes are older than all rhyodacite dikes. Nevertheless, for convenience, this assumption is made, and should be considered tentative.

The Republic dike cuts dikes of granodiorite and quartz monzonite porphyry. It is in turn cut by two types of quartz latite porphyry dikes that are believed to be younger than the sedimentary filling in the Hanover Hole. Northwest of Bull Hill this filling truncates an arm of the Republic dike and contains fragments of that dike.

The relative age of the Turnerville dike has special significance because it seems to be intermediate between the periods of preore and postore intrusions. Although the dike occupies what is apparently a single structure, the rock in the wide, northwestern part of the dike may be younger than the rock in the southeastern part. The relative age of the wide part is fixed within narrow limits by several crosscutting dikes. The wide part of the dike cuts a wide dike of quartz monzonite porphyry and is itself cut by a dike of the next younger group of quartz latite intrusives. Many pebbles in the sedimentary beds that fill the Hanover Hole are identical with the rock that forms the wide part of the Turnerville dike. For this reason the rock in the northwestern part of the Turnerville dike is considered to be older than the hole.

The southeastern part of the Turnerville dike does not intersect dikes of quartz monzonite porphyry. It is, however, cut by the youngest type of pre-Miocene intrusive, a rhyodacite dike. The intensity of alteration, the mineral content, and the presence of quartz-chalcopyrite veinlets suggest that the southeastern part of the Turnerville dike may be an apophysis of the Santa Rita stock or of a granodiorite dike. If so, the rock in the southeastern part of the dike is slightly older than that in the wide, northwestern part.

The relative age of the Trevarrow plug is indicated by several crosscutting relationships. Along its eastern and northeastern margins the plug truncates granodiorite porphyry dikes. At its southwest and north margins it intrudes sills of hornblende quartz diorite. The south-trending apophysis crosses the Turnerville dike; the northwest-trending apophysis crosses the Republic dike and is, in turn, crossed about 50 feet northeast of the Oswaldo No. 1 shaft by a younger northeast-trending quartz latite porphyry.

The dikes and plugs grouped as rhyodacite on the geologic map (pl. 1) are considered to be younger than the quartz latite porphyry plugs and dikes, as previously stated, because several rhyodacite dikes cut the quartz latite porphyry dikes. In the northeast quarter of the quadrangle no crosscutting relations are exposed, and the rhyodacite may not be younger there. However, many of the dikes in that sector are petrographically identical with those known to cut the quartz latite dikes and plugs. Rhyodacite dikes probably are older than the Miocene(?) volcanics, because none are known within the volcanic field. Probably, if they were younger than the Sugarlump Tuff and the Kneeling Nun Rhyolite Tuff they would cut them near the Groundhog mine, where one rhyodacite dike crops out within 200 feet of the edge of the volcanic rocks, or north of Bayard, where the tuffs lie across the trend of a set of these dikes.

VOLCANIC AND SEDIMENTARY ROCKS AND RELATED INTRUSIVE ROCKS OF MIOCENE(?) AGE

In Miocene(?) time most of southwestern New Mexico was deeply blanketed by layers of volcanic rocks ranging in composition from basalt to rhyolite. Their real extent has subsequently been decreased by erosion, especially in areas where they are faulted or jointed. Most of the Santa Rita quadrangle lies within the eastern part of an east-west belt from which these Miocene(?) volcanic rocks and associated conglomerates have been entirely eroded. The volcanic rocks in the northwest corner and in the southern part of the quadrangle were once continuous across the Santa Rita area, and they still extend as great volcanic fields for tens of miles to the north and south. The absence of volcanic rocks from the central part of the quadrangle is due to their original thinness there, which resulted from the higher elevation of the pre-Miocene erosion surface in that area than in areas to the north and south; many of the lower members of the volcanic sequence were either especially thin or never extended over the topographic high.

The present topographic expression of the volcanic rocks is determined by the nearly horizontal attitude of the layers and by the alternation of resistant layers that erode to cliffs and nonresistant layers that erode to gentle slopes. Prominent cliffs and steep-walled canyons are formed in the layers of massive highly indurated or welded tuffs of quartz latite to rhyolite composition. Tuffs of the same mineral composition, but much less indurated, erode to gentle slopes and commonly underlie broad areas. The layers of basaltic andesite and detrital sediments erode to gentle slopes, and the smoothly worn appearance of their outcrop contrasts sharply with the rugged outcrop of the indurated tuffs.

GENERAL CHARACTER AND SUCCESSION

The principal rock types of this volcanic field are dark-colored basalt, basaltic andesite, and rhyodacite flows; white to pink quartz latite or rhyolite crystal-vitric tuffs, variously indurated and devitrified and containing sparse to abundant lithic fragments; and intercalated gravel-and-boulder deposits. In adjoining quadrangles the succession also includes rhyolite flows, but these are of limited areal extent (Elston, 1957). Each type of volcanic rock occurs in stratigraphic zones in the region, and locally the mafic varieties alternate with the felsic. Because the various layers wedge out laterally, in some places abruptly, the stratigraphic successions in localities 5–10 miles apart are commonly quite different.

The generalized succession in the southern part of the Santa Rita quadrangle and in the Dwyer and Lake Valley quadrangles to the southeast includes a lower series of mafic and intermediate flows lying within poorly sorted conglomerate, a middle series of intermediate to felsic tuffs in various stages of induration, and a higher series of mafic flows. The lower series of mafic flows is absent from the northern field. Conglomerate similar in composition to that at the base in the southern field occurs between the felsic tuffs and between the basaltic andesite flows in the northern field.

Minor disconformities indicate that there were several short-lived intervals of erosion. The most pronounced disconformity separates the middle series of felsic tuffs from the top series of mafic flows. The transition from dominantly felsic tuffs to dominantly mafic flows was gradual, as is shown by the intercalation of the two in one area southeast of the Chino mine dump. Thin flows of basalt in the upper Tertiary valley fill are the youngest igneous rock in the region.

For a better appreciation of the regional and local aspects of the volcanic field, the reader is referred to the excellent maps and descriptions by Paige (1916), Elston (1957), and Kuellmer (1954).

Petrography

The three principal volcanic rock types of Miocene(?) age in the Santa Rita quadrangle, from oldest to youngest, are rhyodacite-andesite flows, quartz latite to rhyolite tuffs, and basaltic andesite flows.

The early, rhyodacite-andesite flows and the later, basaltic andesite flows in the Santa Rita quadrangle are similar. Rocks of both flows are dark bluish gray on fresh fracture and deep reddish brown on weathered surfaces. They consist principally of plagioclase feldspar, which ranges from andesine to labradorite; both flows contain augite and an orthopyroxene, probably hypersthene. The early flows contain sparse olivine, largely altered to "iddingsite,"[2] and the late flows contain abundant olivine, also mostly altered to "iddingsite." Sanidine, hornblende, and, more rarely, biotite are present in certain early flows of intermediate composition in the Dwyer quadrangle (Elston, 1957, p. 22) but are absent from the basaltic andesite flows. One flow in the northern field and the tops of most flows are conspicuously vesicular.

All the rhyolite-quartz latite tuffs contain the same minerals, but rarely in the same proportions. Each mineral varies in abundance from place to place, and the rocks differ in color and in degree of induration. The most abundant mineral constituents are glittering clear sanidine, oligoclase-andesine, quartz, and bronze-colored biotite. Fragments of hornblende and augite are rare. The matrix, which is predominantly partly devitrified glass shards, generally makes up about 70 percent of the rock. Spherulitic growths are abundant locally. Accessory minerals are sphene, apatite, zircon, ilmenite, and iron oxides. Banding (eutaxitic structure), rock and pumice xenoliths, columnar joints, and other features typical of ignimbrites are conspicuous in many formations (Elston, 1957). However, some tuffs are well bedded and well sorted; these characteristics indicate that the material was deposited either by running water or by wind. In contrast to the hypabyssal rocks, the volcanic rocks still have their original composition, except along some fissures, where the glassy rocks are altered to montmorillonite.

Chemical composition

The chemical aspects of the extrusive rocks are shown in figures 35 and 36. In figure 35, differences in weight percent of common oxides with respect to silica content are illustrated. Lines connecting the same oxides in the various rocks show the familiar trends from low to high silica rocks. However, since the rocks represented in the middle of the diagram are the oldest and those on the left the youngest, the

[2] Ming-Shan Sun (1957, p. 525) has shown by X-ray powder diffraction studies of iddingsite in samples from New Mexico that "goethite is the only crystalline phase and that other substances shown by chemical analysis to occur in iddingsite are largely amorphous. Iddingsite in this case may therefore be regarded as a complex alteration product of olivine rather than a true mineral." For this reason, material identified by the authors as iddingsite is placed in quotation marks.

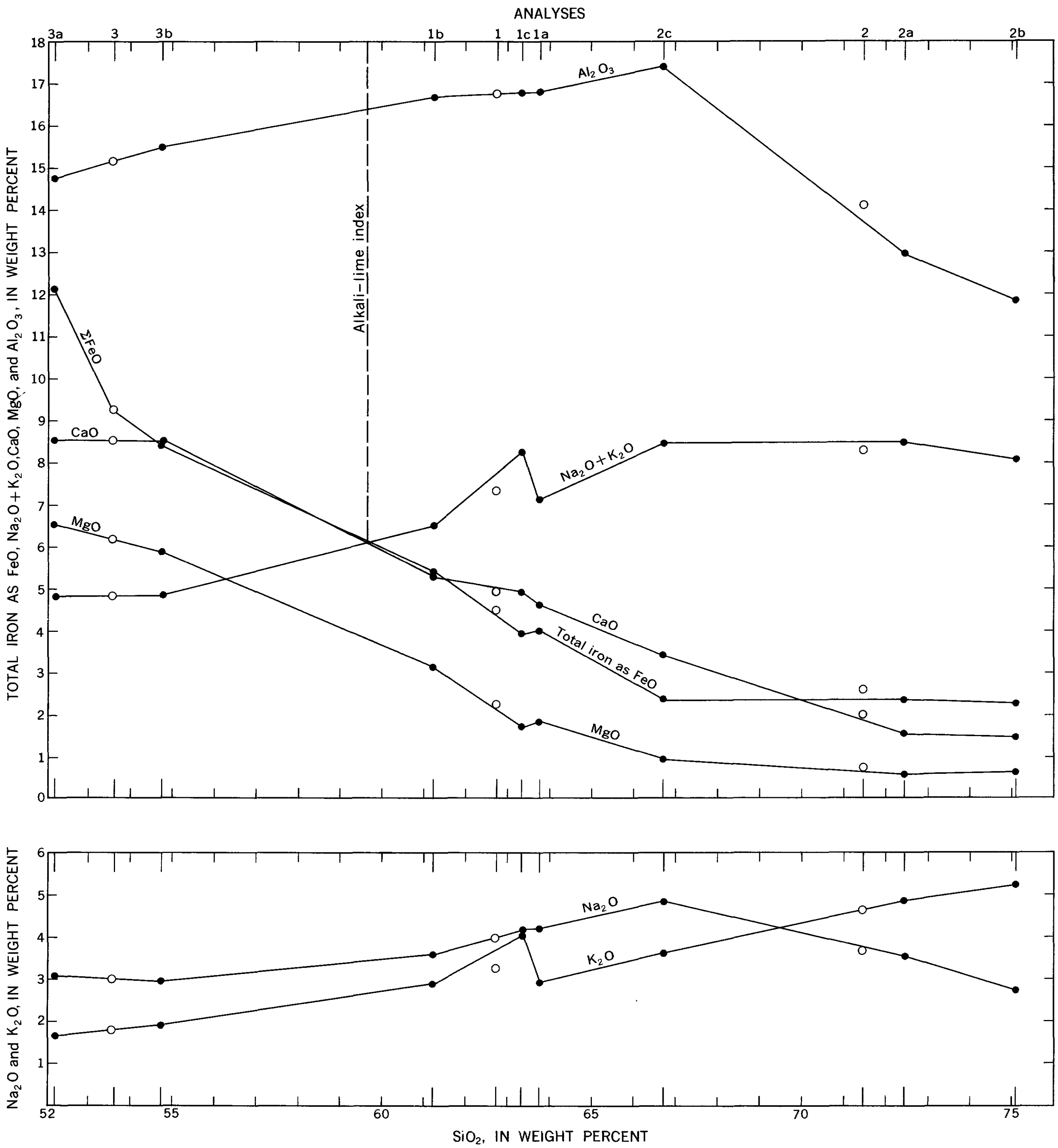


FIGURE 35.—Silica variation in Miocene(?) volcanic rocks in the Santa Rita and nearby quadrangles. Bulk analyses recast with all iron as FeO and excluding volatiles. Open circle indicates plot of average value.

1. Flows in Rubio Peak Formation, average of 3 analyses.
1a. Latite flow in Rubio Peak Formation (Elston, 1957, table 7, col. 4).
1b. Andesite flow in Rubio Peak Formation (Elston, 1957, table 7, col. 3).
1c. Latite flow in Rubio Peak Formation (Elston, 1957, table 7, col. 5).
2. Tuffaceous rhyolite and quartz latite, average of 3 analyses.
2a. Kneeling Nun Tuff, Dwyer quadrangle (Elston, 1957, table 8, col. 2).
2b. Tuffaceous rhyolite, Black Range (Kuellmer, 1954, table 6, R-2).
2c. Kneeling Nun Tuff, Santa Rita quadrangle.
3. Basaltic andesite, average of 2 analyses.
3a. Bear Springs Basalt of Elston (1957, table 5, col. 2).
3b. Late andesites of Kuellmer (1954, table 6, 389-C-87).

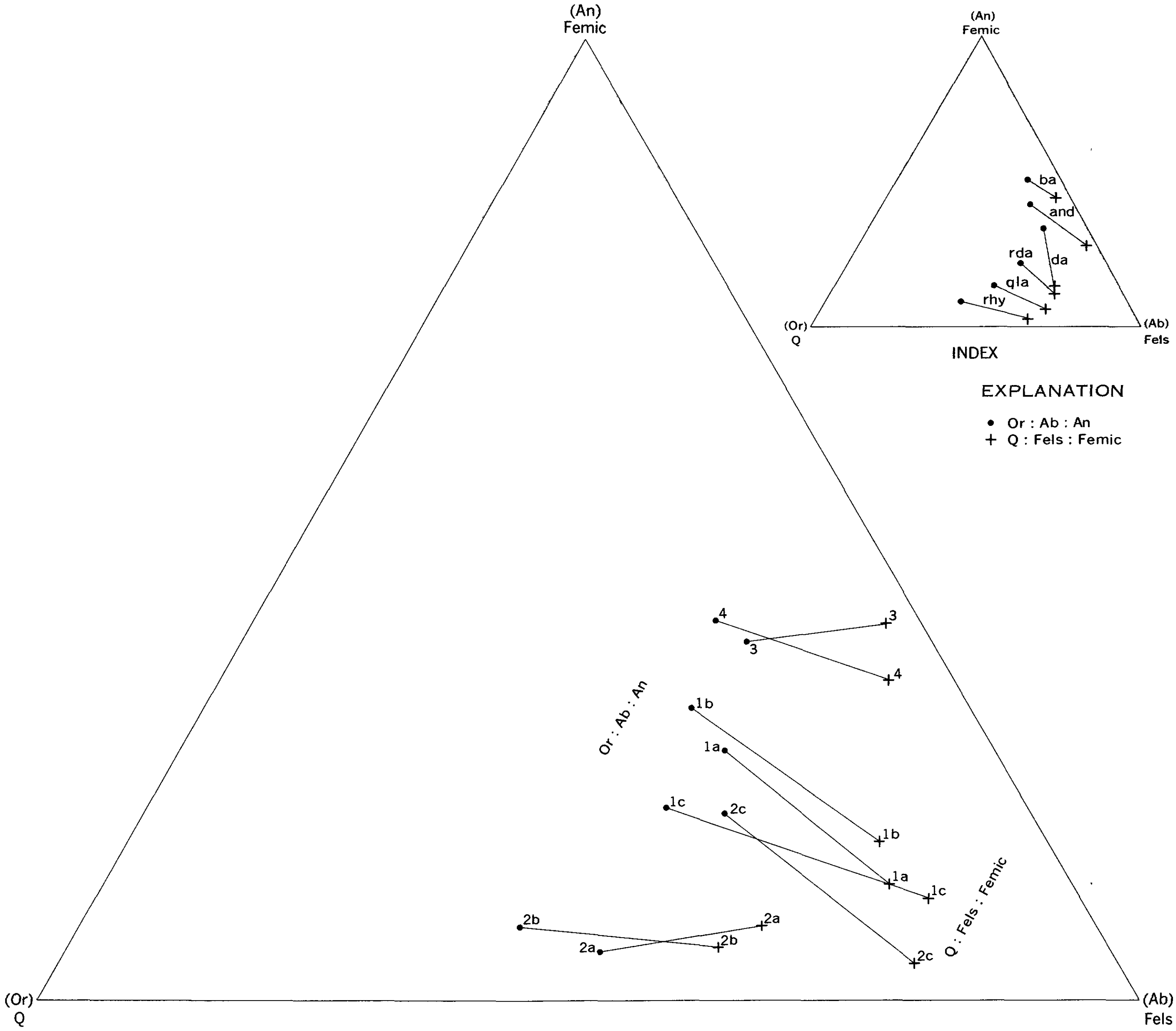


FIGURE 36.—Larsen plot of certain normative constituents in Miocene(?) volcanic rocks in the Santa Rita and adjoining quadrangles Index shows similar plot of several volcanic rocks (Nockolds, 1954).

1a. Flow in Rubio Peak Formation (Elston, 1957, table 7, col. 4).
1b. Flow in Rubio Peak Formation (Elston, 1957, table 7, col. 3).
1c. Flow in Rubio Peak Formation (Elston, 1957, table 7, col. 5).
2a. Kneeling Nun Tuff, Dwyer quadrangle (Elston, 1957, table 8, col. 2).
2b. Tuffaceous rhyolite, Black Range (Kuellmer, 1954, table 6).
2c. Kneeling Nun Tuff, Santa Rita quadrangle.
3. Bear Springs Basalt of Elston (1957, table 5, col. 2).
4. Late andesites of Kuellmer (1954, table 6).

Index: Q, quartz; Fels, total normative feldspar; Femic, diopside, hypersthene, magnetite, ilmenite; ba, average of 137 normal tholeiitic basalts and dolerites; and, average of 49 andesites; da, average of 50 dacites and dacite-obsidians; rda, average of 115 rhyodacites and rhyodacite-obsidians; qla, average of 58 quartz latites (dellenites and dellenite-obsidians); rhy, average of 22 calc-alkalic rhyolites and rhyolite-obsidians.

sequence of extrusion is not the ideal sequence of mafic to silicic; rather, it is a progression from intermediate to silicic to mafic. Field relations suggest the possibility that silicic and mafic magmas may have been emitted contemporaneously from separate volcanoes.

In figure 36 the chemical aspects of the rocks may be readily compared with the average chemical aspects of some common extrusive rocks as given by Nockolds (1954). Comparison of figure 36 with figure 15 shows that the flowrocks of the Rubio Peak Formation and one sample of the Kneeling Nun Tuff are chemically similar to most of the hypabyssal rocks of Late Cretaceous and early Tertiary age. However, the intrusive suite does not include a rock type as mafic as the Miocene(?) basaltic andesite (Bear Springs Basalt of Elston, 1957), the youngest igneous rock in the quadrangle. This fact is also obvious in figure 13, a normative mineral plot of several intrusive and extrusive rocks.

RUBIO PEAK FORMATION

The Rubio Peak Formation crops out in the southeast and southwest corners of the Santa Rita quadrangle. Beyond the quadrangle to the southeast it underlies a broad belt extending through the northwestern and central parts of the Dwyer quadrangle. In this belt it is reported to be as much as 3,200 feet thick, and possibly 5,000 feet thick (Elston, 1957). The Rubio Peak Formation probably extends westward beneath the younger volcanic rocks of the Cobre Mountains and the Hurley East quadrangle, because it is present in the valley of Whitewater Creek and in Bayard Canyon. The formation was believed by Elston (1957, p. 19) to fill a structural basin that reaches its maximum depth in the northwestern part of the Dwyer quadrangle. Farther west, north, and northwest, beyond the margin of the basin, the upper beds of the formation were deposited on a surface that had strong relief, and some of the topographic highs of that time were not covered. Such a high evidently existed over much of the south-central part of the Santa Rita quadrangle, for the formation is not present there.

The unevenness of the surface beneath the Rubio Peak Formation accounts for the variability in the thickness of the formation. The maximum thickness in the Santa Rita quadrangle is about 870 feet. Two series of flows aggregate about 600 feet.

Westward from the Mimbres fault, the Rubio Peak Formation lies on successively younger rocks—the Fusselman Dolomite of Silurian age to the quartz diorite sills of Late Cretaceous(?) age (Kuellmer, 1956). This truncation of older beds suggests that the southwest homoclinal dip of the older rocks west of the Mimbres fault developed prior to deposition of the Rubio Peak Formation in Miocene(?) time. The Rubio Peak Formation seems to be overlain conformably by Sugarlump Tuff throughout the Santa Rita quadrangle, but Elston (1957, p. 23–24) stated that in the Dwyer quadrangle the contact is unconformable in some places and conformable in others. He also stated, and showed on his map (pl. 1), that the two formations interfinger in the area of Mimbres. The white tuffs and tuffaceous gravels lying between the two groups of flows in the southeast corner of the Santa Rita quadrangle might be considered as an interfingering of Sugarlump Tuff on lithologic grounds alone, but the authors saw no reason at the time of mapping to consider it as such. The upper contact of the Rubio Peak Formation is arbitrarily placed at the top of the highest rhyodacite flow or at the top of the highest dark-colored poorly sorted conglomerate such as is exposed in Bayard Canyon and in the Bayard area.

Neither Elston (1957) nor Jicha (1954) described typical stratigraphic sections of the Rubio Peak Formation, because many of the flows are of such limited extent that no one section could be considered typical. In the Santa Rita quadrangle the basal part of the section consists of poorly sorted coarse gravels derived from sedimentary and igneous rocks of the adjacent area. In Bayard Canyon and for a mile or two farther west, the pebbles and boulders in the gravel are largely fragments of andesite breccia, mafic porphyry dikes and plugs, and a hornblende quartz diorite sill that crop out to the north and northwest. Fragments of magnetite, tactite, skarn, and metal sulfides were looked for but not found. If drainage were dominantly toward the southeast, the eroded parts of the ore bodies of the Central district might be concentrated in the gravels of the basal part of the Rubio Peak Formation beneath Rustler Canyon. Immediately west of the Mimbres fault, the base of the Rubio Peak Formation is characterized by a red sandy shale (Elston, 1957, p. 19). Neither the base nor the gravel beds are well exposed farther west. The following section is characteristic of the formation in the southeast corner of the Santa Rita quadrangle.

Rubio Peak Formation

[Near section *I–I'*, pl. 2]

	Thickness (feet)
Sugarlump Tuff.	
Rubio Peak Formation:	
Porphyritic rhyodacite flows: two massive dark-gray slightly vesicular flows separated by oxidized very vesicular material marking the top of the lower flow and by detrital rock. The flows contain phenocrysts of glassy feldspar, dark pyroxene, and red-brown iddingsite pseudomorphs of olivine phenocrysts	200–400
White lithic and pumiceous tuff grading to tuffaceous gravel, and interfingering thin flows of andesite. Lithic fragments are mainly andesite and older lithic tuff. Mineral framgents are biotite, chalcedony, sanidine, and frosted subrounded quartz grains	100–200
Porphyritic flows similar to upper flows	100–200
Semiconsolidated gravel derived from sedimentary and intrusive formations in the area immediately to the north	0–70
Angular unconformity.	
Cretaceous sedimentary and intrusive rocks.	

The white tuffaceous layers which occur in the central part of the quadrangle were also found farther east, and were mapped by Elston with the Sugarlump, which they resemble lithologically. Deposition of both formations may have occurred simultaneously.

The flows within the Rubio Peak Formation are generally fine grained, porphyritic, and dark pink, lavender gray, purple, brown, or black (Elston, 1957); most weathered surfaces are gray, with tinges of red or brown. Phenocrysts are plagioclase (zoned from andesine to labradorite), basaltic hornblende (lamprobolite), zoned augite (average composition according to Elston, p. 22, $(Ca_{86}Mg_{84}Fe_{30})Si_2O_6)$), and hypersthene or bronzite. Plagioclase and augite are generally unaltered. Accessory minerals are biotite, apatite, magnetite, zircon, sphene, and, rarely, quartz and "iddingsite." The groundmass is either finely crystalline or glassy; where crystalline it consists largely of andesine laths but contains some potassium feldspar (Elston, 1957, p. 22). Detailed optical properties and chemical composition of the constituent minerals were given by Elston (p. 21–23) and need not be repeated here. The two specimens from the flows within the Santa Rita quadrangle that were examined microscopically by the authors are similar to the more mafic varieties in the Dwyer and Lake Valley quadrangles. They contain andesine and labradorite, augite, magnetite, apatite, green antigorite or biotite, and wedges of "iddingsite." Small rectangular grains of serpentine may be pseudomorphic after an orthopyroxene. In one thin section the matrix is brown glass, and numerous inclusions of brown glass and other minerals occur within some labradorite phenocrysts. In another section the matrix is in large part a felted mass of andesine microlites, and minute grains of augite and magnetite are disseminated throughout. Some grains of "iddingsite" and serpentine are presumably pseudomorphic after olivine. No hornblende, biotite, potassic feldspar, or quartz was present in the thin sections examined, but hornblende and biotite were observed in some flows during mapping. The thin flows intercalated in the white tuffaceous layers have little or no "iddingsite," and the feldspar seems to be less calcic.

The nature of the pyroclastic rocks in the formation to the southeast was described by Elston (1957, p. 21–23):

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 latite breccias that show no evidence of reworking were deposited usually in irregular mounds or in beds of short lateral extent.

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.

Samples from three flows within the Rubio Peak Formation were analyzed by Elston (1957), and the results are shown in this report (table 17, cols. 1–3). An average of the three analyses appears in column 4, and can be compared with the analysis in column 5, which is the average of analyses of 115 rhyodacites and rhyodacite-obsidians by Nockolds (1954, p. 1014).

The flows within the Rubio Peak Formation were classified on a modal basis by Elston (1957) and Jicha (1954) as hornblende latites and pyroxene andesites, but in this report they were classified as rhyodacites because of the abundance of normative quartz, about 15 percent. (See table 17.)

TABLE 17.—*Chemical analyses and norms of flows in the Rubio Peak Formation*

	1	2	3	4	5
Chemical analyses					
SiO_2	62.43	59.37	61.88	61.23	66.27
Al_2O_3	16.50	16.17	16.46	16.38	15.39
Fe_2O_3	4.32	4.49	3.48	4.09	2.14
FeO	.43	1.20	.72	.78	2.23
MgO	1.78	3.00	1.66	2.15	1.57
CaO	4.55	5.12	4.75	4.80	3.68
Na_2O	4.10	3.46	4.08	3.88	4.13
K_2O	2.87	2.81	4.00	3.23	3.01
H_2O+	1.52	1.80	.59	1.30	.68
H_2O-	.86	.86	.73	.82	----------
TiO_2	.70	1.01	.45	.72	.66
P_2O_5	.29	.36	.25	.30	.17
MnO	.08	.07	.10	.08	.07
CO_2	----------	----------	1.02	----------	----------
Total	100.43	99.72	100.17	99.76	100
Normative minerals					
Quartz	16.50	14.70	13.26	14.82	20.8
Orthoclase	17.24	16.68	23.91	19.28	17.8
Albite	34.58	29.34	34.58	32.83	35.1
Anorthite	18.07	20.29	14.73	17.69	14.5
Corundum	----------	----------	----------	----------	----------
Wollastonite	.81	.93	1.04	.92	1.3
Enstatite	4.50	7.50	4.77	5.59	3.9
Ferrosilite	----------	----------	----------	----------	1.3
Magnetite	----------	1.16	1.16	.77	3.0
Ilmenite	1.06	1.98	.91	1.32	1.4
Apatite	.67	1.01	.67	.78	.3
Calcite	----------	----------	2.30	.77	----------

1. Amphibole latite, H. B. Wiik, analyst (Elston, 1957, table 7, col. 4).
2. Pyroxene andesite, H. B. Wiik, analyst (Elston, 1957, table 7, col. 3).
3. Amphibole latite, H. B. Wiik, analyst (Elston, 1957, table 7, col. 5). (Norm recalculated.)
4. Average of 1, 2, and 3.
5. Average of 115 analyses of rhyodacite plus rhyodacite obsidian (Nockolds, 1954, p. 1014, col. 4).

The normative orthoclase is generally about three times that of average andesite (6.7 percent), but about one-fourth less than that of average latite (26.1 percent) (Nockolds, 1954, p. 1017, 1019). Figure 35 shows that silica content in flows in the Rubio Peak Formation is intermediate between that in the basaltic andesites and that in the rhyolite tuffs. The flows in the Rubio Peak Formation are chemically similar to the sill rocks and to the granodiorite forming the Hanover lobe of the Hanover-Fierro pluton.

SUGARLUMP TUFF

Loosely consolidated deposits of gravel, sand, and tuff that rest directly on the eroded surface of Upper Cretaceous and lower Tertiary rocks in the southern part of the Santa Rita quadrangle but on the Rubio Peak Formation in the southeast and southwest corners of the quadrangle were originally called the Lucky Bill Formation by Hernon, Jones, and Moore (1953, p. 120). Jicha (1954) and Elston (1957) called corresponding deposits the Sugarlump Tuff, after Sugarlump Mountain in the Dwyer quadrangle. To avoid confusion, and because Jicha's and Elston's areas include a much greater part of the volcanic field, the authors have changed the name of this formation to Sugarlump Tuff. The broadest exposures are within the west-central part of the Dwyer quadrangle and in the northwestern part of the Lake Valley quadrangle, a 15-minute quadrangle adjoining the Dwyer quadrangle on the east. Within the Santa Rita quadrangle the formation crops out locally along the escarpment that crosses the quadrangle from the southeast corner to the southwest corner, and in small areas in canyons that drain the highlands south of the escarpment. The formation does not occur in the volcanic rocks that underlie the northwest corner of the quadrangle.

Because these deposits are poorly consolidated, their outcrop generally erodes to a gentle slope and is commonly covered with talus. The outcrop south of the Chino mine is rapidly being buried beneath the mine dumps.

The thickness of the Sugarlump Tuff in the Santa Rita quadrangle ranges from 50 to 800 feet because of irregularities in the surface upon which the tuffs were deposited. The thinnest section is in the escarpment southeast of the Chino mine, where only the uppermost beds were deposited. The formation thickens to the east and west and is about 300–400 feet thick in the Groundhog mine area and 800 feet thick in the southeast corner of the quadrangle. In the Dwyer quadrangle the maximum thickness reported is 1,400 feet (Elston, 1957, p. 24); in the Lake Valley quadrangle, 1,000 feet (Jicha, 1954, p. 44); and in the Hurley East quadrangle, to the south, 530 feet (Pratt, 1967).

No stratigraphic section of the Sugarlump Tuff can be considered typical of the entire formation. In the Santa Rita quadrangle the formation includes deposits of gravel, brown, green, and gray sand, and white to cream-colored pumiceous tuffs containing variable amounts of crystal and lithic fragments. Perfectly exposed sections reveal gradation through a zone 10–15 feet thick into the overlying lavender Kneeling Nun Tuff of Miocene(?) age. In the Dwyer quadrangle the formation includes both massive and bedded pyroclastics (Elston, 1957, p. 23–24). In the Lake Valley and Hurley East quadrangles several massive vitric-crystal tuffs 20–50 feet thick are intercalated with bedded tuffs. Some tuffs are finely bedded; others are crossbedded and may contain symmetrical ripple marks. Graded bedding was noted by both Lasky (1936) and Elston (1957). The bottom layers of the formation are composed principally of bedded conglomeratic tuffs.

The following section was measured east of the Chino mine.

Section measured on northwest slope below Kneeling Nun landmark

	Thickness (feet)
Massive crystal tuffs of the Kneeling Nun Tuff.	
Sugarlump Tuff:	
Tuff, light-gray, in part pumiceous; 25–30 percent of volume is crystal and lithic fragments. Crystal fragments are quartz, glassy feldspar, and well-preserved books of golden-brown biotite; lithic fragments are of an unidentified brown igneous rock. Chalcedony is present as both cement and fragments. Grades upward into overlying massive tuffs	100
Sandstone, brown; composed of fine to coarse grains of quartz, glassy feldspar, and deformed books of golden biotite	11
Conglomerate, pumiceous; contains some crystal and lithic fragments; lower half contains a 1-ft-thick bed of brown sandstone with sandstone pebbles	5
Sandstone, gray, brown; 2 ft of pumiceous tuff at top	8
Tuff, pinkish-gray, fine-grained, relatively homogeneous; crystal and lithic fragments in streaks; forms a conspicuous ledge	25
Tuff, massive, soft; contains pumice and other lithic fragments ½–8 in. long. Small angular fragments of felsite(?) and golden biotite crystals are common	50
Tuff, pumiceous, massive; white in upper part, gray in lower; contains sparse crystal and lithic fragments	270
Total	469
Colorado Formation.	

The brown sandstone near the top of the section is an excellent horizon marker and has been differentiated on larger scale maps (Lasky, 1936). The distinctive color of the rock is due primarily to limonitic pigment and cement (Lasky, 1936, p. 41). In cross sections published by Graf and Kerr (1950, p. 1036–1038), based on drill-hole data, green sand layers are shown underlying the brown sand or interbedded with it.

The proportions of various constituents in individual layers of the Sugarlump Tuff are not consistent. In some layers the dominant material is fragmental volcanic rock, in others it is perlite, and in others, pumice. Some layers contain various mineral fragments. Fragments of quartz, biotite, sanidine, oligoclase, andesine, apatite, sphene, augite, hornblende, zircon, and magnetite have been recognized in the crystal and crystal-vitric tuffs. Layers of light-bluish-green clinoptilolite occur in the uppermost beds of sandstone southeast of Bayard. The matrix of the tuffs is commonly made up of glass shards in various stages of devitrification.

Locally, the tuffs in the lower part of the formation are partly to completely altered to pink and white montmorillonite (Graf and Kerr, 1950, p. 1033). Lasky (1936, p. 40) previously reported montmorillonite adjacent to some of the strong faults in the Bayard area.

KNEELING NUN RHYOLITE TUFF

The Kneeling Nun Rhyolite Tuff was first named by Jicha (1954, p. 44) for the Kneeling Nun landmark at Santa Rita, N. Mex.

The tuff underlies several square miles of the southern part of the quadrangle and crops out continuously almost to the center of the Dwyer quadrangle.

The tuff is conformable with the underlying Sugarlump Tuff; the contact is gradational and is arbitrarily placed where the rhyolite tuffs change downward from pink or purple gray to white or light gray, and from massive indurated tuff to well-bedded weakly consolidated tuff. The upper contact of the Kneeling Nun Tuff is an erosional surface of low relief. In the southeast corner of the Santa Rita quadrangle the Kneeling Nun is overlain by flows of basaltic andesite, but in the south-central part a lens consisting of a highly indurated rhyolite tuff, a pitchstone flow, and a bed of sandstone intervenes between the Kneeling Nun Tuff and the lowest basaltic andesite flow. This lens is mapped separately, and is described under the heading "Pitchstone, Sandstone, and Rhyolite Tuff."

From a distance the Kneeling Nun Tuff appears stratified, especially near its base (Lasky, 1935, pl. 8*A*). Actually, the apparent stratification is caused by a strong set of nearly flat joints. Closer inspection of the outcrops reveals crude bedding, a resultant of the tendency of lithic fragments to be nearly flat and to be oriented with their long dimensions parallel. Elston (1957, p. 26) noted that near the base there is an alinement of irregular cavities as much as 8 inches in diameter and 1½ inches high; these cavities contribute to the bedded or sheeted appearance of the rock. Columnar joints are also conspicuous, except in the upper fourth of the formation.

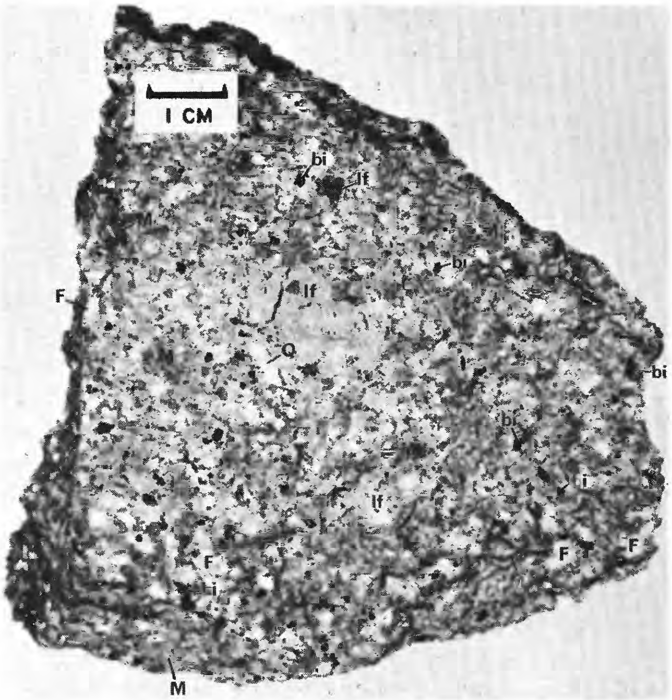


FIGURE 37.—Kneeling Nun Tuff. Fragments and crystals of bronze biotite flakes, bi; quartz, Q; and feldspar, F, set in lavender partly devitrified matrix, M; lithic fragments, lf.

The Kneeling Nun Tuff is 400–600 feet thick in the Santa Rita area, and the thickest part is south and southwest of the Chino mine dump. Elston (1957, p. 26) reported a thickness of 200–400 feet in the Dwyer quadrangle, and Jicha (1954, p. 45) reported a maximum thickness of 200 feet and a minimum of only 6 feet in the Lake Valley quadrangle. The range in thickness is only partly due to original thickness, as the upper surface is weathered and dissected, and some of the formation has been eroded.

The rock is a pinkish- to purplish-gray massive crystal-vitric tuff, containing sparse lithic fragments in some layers. (See fig. 37.) Crystal fragments, ranging in size from a fraction of a millimeter to 5 mm, constitute 30–45 percent of the rock. In hand specimens, quartz, sanidine, plagioclase, biotite, and, less commonly, hornblende are readily identifiable. Microscopic examination reveals the presence of apatite, zircon, sphene, magnetite-ilmenite, and, rarely, augite. The proportion of each mineral constituent in samples from widely spaced localities is given in table 18. The crystal fragments are set in a pinkish-brown aphanitic matrix which microscopic examination shows to be principally glass in various stages of devitrification or of replacement by fibrous and spherulitic growths of chalcedony and potassic feldspar. Straight, curved, and forked forms in the glassy remnants are believed to be deformed shards. They are commonly draped around the sharp corners of crystal fragments.

Quartz and sanidine are present as broken euhedra, sharp wedges, and grains with smooth but highly irregular outline. The angular fragments of plagioclase have a composition of about An_{30}. Biotite occurs as fresh shiny bronze flakes and thin books; it is strongly pleochroic (deep reddish brown to yellowish green) and, in some specimens, is extensively altered to magnetite. A few grains of hornblende (lamprobolite), which are black and shiny in hand specimen, have the same strong pleochroism as the biotite.

TABLE 18.—*Modes of Kneeling Nun Tuff from the Santa Rita and adjoining quadrangles, in percent*

[X, present]

Major constituents	1	2	3	4	5	6
Quartz	15.8	21.5	16.5	9.6	7.8	14.2
Sanidine	14.7	7.9	4.7	6.1	8	8.3
Plagioclase [1]	10.1	1.6	7.9	18.1	8.5	9.6
Biotite	1.1	1	1.5	5	2.8	2.3
Magnetite-ilmenite	.2	.5	.5	1.2	<1	.6
Lithic fragments	1.5	X	X	X	X	X
Matrix	55.6	67.5	68.9	59.2	71	64.4

[1] Oligoclase-andesine (An_{10-35}).

Minor constituents are albite, tridymite, cristobalite, augite, apatite, sphene, zircon, rutile, hematite, leucoxene, sericite, chlorite, calcite, and hornblende, but they are not all present in any one specimen.

SAMPLE DESCRIPTION

1. Average mode of tuffaceous rhyolite (Kuellmer, 1954, p. 46).
2. Kneeling Nun Tuff, center northern boundary, sec. 17, T. 19 S., R. 10 W. (Jicha, 1954, p. 45).
3. Base of Kneeling Nun Tuff, Dwyer quadrangle, south slope of Mimbres Peak, SE¼NW¼ sec. 17, T. 19 S., R. 10 W. (Elston, 1957, p. 27).
4. Specimen JC-1-54, Kneeling Nun Tuff, 2,000 ft north of BM 6584, sec. 7, T. 18 S., R. 12 W., Santa Rita quadrangle. Core from drill hole. Chemical analysis given in table 19, col. 2.
5. Average of four estimates made by Lasky (unpub. data).
6. Average of cols. 1-5.

The three chemical analyses listed in table 19 indicate a range in composition from quartz latite, or even rhyodacite, to rhyolite. This range is brought out in the normative plot (fig. 36), from which it can be seen that two specimens (2a, 2b) plot close to Nockolds' average rhyolite, and that one (2c), from the Santa Rita quadrangle, plots close to Nockolds' average rhyodacite. In the normative diagram of figure 13 the Kneeling Nun Tuff from the Dwyer quadrangle (point 17) plots within the granite-rhyolite field, but the sample from the Santa Rita quadrangle (point 18) plots within the granodiorite-rhyodacite field.

TABLE 19.—*Chemical analyses and norms of Kneeling Nun Tuff*

[nd, not determined; --, absent]

	1	2	3
Chemical analyses			
SiO_2	72.82	66.17	71.23
Al_2O_3	11.49	17.30	12.72
Fe_2O_3	1.67	2.21	2.72
FeO	.67	.33	.72
MgO	.61	.86	.55
CaO	1.43	3.33	1.49
Na_2O	2.70	4.79	3.50
K_2O	5.13	3.58	4.81
H_2O+	2.12	.30	.83
H_2O-	.54	.47	.49
TiO_2	.33	.39	.44
P_2O_5	.10	.20	.12
MnO	.06	.05	.06
BaO	nd	.10	nd
CO_2	0	.01	0
ZrO_2	nd	.02	nd
Total	99.67	100.11	99.68
Normative minerals			
Quartz	34.38	17.96	30.12
Orthoclase	30.02	21.13	28.36
Albite	23.06	40.35	29.34
Anorthite	4.17	15.01	3.06
Wollastonite	.93	.70	1.81
Enstatite	1.50	--	1.40
Magnetite	1.39	--	1.39
Ilmenite	.61	.76	.76
Hematite	.80	.70	1.81
Apatite	.34	0	.46
Calcite	--	--	1.60

1. Tuffaceous rhyolite, Black Range, near State Highway 90; H. B. Wiik, analyst (Kuellmer, 1954, R-2, p. 63-66).
2. Kneeling Nun Tuff, Santa Rita quadrangle; L. L. Trumball, analyst. Specimen CA-1-53.
3. Kneeling Nun Tuff, Dwyer quadrangle; H. B. Wiik, analyst (Elston, 1957, p. 44, table 8, col. 2).

RHYOLITE TUFF IN NORTHERN PART OF QUADRANGLE

Erosional remnants of an indurated crystal-vitric tuff, lithologically indistinguishable from the Kneeling Nun Tuff and other indurated rhyolite tuffs of the region, crop out along the escarpment north of Hanover Mountain. This tuff ranges in thickness from 0 to 40 feet and rests on an eroded surface underlain by the Colorado Formation and sills of hornblende quartz diorite. The upper contact of the tuff is an erosional surface on which sandstone, rhyolite tuff breccia, and basaltic andesite flows were deposited, in that order. Because this unit cannot be correlated directly with a specific rhyolite tuff in the volcanic field to the south, it is shown on the geologic map by a distinctive symbol.

FELSITIC RHYOLITE PLUGS AND DIKES

Plugs and dikes of nearly aphanitic flow-banded rhyolite intrude Paleozoic and Mesozoic sedimentary rocks near the quadrangle boundary, east of the Kneeling Nun landmark (secs. 31 and 32, T. 17 S., R. 11 W.). A rhyolite dike is crossed by State Highway 90 about a quarter of a mile east of the quadrangle boundary; it intrudes Percha Shale and sills of rhyolite porphyry. A north-trending felsite dike 10 feet wide and 300 feet long cuts the Colorado Formation in North Star Basin, 6,750 feet S. 80° W. from the top of Hermosa Mountain.

The largest rhyolite plug, in the E½ sec. 32, T. 17 S., R. 11 W., was mapped and described by George Koch (fig. 38). His description, slightly modified, follows.

The plug is about 1,518 feet long and 450–660 feet wide; the long axis trends due north. Almost all the rock is well foliated and breaks into plates ⅛–¼ inch thick. In a few places, dikes of unfoliated rhyolite cut the plug, but these dikes are not differentiated on the map (fig. 38). In other places, such as at the extreme southwest margin of the plug, the rhyolite is brecciated and contains inclusions of gray limestone. The flow banding parallels the east and west margins in the north-central part of the plug, but it is arranged across the long axis at the north tip and in much of the south half (fig. 38). The flow layers dip steeply, from 60° to 90°. Locally, flow layers are intricately contorted. Axes of the smaller folds appear to have a random orientation but tend to parallel lineation in some places; orientation of some of the axes of larger folds can be inferred from the map pattern. A fluting, consisting of folds whose wave lengths are an inch or less, is locally prominent. Lineations of mineral streaking, mostly biotite, are common, and almost without exception plunge directly down the dip of the flow layers.

The rhyolite of the plug is a white to pink dense porphyritic rock with phenocrysts of quartz and biotite in a light-colored aphanitic groundmass. The quartz phenocrysts, some three-sixteenths of an inch long, are generally stubby prisms, but some have pyramidal terminations. The biotite occurs as small equidimensional books and as barely perceptible fine grains.

The felsite dike in North Star Basin is light tan on fresh fractures and chocolate brown on weathered surfaces. No phenocrysts are visible. Flow banding is evident in a few exposures.

The relative age of the felsitic rhyolite plugs and dikes cannot be determined within the quadrangle boundary. Some indication of their age, however, is furnished by the work of Elston (1957) in the Dwyer

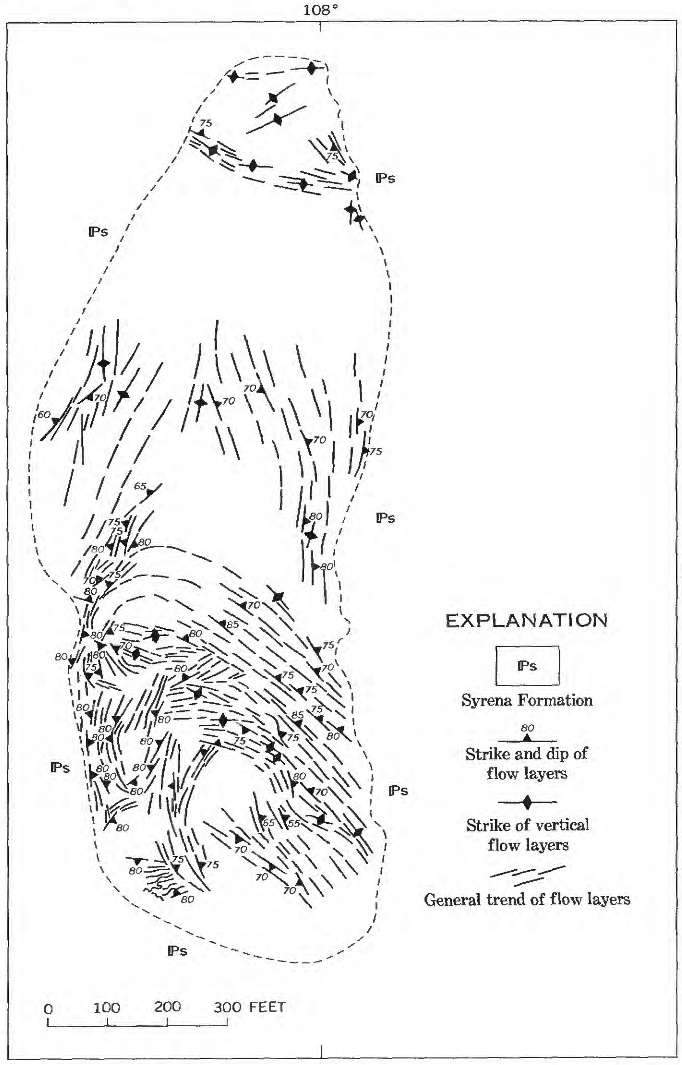


FIGURE 38.—Internal structure of rhyolite plug in sec. 32, T. 17 S., R. 11 W., Santa Rita quadrangle, New Mexico. Map by George Koch, 1950.

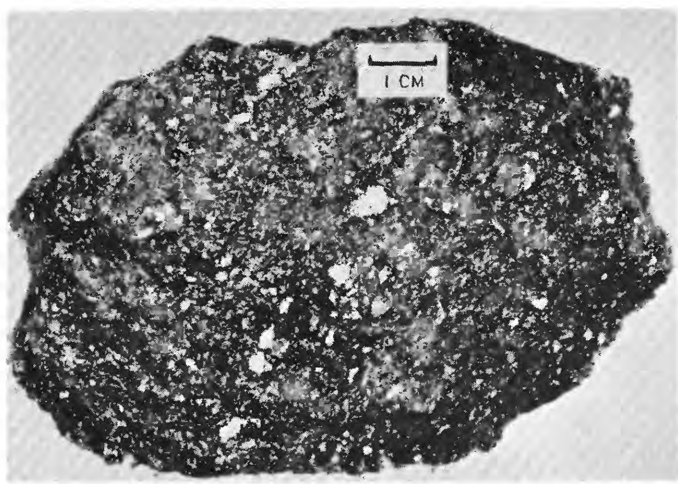


FIGURE 39.—Pitchstone of Miocene(?) age. Small light-colored grains are fresh plagioclase, orthoclase, and quartz. Larger white areas are rock fragments.

quadrangle, where a similar rhyolite was intruded after deposition of the Kneeling Nun Tuff. In one place the rhyolite was intruded before deposition of the overlying highly indurated tuff (Box Canyon Rhyolite Tuff) and in another place, after some of the basaltic andesite flows had occurred. The felsitic rhyolite of the Santa Rita quadrangle is probably contemporaneous with one or the other of these rhyolite intrusives in the Dwyer quadrangle.

PITCHSTONE, SANDSTONE, AND RHYOLITE TUFF

From the Chino mine dump to beyond the south boundary of the Santa Rita quadrangle, the Kneeling Nun Tuff is locally overlain by a sequence of beds which includes, from the bottom up, a thin black pitchstone, a sandstone, and an indurated rhyolite tuff. Locally, both the pitchstone and the sandstone are missing, and the highly indurated rhyolite tuff rests directly on the Kneeling Nun Tuff. At the scale of the geologic map, the pitchstone, sandstone, and indurated tuff cannot be differentiated; so all three are included in one map unit. Because the pitchstone and sandstone are generally thin and poorly exposed, the map unit largely reflects the outcrop of the ledge-forming indurated tuff. The pitchstone and sandstone were correlated by Elston (1957, pl. 3) with his Mimbres Peak Formation, and the indurated tuff, with his Box Canyon Rhyolite Tuff. All three units are absent over a distance of about 7 miles between the exposures in the Santa Rita quadrangle and those in the Dwyer quadrangle, presumably because of erosion.

The pitchstone is a generally shiny black, but sometimes red, porphyritic rock which contains lithic fragments and crystals of biotite, albite, sanidine, oligoclase, quartz, augite(?), and magnetite (fig. 39). It ranges in thickness from 0 to 10 feet. In the Santa Rita quadrangle many exposures show drawn-out vesicles, which suggest that the material flowed during or soon after formation of the vesicles. Elsewhere, the pitchstone differs from the crystal-vitric tuffs of the Kneeling Nun and Sugarlump Formations only in that the glass matrix is black or red rather than white or salmon pink. The glass of the pitchstone has a refractive index of about 1.505, which indicates a silica content of about 72 percent (George, 1924, p. 365).

The sandstone that commonly overlies the pitchstone is fine to medium grained and in part tuffaceous, and it locally contains grains of black pitchstone. It ranges in thickness from 0 to 30 feet.

The tuff is a massive thoroughly indurated pinkish-gray crystal-vitric rhyolite tuff and ranges in thickness from 0 to 65 feet; where thick, it erodes to form a cliff which is conspicuous along the canyon walls. Like the Kneeling Nun Tuff, which it resembles very closely, it contains crystals of oligoclase-andesine, quartz, biotite, sanidine, augite, sphene, and magnetite, and sparse lithic fragments including pumice set in a pink to light-gray glass matrix. No chemical analyses have been made of this crystal tuff.

230-093 O—66——8

RHYOLITE TUFF INTERCALATED BETWEEN FLOWS OF BASALTIC ANDESITE

A unit of rhyolite tuffs (Caballo Blanco Rhyolite Tuff of Elston, 1957) that consists of massive tan rhyolite crystal tuff and is both capped and underlain by soft white pumiceous tuff containing crystal and lithic fragments underlies an area of several square miles in the Santa Rita, Hurley East, and Dwyer quadrangles. The unit ranges in thickness from 0 to 280 feet in the Santa Rita quadrangle but is 325 feet thick in the Dwyer quadrangle. Throughout most of its extent it is underlain and overlain by one or more flows of basaltic andesite. However, south-southwest of the Chino mine and in the central part of the Dwyer quadrangle the underlying mafic flows are absent, and the tuffs rest on the highly indurated crystal-lithic tuffs (the Box Canyon Rhyolite Tuff of Elston) or on the Kneeling Nun Tuff. The thickest section in the Santa Rita quadrangle consists of three gradational units, as follows:

Unit	*Character*	*Range in thickness (feet)*
Upper	White pumiceous tuff; contains some crystal and lithic fragments.	0–70
Middle	Tan to brown massive rhyolite crystal tuff.	0–170
Lower	White pumiceous tuff; contains many lithic fragments.	0–40
		0–280

Elston (1957, p. 30, 31) named these deposits the Caballo Blanco Rhyolite Tuff for Caballo Blanco Mountain, in the Dwyer quadrangle, and described them as follows:

> 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 drawn out, compressed, and welded glass shards. Devitrification 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. West of Caballo Blanco the basal 6–12 inches of tuff is usually compressed and dense.

In specimens from the Santa Rita area, green to brown hornblende was noted in one thin section, and the plagioclase is zoned andesine-oligoclase.

Exposures of the massive, middle unit of the tuff were shown by Paige (1916, pls. 2, 6). This unit may erode over several square acres to closely spaced rounded pinnacles as much as 20 feet high.

GRAVEL AND BOULDER DEPOSITS IN NORTHWESTERN PART OF QUADRANGLE

Semiconsolidated gravel and boulder deposits are restricted to the northern volcanic field. They lie beneath the flows of basaltic andesite in the Fort Bayard and Allie Canyon quadrangles and in the northwest corner of the Santa Rita quadrangle. They fill swales, gulches, and deep canyons cut in the older rocks. The surface of the gravels is somewhat dissected, and the channels are filled with basaltic andesite. In places the gravel and boulder deposits change abruptly in thickness across faults, either because they were laid down against fault scarps or because they were later faulted and eroded. The deposits are lenticular, and the bedding, where discernible, is nearly horizontal. In the Santa Rita quadrangle they have a maximum thickness of about 250 feet.

The deposits are made up of unbedded lenses of large boulders and crudely bedded lenses of gravel and some boulders; both types have a sandy matrix. Many of the larger pebbles and boulders were clearly derived from formations in the adjacent hills. The deposits near or in contact with the pink crystal tuffs contain little else than pieces of this tuff. Those at the west edge of the quadrangle contain pebbles and boulders of rocks exposed in North Star Basin; mafic porphyries, lamprophyric dike rock, sandstone and shale, and sparse large boulders of the crystal tuffs that crop out northwest of the quadrangle. At this locality the gravels rest on the andesite breccia of Late Cretaceous and early Tertiary age, which they resemble superficially. Near the head of Little Shingle Canyon, sec. 34, T. 16 S., R. 12 W., as much as 30 feet of finely banded sandstone and sandy basaltic tuff underlies the basaltic andesite flows and rests on an indurated pink crystal tuff. The layers strike close to north and dip 25° W. They are included in the map unit representing the boulder and gravel deposits, although the included basaltic material may indicate that they belong to an early phase of the basaltic andesite flows.

BASALTIC ANDESITE FLOWS

Flows of basaltic andesite cover areas of several square miles south of the Chino mine and in the northwest corner of the quadrangle; for the most part they were deposited on erosion surfaces cut on older volcanic rocks. In the southern part of the quadrangle the flows rest on the Kneeling Nun Tuff in some places and on stratigraphically higher rhyolite tuffs in others. In the northern part of the quadrangle they rest on the boulder and gravel deposits in a few places, and elsewhere on an erosion surface cut on crystal tuff and still older rocks.

The basaltic andesite in the southern part of the quadrangle reaches a maximum thickness of about 500 feet, excluding an intercalated lens of rhyolite tuff that is described on preceding pages; this thickness is somewhat less than the original thickness, because the upper surface of the flows is the present surface of erosion. The basaltic andesite beneath the intercalated tuff is thickest (about 200 feet) in the east half of the area. It thins and wedges out to the west, but toward the south and southeast it continues to the center of the Dwyer quadrangle. The basaltic andesite above the tuff aggregates about 300 feet in thickness; individual flows are about 40 feet thick. This series of flows underlies an area of many square miles to the south and southeast. The lower basaltic andesite was named the Rustler Canyon Basalt by Elston (1957, p. 30). It is not named in this report because it is indistinguishable from the upper basaltic andesite where the intercalated rhyolite tuff is absent.

The basaltic andesite flows in the northern part of the quadrangle have an aggregate thickness of about 850 feet and underlie an area of many square miles north and northwest of the quadrangle.

The general aspect of the mafic volcanic series varies within the region and within individual flows in such details as texture, granularity, proportion of mineral constituents, and nature of the pyroxene and plagioclase. Detailed petrographic descriptions have been published by Kuellmer (1954), Jicha (1954), and Elston (1957). Kuellmer (p. 82) noted a cyclical sequence of units in the series east of the Mimbres River which has not been recognized elsewhere. Elston (p. 35) described alternating layers of flows and pyroclastic rocks, that include bombs as much as 18 inches in diameter east of the Mimbres River, near sec. 23, T. 18 S., R. 10 W.

In the Santa Rita quadrangle the andesite is porphyritic and the groundmass is aphanitic to fine grained; the top and, less commonly, the bottom of the flows are reddish-gray, vesicular, and brecciated. The interior of the flows is gray to dark gray and has a purplish tinge. Weathered outcrops are dark reddish brown.

The range in modes is brought out in table 20.

TABLE 20.—*Analyses, norms, and modes, in percent, of basalt and basaltic andesite*

[nd, not determined; ng, not given; Tr., trace (<0.3); --, absent]

Chemical analyses

	1	2	3		1	2	3
SiO_2	53.55	51.17	54.20	H_2O+	1.14	1.68	0.86
Al_2O_3	15.09	14.43	17.17	H_2O-	.28	.19	ng
Fe_2O_3	3.01	4.49	3.48	TiO_2	1.44	2.00	1.31
FeO	5.46	5.90	5.49	P_2O_5	.35	.55	.28
MgO	5.72	6.43	4.36	MnO	.16	.17	.15
CaO	8.22	8.33	7.92	CO_2	.71	nd	ng
Na_2O	2.90	3.05	3.67				
K_2O	1.84	1.62	1.11	Total	99.87	100.01	100

Semiquantitative spectrographic analyses [1]

	4	5		4	5		4	5
Ba	0.07	0.15	La	0.003	0.003	V	0.015	0.007
Co	.003	.003	Ni	.003	.007	Y	.003	.003
Cr	.003	.007	Sc	.003	.0015	Yb	.0003	.0003
Cu	.007	.003	Sr	.15	.15	Zr	.015	.03
Ga	.0007	.0007						

Norms

	1	2	3		1	2	3
Quartz	6.42	3.30	5.7	Hematite	--	--	--
Orthoclase	10.56	9.45	6.7	Wollastonite	4.76	6.96	4.2
Albite	24.63	25.68	30.9	Enstatite	14.30	16.10	10.9
Anorthite	22.80	20.85	27.2	Ferrosilite	5.41	4.09	5.3
Ilmenite	2.74	3.80	2.4	Apatite	.67	1.34	.7
Magnetite	4.41	6.50	5.1				

Modes

	6	7	1	8	9	10
Matrix	32	65	ng	75	ng	95
Primary minerals:						
Plagioclase	41	14	57	75	45	68
Range An content	An_{61}	An_{45}	An_{35-50}	An_{26}	An_{43-63}	An_{62}
Hypersthene	22	--	--	5	37	--
Augite	1			--	--	18
Pigeonite	--	6	31	--	--	--
Olivine	Tr.	--	1	--	5	Tr.
Hornblende	--	Tr.	--	--	--	--
Uralite	--	2	--	--	--	--
Biotite	--	2	--	--	--	--
Quartz	--	4	--	--	--	--
Sphene	Tr.	--	--	--	--	--
Magnetite	2	3	6	3.1	11	5
Hematite	--	4	Tr.	--	--	--
Secondary minerals:						
Iddingsite	Tr.	--	3	5.4	2	9
Zeolite	--	--	--	Tr.	--	--
Calcite	1	--	--	11.5	--	--
Sericite	1	--	--	--	--	--

[1] Analyst: J. C. Hamilton. Figures reported to nearest number in series 7, 3, 1.5, 0.7, 0.3, 0.15. Looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ce, Dy, Er, Eu, Gd, Ge, He, Hf, Hg, In, Ir, Li, Lu, Mo, Nb, Os, Pb, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.

SAMPLE DESCRIPTION

1. Field No. 389–C–87. Andesite flow in sec. 8, T. 17 S., R. 10 W., 300 feet north of State Highway 90. Chemical analysis by H. B. Wiik (Kuellmer, 1954, p. 64, 65); norm and mode by Kuellmer (1954).
2. Field No. 413–A–b2. Bear Springs Basalt of Elston (1957, p. 40, 41); west of Mimbres River, SE¼SE¼ sec. 33, T. 18 S., R. 10 W. Chemical analysis by H. B. Wiik (Elston, 1957, p. 40); norm by Elston (1957).
3. Average andesites of Nockolds (1954, p. 1019).
4. Field No. JC–7–52. Small plug of basaltic andesite 2,600 feet west of Hanover Mountain.
5. Field No. JC–1286–54. Chip samples of basaltic andesite flow in SE¼ sec. 36, T. 16 S., R. 13 W.
6. Hypersthene andesite, north line NE¼ sec. 17, T. 17 S., R. 10 W. (Kuellmer, 1954, p. 83, mode p. 64).
7. Andesite, 3 miles south of Lorenzo, east bank of Mimbres River (Kuellmer, 1954, p. 83, mode p. 65).
8. Bear Springs Basalt of Elston (1957); citation and mode by Jicha (1954, p. 49).
9. Bear Springs Basalt of Elston (1957); Dwyer quadrangle; mode (Elston, p. 49).
10. Field No. HC–5–52. 10,400 feet south of Chino mine.

Microscopic examination of five thin sections of basaltic andesite from widely spaced outcrops and from several stratigraphic positions in the Santa Rita quadrangle showed that the rocks are almost identical. Reddish-brown phenocrysts 0.5–1 mm in diameter, some of which have the crystal form of olivine, and others that of pyroxene, constitute 3–9 percent of the rock volume. These grains are probably goethite (Sun, 1957, p. 525–533). The matrix is mostly composed of laths of labradorite about 0.2 mm long. Minute grains of pyroxene, 0.02–0.2 mm long, are partly or entirely replaced by goethite. Opaque grains, probably magnetite, 0.02–0.1 mm in diameter, are disseminated throughout the rock. Brown glass is interstitial to the feldspar laths. The feldspar laths are alined in some places and haphazardly arranged in others.

For further petrographic details the reader is referred to descriptions by Paige (1916, p. 10), Kuellmer (1954, p. 82–83), and Elston (1957, p. 35).

No chemical analyses of the basaltic andesite flows in the Santa Rita quadrangle are available. The analyses in table 20 are of similar flows in the Dwyer and Mimbres quadrangles; the composition of Nockolds' (1954, p. 1019) average andesite is listed for comparison. Although considerable olivine is reported in the mode of the basaltic andesites, none appears in the norm. Conversely, no quartz is present in the mode, but as much as 6 percent appears in the norm. The plot of normative constituents falls closer to that of the average andesite or diorite than to that of the tholeiitic basalt (fig. 13, point 16; fig. 36, lines 3, 4). The name "basaltic andesite" seems to be appropriate for the series as a whole.

BASALTIC ANDESITE PLUGS AND DIKES

Five plugs and one dike which have the same mineral composition as the basaltic andesite flows crop out within the Santa Rita quadrangle. Similar dikes and plugs are present in the Dwyer quadrangle (Elston, 1957, p. 35). Of the five plugs in the Santa Rita quadrangle, four are in the SW¼ sec. 4, T. 17 S., R. 12 W., less than 1 mile west of Hanover Mountain, and the fifth is at the south margin of the small plug in North Star Basin, sec. 6, T. 17 S., R. 12 W. The basaltic andesite plugs are elliptical in outline and have long axes 200–600 feet long. The basaltic andesite of the plugs commonly breaks into thin slabs along flow-banding surfaces. Vesicles are common in the margins of the plugs and dikes.

The plug nearest the boundary between secs. 4 and 5 contains large masses of the pink indurated rhyolite crystal tuff. These masses must have sunk at least 100 feet in the magma, as the wallrock of the plug is the Colorado Formation at a position 100 feet stratigraphically below the lowest crystal tuff.

Although the degree of crystallinity differs somewhat from place to place within each basaltic andesite plug and from one plug to another, the rock in all the plugs is essentially identical; it is different from the basaltic andesite flows in that there is more glass in the matrix. In this glassy matrix are crystals of augite, hypersthene, olivine, and magnetite. Some olivine grains are fresh, but others are altered to goethite or antigorite. Small vesicles filled with calcite were noted in some thin sections.

A large basaltic andesite dike cuts vertically through the rhyolite tuff series south of Lucky Bill Canyon (secs. 8 and 9, T. 18 S., R. 12 W.). This dike strikes N. 72° W., is more than a mile long, and has a maximum width of 50 feet. South of BM 6912, in sec. 9, the dike seems to merge with a flow of basaltic andesite.

Two andesitic dikes crop out half a mile north of Hanover Mountain; both strike east and are 5–10 feet wide. One has a strike length of about 1,000 feet, the other about 500 feet. These dikes are exceptional in that they contain partly resorbed hornblende phenocrysts and considerable interstitial quartz. Much of the matrix consists of plagioclase laths and interstitial chlorite; minute grains of magnetite-ilmenite and leucoxene are abundant. The rock contains no fresh olivine, but rounded areas of serpentine and chlorite may be pseudomorphic after olivine. A few sparse relatively large phenocrysts of twinned augite were present in one thin section. Many vesicles are filled with calcite. The rock resembles the pyroxene andesite in the Rubio Peak Formation as described by Elston (1957, p. 21–22).

SEMICONSOLIDATED GRAVEL DEPOSITS IN THE MIMBRES RIVER VALLEY

In the northeast corner of the Santa Rita quadrangle is a small part of the extensive but deeply dissected deposit of semiconsolidated gravel which lies within the Mimbres River valley to the east. The gravel deposits are well exposed in the quadrangle on the north side of Shingle Canyon, 1 mile north of Georgetown; at most places within the quadrangle, however, they are covered by debris derived from the disintegration of the deposits themselves. The thickness of the beds exposed in the north wall of Shingle Canyon is about 250 feet; a hole drilled in the canyon floor penetrated 570 feet of gravel and did not intersect older formations. Thus, the valley fill in the Shingle Canyon area is at least 820 feet thick; farther east, toward the center of Mimbres Valley, the deposits are undoubtedly much thicker. Within the Santa Rita quadrangle the gravel deposits are in fault contact with the older bedrock, but elsewhere they gradually thin out against the rising bedrock surfaces of the adjoining ranges.

The gravel deposits within the quadrangle are dissected by Shingle and Willow Springs Canyons and by smaller canyons and draws. The drainage pattern is dendritic, and the area has been eroded to a surface of early maturity. The ridge crests correspond approximately in level and may be near the former level of the uneroded alluvial plain, but more likely they are remnants of a surface developed on the conglomerate during an earlier cycle of erosion. (See description of "Bayard Surface," p. 134–135.)

The gravel is poorly sorted but shows crude bedding. The pebbles and cobbles are angular to subrounded and most are 2–4 inches long. Some boulders and large cobbles range in greatest dimension from 10 to 24 inches; these are irregularly distributed through the exposed section. Interstices between the rock fragments are filled with granules and sand; silt and clay are inconspicuous or absent. The cement is mainly calcium carbonate.

The rock fragments represent all of the more resistant rocks of the mountains for several miles around. Most of the materials of the formation are clearly derived from local sources, as pointed out by Paige (1916, p. 6). The rocks represented include Paleozoic limestone, Cretaceous sandstone and quartzite, andesite breccia, Upper Cretaceous(?) and Tertiary intrusive rocks, and extrusive rocks of the Miocene(?) volcanic suite, as well as much unidentified material.

The crude bedding of the formation is nearly horizontal; a slight eastward dip toward the Mimbres River is suggested in places, but good exposures are too limited in the quadrangle to be certain.

The origin of the gravel of the region was discussed by Paige (1916, p. 6–7). The gravel is clearly a valley-fill type of deposit; the mountainous areas supply the materials and are gradually buried in their own debris.

The gravel rests unconformably on many older formations in the Mimbres River valley, including the Miocene(?) volcanic rocks. Its exact age is not known, but it is correlated with similar formations of Miocene(?) and Pliocene age (Knechtel, 1936; Heindl, 1952). The gravel seems to merge at the headwaters of the Mimbres River valley with the conglomerate in the Gila River drainage area west of the Continental Divide. Jicha (1954) and Elston (1952) correlated the conglomerate farther south in the Mimbres River valley with the Santa Fe Formation of late Tertiary to early Quaternary age.

QUATERNARY ALLUVIUM AND COLLUVIUM

Alluvium and colluvium were mapped only where they cover large areas; where they cover small areas they were mapped only where critical or where otherwise important bedrock geology is obscured.

Alluvium and colluvium of at least two ages have been recognized in the Santa Rita quadrangle, and these are differentiated on the map; they comprise younger virtually unconsolidated sand and silt of valley floors and flat uplands, and older partly cemented deposits that may occur anywhere from the valley floors to crests of minor divides. Younger deposits shown on the map locally may include small areas of adjacent older deposits. All coarser deposits that are not on either valley floors or flat uplands are classed as older deposits; they locally may include some younger deposits, such as talus. In places, alluvium and (or) colluvium obscure formational contacts, and they are only approximately located.

Erosion during the time of deposition of older and younger deposits seems to have been marked by continuous downcutting, for prominent paired terraces are unknown in the quadrangle. They are known southwest of the quadrangle, however, and once may have existed within it.

OLDER ALLUVIUM

In any given locality the oldest alluvium rests on remnants of a plane to rolling surface that is 50–200 feet above the nearest master valley. The deposits include materials of both local and distant origin.

The area on the flat divide south of the settlement of Wimsattville is easily accessible, but the deposits there are poorly exposed. The materials are altered sedimentary rocks, igneous rocks, and magnetite derived from within a maximum distance of a few miles. The older alluvium north of the Chino mine includes caliche and red silty gravel, the mutual relations of which are obscure.

Small patches of locally derived debris, cemented by iron oxide, cap the flat divide above the Treasure Vault shaft west of Santa Rita. Similarly cemented hillside rubble, such as that exposed about three-fourths of a mile south of Turnerville, continues downslope and dips under the younger uncemented alluvium of the valley floor. Such mantle rock and alluvium, cemented by iron oxide, is restricted to pyritized areas of the region. It apparently became cemented by shallow ground-water action while near-surface pyrite was being oxidized.

Comparison of elevations of the higher deposits of older alluvium with elevations of concordant ridge crests in the northeast corner of the quadrangle suggests that the surface represented by the concordant ridges is near the base level of the older alluvium as originally deposited. The amount of downcutting since the highest alluvium was deposited would seem to require a fairly early Pleistocene or even Pliocene age for these oldest deposits.

The cemented deposits at the bottoms of valleys have yielded fossils. A tooth collected 28 feet below the collar of a shaft in the Chino mine area was identified, according to G. J. Ballmer, Superintendent of Mines (oral commun., 1950), as that of a Columbian elephant. The possibility exists, however, that such a specimen was derived from an older deposit and redeposited where found.

Disarticulated fossil remains were collected from moderately cemented gravel at a point 8 miles west of Vanadium, N. Mex. The thin cemented gravel that contained the fossils underlies silt of the younger alluvium and rests on the Colorado Formation. The formations are exposed in a ravine near the center of a broad minor valley which is cut more than 175 feet below the adjacent divides. C. Lewis Gazin, Curator of Vertebrate Paleontology at the National Museum, stated (written commun., 1952): "I cannot distinguish these specimens from the common Pleistocene mastodon, *Mammut americanum*, and there is no evidence as to the portion of the Pleistocene represented. I would say, however, that the age is likely Pleistocene rather than Pliocene."

YOUNGER ALLUVIUM, TALUS, AND LANDSLIDE DEBRIS

Younger alluvium is found only in the bottoms of stream valleys and, as silt, on higher flats where these flats are protected from active erosion. The silt areas are cultivated locally. Talus accumulations prevent accurate mapping of contacts in many places but are most extensive on the slopes east and southeast of Kneeling Nun where they are continuous with similar cover on the flatter lower slopes. Both the younger alluvium and the talus include gravel, sandy gravel, sand, and silt, and both are unconsolidated or nearly so. Most of the deposits are cut by gullies, most of which, according to long-time residents, have been cut during the last 75 years.

Landslides at several places in the quadrangle are shown on the map. The large slide southeast of the Chino mine deserves special mention. In places it apparently merges into or is masked by talus, but at the upper end it is preserved in a slumped part of the relatively flat erosion surface developed on the volcanic rocks. This slide and talus area is localized where the volcanic rocks have been greatly weakened by joints that trend both northeast and northwest. The intensity of the northwest joint set decreases on either side of the slide.

STRUCTURE

REGIONAL STRUCTURAL SETTING

The location of the Santa Rita quadrangle in relation to the structural framework of southwestern New Mexico is shown in figure 40. The quadrangle lies on the boundary between the Basin and Range province and the Datil section of the Colorado Plateaus province, but its structure is more typical of the Basin and Range province, which in this region is characterized by broad open folds and steep north- or northwest-trending normal faults that bound horsts, grabens, and tilted blocks. The Santa Rita quadrangle lies on the northeast side of one of the prominent horsts that is bounded by northwest-striking faults, in an area where the horst is cut by a set of northeast-striking transverse faults (fig. 41). The strata within the horst form a broad shallow syncline that is locally modified by domes, arches, and tight superficial folds peripheral to several funnel-shaped plutons.

Although the structural grain of the region (fig. 40) largely reflects faulting in Miocene, or more recent times, the fault pattern probably developed as early as Late Cretaceous or early Tertiary time. Evidence is given later in this section to show that the fault (the Mimbres) bounding the horst on the northeast coincides in places with an older fault that served as a channelway for magma and mineralizing fluids probably in the early Tertiary. The initial movement on north-, northeast-, and east-northeast-trending faults in the Santa Rita quadrangle preceded the intrusion of early Tertiary stocks and the introduction of ore-forming solutions.

STRUCTURAL FEATURES OF THE SANTA RITA QUADRANGLE

Erosion of Miocene(?) and younger rocks from part of the east flank of the horst has revealed a crudely triangular subsidiary uplifted block, here named the Santa Rita horst. (See fig. 42.) The base of the triangular horst is an 8-mile-long segment of the Mimbres fault; the northwest side is marked by the Barringer fault, and the south side principally by a zone of discontinuous normal faults trending N. 75° E. Because the Barringer fault and the fault zone along the south side die out westward and do not intersect, the western apex of the triangular block is poorly defined. The surface area of the Santa Rita horst is about 40 square miles, and within the horst the strata are flexed into elongate arches, domes, small synclines, and locally into tight folds.

Differential movement of small blocks within the Santa Rita horst has formed subsidiary grabens and horsts. One of the earliest formed structures is the Fort Bayard arch, which extends from the town of Central almost to the northern apex of the Santa Rita horst. (See fig. 42.) Initially, the strata were arched by a series of overlapping lens-shaped sills, but intrusions and faults later deformed the arch. Its northwest flank is accentuated by downward flexing along the Barringer fault, and its south flank, by displacement along the Mirror and Hobo faults. The arch is further modified by a transverse elongate dome that formed consequent to intrusion of the Hanover-Fierro pluton. A shallow transverse downwarp parallels the transverse dome on the west, and this downwarp forms the northeast flank of a gentle dome which crests near Copper Flat. A similar shallow transverse syncline parallels the transverse dome on the east, between the Hanover-Fierro pluton and the Mimbres fault.

Several minor anticlinal and synclinal folds are recognized within and adjacent to the Santa Rita horst block. The strata are slightly domed over the south half of the Santa Rita stock, and farther east the Cretaceous beds are downwarped south of the Nancy and Hornet faults. Between the Hobo and Carbonate faults the beds are flexed downward and form a shallow syncline. (See pl. 2, cross section *F–F′*.) A segment of the east limb of this syncline is downdropped along northwest-trending faults in the area between Turnerville and Lee Hill, and in the vicinity of Hanover the north end of the syncline is downdropped in a wedge-shaped block. Northeast of Santa Rita a crescent-shaped graben, concave to the southeast, is bounded by the North and South Joy faults (pl. 2, cross section *E–E′*). A major graben, in the area of the Santa Rita stock, is bounded on the northwest by the Groundhog–Lovers Lane and Carbonate faults and on the southeast by unnamed faults trending N. 10°–15° E. These faults converge three-quarters of a mile northeast of the stock, near section line *G–G′*, to form the northern apex of the graben. The graben is covered to the south by mine dumps and volcanic rocks of Miocene(?) age. Renewed movement on the principal bounding faults of this graben in post-Miocene time produced a minor graben in the volcanic rocks.

Several breccia pipes and the Hanover Hole, a deep cylindrical cavity filled with sediments (p. 130), are the remaining major structural features of the quadrangle.

STRUCTURAL HISTORY

Little is known of the deformation during Precambrian time because exposures of rocks of this age are small and widely separated. No folds or faults are known to have formed during the entire Paleozoic Era.

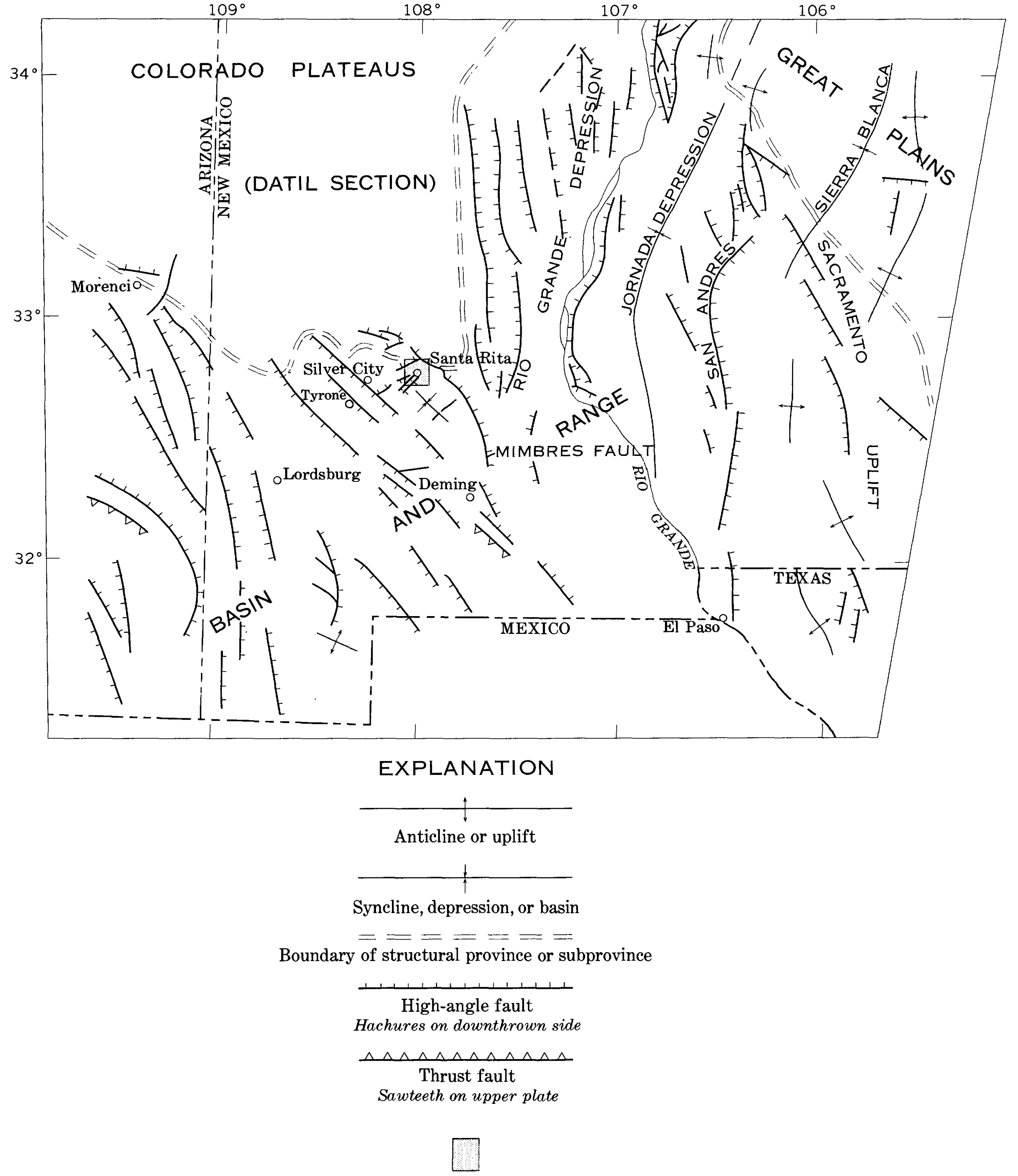


FIGURE 40.—Laramide-age and younger tectonic features of southwestern New Mexico. (Modified from Kelley and Silver, 1952, fig. 20.)

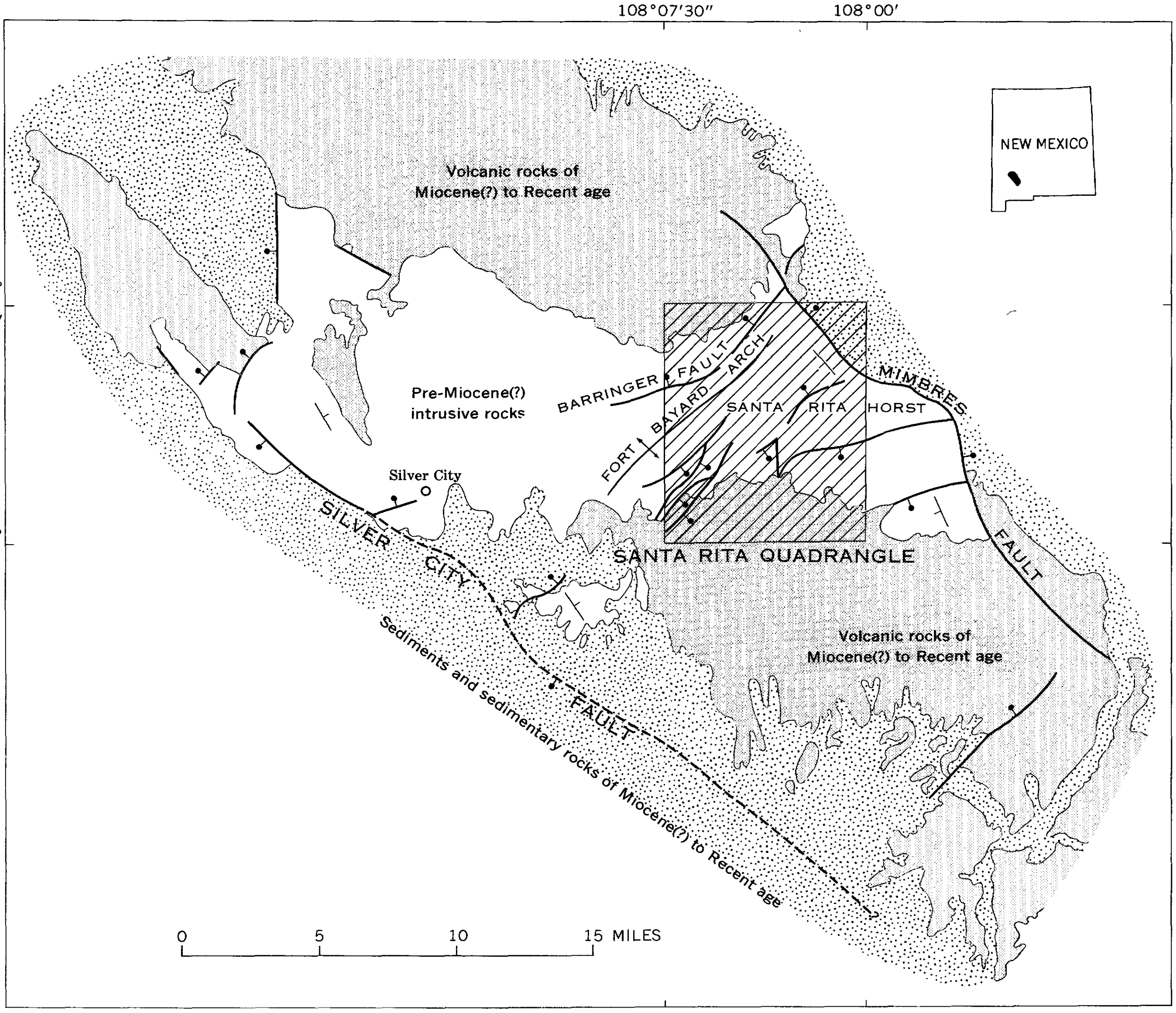


FIGURE 41.—Structural geologic setting of the Silver City region, Grant County, N. Mex. Strike and direction of dip of beds are shown. Faults are dashed where inferred; bar and ball on downthrown side. (Modified from Jones and others, 1961; and Dane and Bachman, 1961.)

The general parallelism of the Beartooth Quartzite and formations of the Paleozoic Era indicates that the strata were not folded or faulted before the quartzite was deposited in Late(?) Cretaceous time. The Paleozoic formations were probably domed in the southwest quarter of the quadrangle, however, because the Abo and Syrena Formations were eroded there prior to deposition of the Beartooth Quartzite. No rocks of Triassic or Jurassic age occur in the area; if they were deposited, they were eroded prior to deposition of the Beartooth Quartzite. The Santa Rita-Silver City region probably was above sea level during Early Cretaceous time. However, the region to the southwest, the Sonoran geosyncline, at the same time accumulated thousands of feet of sediment and volcanic rocks.

The major structural features of the Santa Rita quadrangle previously described date from the first intrusions of Late Cretaceous(?) time and are largely, if not entirely, the result of deformation during the Cenozoic Era. Much of the sequence of the major Cenozoic events in the structural and erosional evolution of the area is deduced from the sequence of igneous activity. Most of the folds and faults are directly or indirectly related to intrusions of sills, laccoliths, stocks, and dikes in the interval between Late Creta-

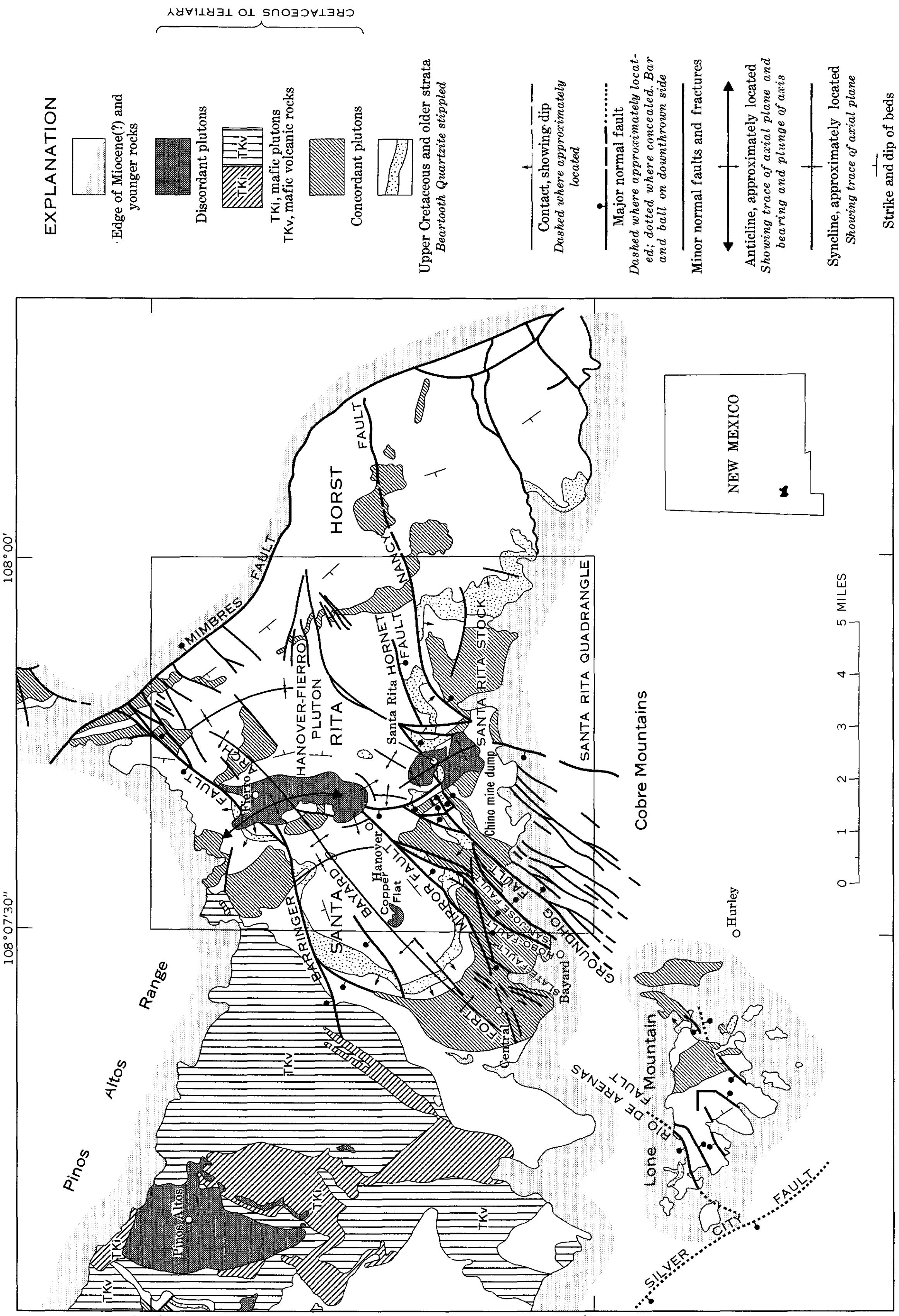


FIGURE 42.—Structural geologic setting of the Santa Rita quadrangle. Geology east of 108° based on Kuellmer (1956); west of 108° by U.S. Geological Survey.

ceous and Miocene(?) time. The sequence of deformation during this interval can be divided into the following four stages:

1. Deformation related to the intrusion of sills.
2. Deformation during the interval between the intrusion of sills and the intrusion of stocks.
3. Deformation related to the intrusion of stocks.
4. Deformation during the intrusion of dikes and plugs.

Much more detailed mapping is needed before faults of Miocene(?) to Recent age can be assigned a chronological order. However, available data clearly indicate that faulting took place intermittently during the deposition of Miocene(?) volcanic rocks. Some movement was on new faults, but much was on reactivated pre-Miocene faults.

Basin-and-Range-type faults, some of which displace the upper Tertiary to lower Quaternary valley-fill deposits, dominate the structural map of southwestern New Mexico. Some of these faults may have formed soon after Miocene(?) volcanic activity ceased, whereas others may have formed later, during the time the Gila and the Santa Fe gravels were being deposited. The movement on other faults, such as the Mimbres, which displaced the gravel formations, may have occurred as recently as late Pleistocene.

The Laramide volcanic epoch, during which 2,000–3,000 feet of andesite breccia and mafic flows accumulated and thousands of mafic dikes and a few mafic plugs were intruded, cannot be confidently dated with respect to the four stages of deformation of the Late Cretaceous and early Tertiary interval. However, the andesite breccia and many of the mafic dikes are younger than one of the major sills of syenodiorite porphyry; they are probably older than sills of hornblende quartz diorite, and are definitely older than the Pinos Altos stock. This stock is chemically and mineralogically identical with two stocks in the Santa Rita quadrangle and is therefore probably of the same age. The areas that had been domed by mafic sills and laccoliths were apparently truncated to the general level of the intervening areas before the andesite breccia was deposited as nearly flat-lying cover. The volcanic epoch is tentatively considered to have intervened between the intrusions of syenodiorite porphyry and hornblende quartz diorite.

The fault and fracture pattern formed principally during the interval between the intrusion of sills and the intrusion of granodiorite porphyry dikes which cut off and filled many faults. Only a few major faults, however, are demonstrably older than the major stocks, and the dating of many faults as prestock is based on the conclusion that the principal sets of faults are conjugate and generally contemporaneous. Hence, if a major fault of any one set is intruded by stock rock—and faults of all three major sets are—other members of the set probably also predate the stocks.

The total measurable displacement on many of the faults is the result of recurrent movement during the intervals between events other than faulting, such as the intrusion of stocks and dikes, the injection of ore-bearing fluids, and the extrusion of tuffs and flows. It is not always possible to allocate the total displacement to the various times of activity, as Lasky was able to do for the Groundhog–Ivanhoe–Lovers Lane fault. Regarding this fault he stated (in Lasky and Hoagland, 1948, p. 16), "The pre-dike movement yielded a throw on the order of 1,000 feet; the post-dike, preore throw averages about 250 feet; and the postvolcanic throw aggregates 330 feet." Thus, along this master fault of the district, the predike movement represents about 60 percent of the total, and this factor might apply to movement on the nearby parallel faults.

Six breccia pipes are exposed within the Santa Rita quadrangle; these are described under stage 3, deformation related to the intrusion of stocks. Although the oldest pipe may predate the stocks, two definitely postdate them, and the ages of the others cannot be fixed with respect to stages 2, 3, or 4.

The following description of structural features of the Cenozoic Era (table 21) is consistent with the chronological order outlined above.

DEFORMATION RELATED TO THE INTRUSION OF SILLS

In the Santa Rita region, several sills, locally enlarged to laccolithic proportions and ranging in thickness from a few tens of feet to as much as 1,100 feet, were intruded into the strata of Mesozoic and Paleozoic age in Late Cretaceous(?) time. Erosion and block faulting have obliterated most of the domical uplift that must have resulted from the cumulative effect of multiple intrusions. This is especially true of domed areas above sills in the Upper Cretaceous rocks, which, because they were nearer the surface and topographically high, were more easily eroded. Most of the strata of Late Cretaceous age was eroded from the Santa Rita horst. North and south of the horst, however, the Upper Cretaceous rocks are partly preserved and contain thick sills whose aggregate thickness is as much as 1,800 feet in the vicinity of San Jose Mountain.

TABLE 21.—*Chronological summary of structural and igneous activity in the Santa Rita quadrangle during late Mesozoic and Cenozoic time*

Igneous activity	Structural activity
Late Cretaceous(?)	
Sills of hornblende-augite syenodiorite porphyry.	Beginning of deformation. Strata domed above thick sills of hornblende-augite syenodiorite porphyry in northwestern quarter of Santa Rita quadrangle.
Late Cretaceous or early Tertiary	
Intrusive and extrusive rocks of Laramide volcanic epoch following erosion sufficiently deep to expose some sills.	Area covered with about 2,000 ft of andesite breccia. Radial fracture pattern formed in North Star Basin area, and fractures were intruded by dikes radiating from a small mafic plug. Relative time of this deformation and volcanism is not known positively.
Sills of quartz diorite porphyry.[1]	Strata domed above thick sills of quartz diorite porphyry. Lack of dikes indicates lack of steep fractures in area at this time.
Sills and a few dikes of hornblende quartz diorite.	Strata domed and locally uplifted in trap-door fashion by intrusion of hornblende quartz diorite. (Pl. 2, cross section *B–B′*.) Sparsity of dikes indicates that few steep fractures existed in area at this time. Doming in Copper Flat area may have caused initial movement on western part of Barringer fault. A series of overlapping lens-shaped sills produced Fort Bayard arch. Extensive doming of Upper Cretaceous beds in Vanadium area.
	Initial formation of major fault and fracture pattern in Santa Rita and adjoining areas. Santa Rita horst block outlined when Mimbres, Barringer, and east-northeast-trending belt of normal faults formed. Numerous north- to northeast-trending faults formed across central part of quadrangle. Within and adjacent to the Santa Rita horst, small horsts and grabens formed, and strata were flexed along major faults.
Early Tertiary	
Quartz monzonite and granodiorite porphyry stocks.	Strata domed over stocks and compressed into tight folds around periphery of south lobe of Hanover-Fierro stock and around stock at Copper Flat.
Granodiorite porphyry dikes.	Breccia pipes formed in Hanover-Turnerville area prior to intrusion of granodiorite porphyry dikes and possibly of major stocks. Fractures of dominantly north to northeast, but also northwest, trend formed in belt passing through central part of Santa Rita quadrangle before and during introduction of dikes. (See fig. 47*A*.) Renewed movement on some older faults.
Quartz monzonite porphyry.	Reopening of existing faults and fractures and formation of new breaks. (See fig. 47*B*.) Fracture pattern closely parallel to trend of granodiorite porphyry dikes, many of which had been brecciated, mineralized, and otherwise altered by hydrothermal fluids prior to intrusion of quartz monzonite porphyry.
Quartz latite porphyry dikes and plugs.	Some fracturing in and along quartz monzonite porphyry dikes. Repeated fracturing of northeast, east, and northwest strike within a radius of 2 miles from Hanover. (See fig. 47*C*.) Hanover Hole formed during this intrusive epoch; some dikes are older than hole, some are younger. Breccia pipe north of Hermosa Mountain probably formed at this time.
Rhyodacite porphyry plug and dikes.	Repeated fracturing in wide belt extending northeasterly across Santa Rita quadrangle during time of dike emplacement. (See fig. 47*D*.)
	Erosion lowered surface to expose stocks and dikes much as they are at present.
Miocene(?) to Recent	
Basalt and basaltic andesite flows, rhyolite and quartz latite tuffs.	Faulting during and after Miocene(?) Epoch. Adjustments made for most part on existing faults in underlying rocks. Fracturing and sheeting along northeast- and northwest-trending belts.
Basalt flows intercalated in Pliocene and Pleistocene gravel deposits.	
	Minor faulting younger than cemented older alluvium. Landslides mainly in areas of volcanic rocks. Major faulting that gives rise to first-order regional horst blocks, affects Miocene(?), Pliocene and Pleistocene(?) valley fill in Mimbres River Valley and elsewhere in region. Uplift accelerated erosion.

[1] Age relative to syenodiorite porphyry and rocks of Laramide volcanic epoch assumed.

The thicker parts of sills in the strata of Paleozoic age are within the Santa Rita horst; all but one of the local swellings occur along the north side of the horst, parallel to the trace of the Barringer fault ½–1 mile to the south (section *B–B′*). The other swelling is near the southeast corner of the Santa Rita horst. This sill has been displaced by the Nancy fault, one of the set of normal faults that forms the southern limit of the Santa Rita horst.

Domical uplifts in the deeper Paleozoic rocks are better preserved, but even some of these are partly eroded. The only dome in which erosion has not penetrated to the sill is in the west-central part of the quadrangle. This uplift, designated as the Copper Flat dome in figures 42 and 43, was formed by the intrusion of hornblende quartz diorite near the base of the Oswaldo Formation. The sill has a maximum thickness of about 900 feet, which is the extent to which overlying rocks were raised relative to rocks around the periphery of the dome. The dome is bounded on the north and northwest by a segment and a spur of the Barringer fault (fig. 43) which may have originally moved during the formation of the dome. Possibly, much of the displacement along the Barringer fault west of the Hanover-Fierro pluton may have been caused by the intrusion of one or more sills into the Paleozoic formations south of the Barringer fault, provided that sills were not similarly emplaced north of the fault. If the faults north and northwest of the Copper Flat dome originated in the manner proposed above, they may not extend any deeper than the base of the lowest sill in the Paleozoic formations south of the fault. Perhaps this hypothesis explains why ore deposits are not found along the western extremity of this segment of the Barringer fault. The ore bodies of the Pearson and Blackhawk (Continental) mines, located farther east along the Barringer, were probably deposited by fluids that rose along the margins of the Hanover-Fierro pluton and moved laterally about 2,000 feet westward along the Barringer fault.

Near Fierro Hill, a similar swelling of another sill at the base of the Oswaldo Formation raised the overlying beds 500–1,000 feet. This sill thins abruptly across a northeast-striking vertical fault southeast of Fierro Hill. The original movement on the fault is attributed to differential uplift of the north side by the expansion of the sill. Note that the fault does not extend below the base of the sill (pl. 1). Small offsets of formational contacts are shown below (southwest of) the sill, but these are along a later fault that has a more easterly strike; also, the relative movement was such that the north side is downthrown.

In summary, the injection of sills caused domal uplifts and some faulting. The thicker part of a series of overlapping lenslike masses coincides with the axis of the Fort Bayard arch. Evidence of doming in the strata above the Beartooth Quartzite was largely removed by erosion or was covered by volcanic rocks of Miocene(?) age. There is little doubt, however, that the domal structure of the Upper Cretaceous beds was more pronounced and of much greater areal extent than that of the strata below the Beartooth Quartzite. The cumulative effect of the multiple injection of sills must have raised the uppermost beds at least a few thousand feet above their original positions, now evident only in adjoining parts of the region. The stocks, and many dikes intruded after the sills, are within the limits of this domal uplift.

DEFORMATION DURING THE INTERVAL BETWEEN THE INTRUSION OF SILLS AND THE INTRUSION OF STOCKS

Deformation in the Santa Rita region during the interval between the intrusion of sills and the intrusion of stocks was characterized by normal faulting. However, striations and mullion structures on some faults exposed in the mine workings are inclined to horizontal, which indicates a strike-slip component, at least locally. Small reverse faults have been reported in the Ivanhoe and Mabel mines, but these, as well as the reverse faults along the margins of the funnel-shaped stocks, probably formed later than the initial epoch of normal faulting and are related to compressional stresses induced by emplacement of the stocks. The early age of some of the normal faults is not everywhere obvious because of intermittent movement along them throughout the Cenozoic Era.

Many faults are simple sharp breaks, but major faults locally have multiple branches which become complex linked systems and then die out by splitting into several members, by a simple decrease of throw, or by ending against another fault. Several of the major faults change course abruptly near their western extremity, from N. 75° E. to about N. 40° E. The block on the concave side of such faults is generally downthrown, as along the Nancy, Copper Glance, Apollo, and North Joy faults; however, along the western extremity of the Barringer fault and along the South Joy and Hobo faults the block on the concave side is upthrown.

The stratigraphic throw of the normal faults is commonly less than 300 feet, but it is as much as 1,700 feet on a few faults. Many of the observed offsets across faults appear to be larger on the map because of the relatively flat dip of the displaced layers. A glance at the structure map (fig. 43) reveals that most faults strike northeastward, a few northwestward, and a few nearly due north. Of those striking northeastward, most strike N. 30°–50° E., but some strike N. 70°–85° E. The traces of several faults curve abruptly from a northeasterly course to an east-northeasterly course, as previously mentioned.

The Mimbres fault and a few faults west of the Chino pit area strike N. 30°–45° W., approximately normal to the dominant set of northeast faults but parallel to the dominant regional trends (fig. 40). Northwest-trending faults west of the Chino pit which parallel the long axis of the Santa Rita stock are within a northwest-trending graben whose origin may be related to the emplacement of that stock. However, an apophysis of the stock apparently was intruded along one northwest-trending fault, which indicates that this fault predated the stock.

In the central part of the quadrangle several faults and fractures strike approximately due north. Most of them are intruded by dikes younger than the stocks and probably did not form prior to the intrusion of the stocks. However, the north-striking faults that intersect the Carbonate (Romero) fault northeast of the Chino pit area probably formed contemporaneously with the Carbonate fault, which is older than the stock.

NORTHEAST AND EAST-NORTHEAST FAULTS

The major faults having northeast or east-northeast strikes are most abundant along the jagged south margin of the Santa Rita horst (fig. 42). The Barringer fault, which strikes east-northeast and northeast, is the only major fault in the northwestern part of the quadrangle, and it marks the curved north margin of the Santa Rita horst. Several minor faults that strike northeast are concentrated along the southwest side of the Mimbres fault, which marks the northeast side of the Santa Rita horst; and a few minor faults and many fractures occur elsewhere within the horst block. Many of these are partly filled with dikes younger than the stocks, and it seems likely that they formed during the prestock epoch of intense faulting; their age, however, cannot be proved.

The major faults of the northeast set are in the southwest quarter of the Santa Rita quadrangle, within a zone about 2½ miles wide. This zone cannot be traced southwestward beyond the town of Bayard because of the valley fill, but, as Lasky pointed out (1936, p. 52), the zone probably is continuous through Lone Mountain (fig. 42). It trends N. 40° E., almost normal to the major northwest faults of the region. Northeastward, it ends in the area between Hanover and Santa Rita, where individual faults merge or intersect with faults striking north to northwest. The Mirror fault joins the Hobo fault zone southwest of Hanover and continues almost to the margin of the Hanover-Fierro pluton, where it ends on a set of faults of north to north-northwest strike. The wedge-shaped block at the intersection is downthrown. The Groundhog–Lovers Lane fault, the largest fault of the northeast zone, ends against a northwest-striking fault southwest of Lee Hill. The presence of northeast-striking faults beyond the northwest fault, in the area of the Oswaldo 2 mine, however, suggests that the northeast zone extends a mile or more farther northeast, beneath the leaching ponds in sec. 27, T. 17 S., R. 12 W. Faults in this block of ground undoubtedly account in part for the localization of the large magnetite-chalcopyrite ore body currently (1965) being mined.

The major faults and numerous small fractures of the northeast zone are deflected to the east or end on a narrow belt of discontinuous faults that extends about 12 miles N. 75° E., from near the town of Central to the Mimbres fault. From west to east, the faults of this belt are the Slate, Copper Glance, Carbonate, Hornet, and Nancy. They curve near their west ends and become parallel to major faults of the strong northeast zones. The east-northeast faults and the northeast faults are probably conjugate. All the faults are normal, and the downthrown blocks are on the southeast or south; the net result is a downward shift to the southeast across a series of step faults. Steep antithetic faults in the hanging wall of major northeast faults, such as the Hanover Creek fault in the hanging wall of the Hobo fault, modify the general downward shift to the southeast by creating narrow horsts and grabens. In general, the step blocks south of the east-northeast lineament are structurally lower than their counterparts north of the lineament because of the general downward shift from north to south across the lineament, which is augmented by the regional southward inclination of the formations. The relative level of the various blocks before intrusion of the stocks is shown in figure 44.

The Barringer fault in part parallels the dominant northeast set of faults, and in part parallels the east-northeast belt of faults in the south half of the quadrangle. The parallelism of part of the Barringer fault to the axis of the Fort Bayard arch (fig. 42) suggests that the original movement on the fault may have been initiated by the injection of sills into the strata south of the fault. However, the abundance of northeast-striking normal faults in the area suggests that lateral tension existed in a northwest-southeast direction after the intrusion of sills and before the intrusion of stocks.

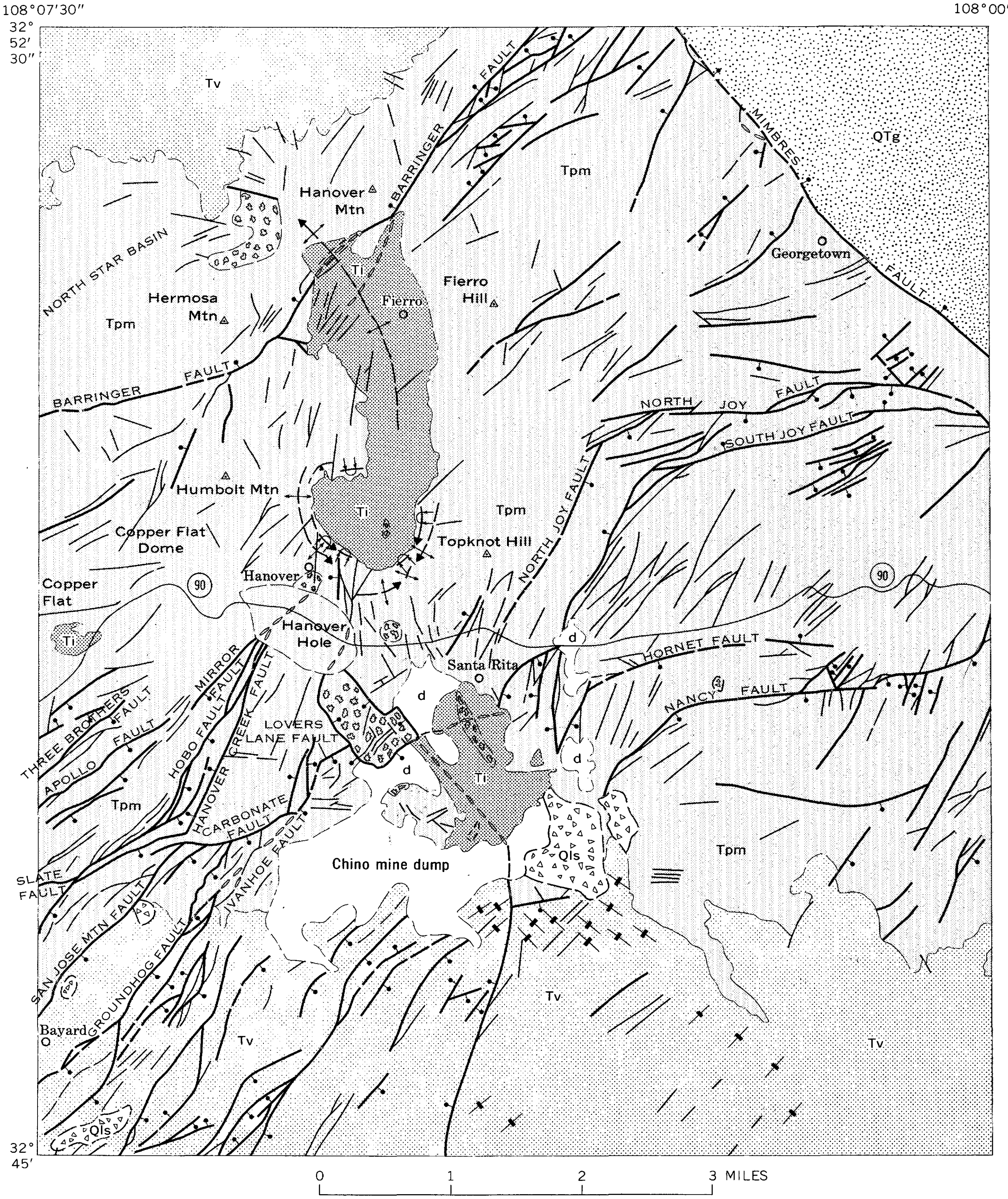
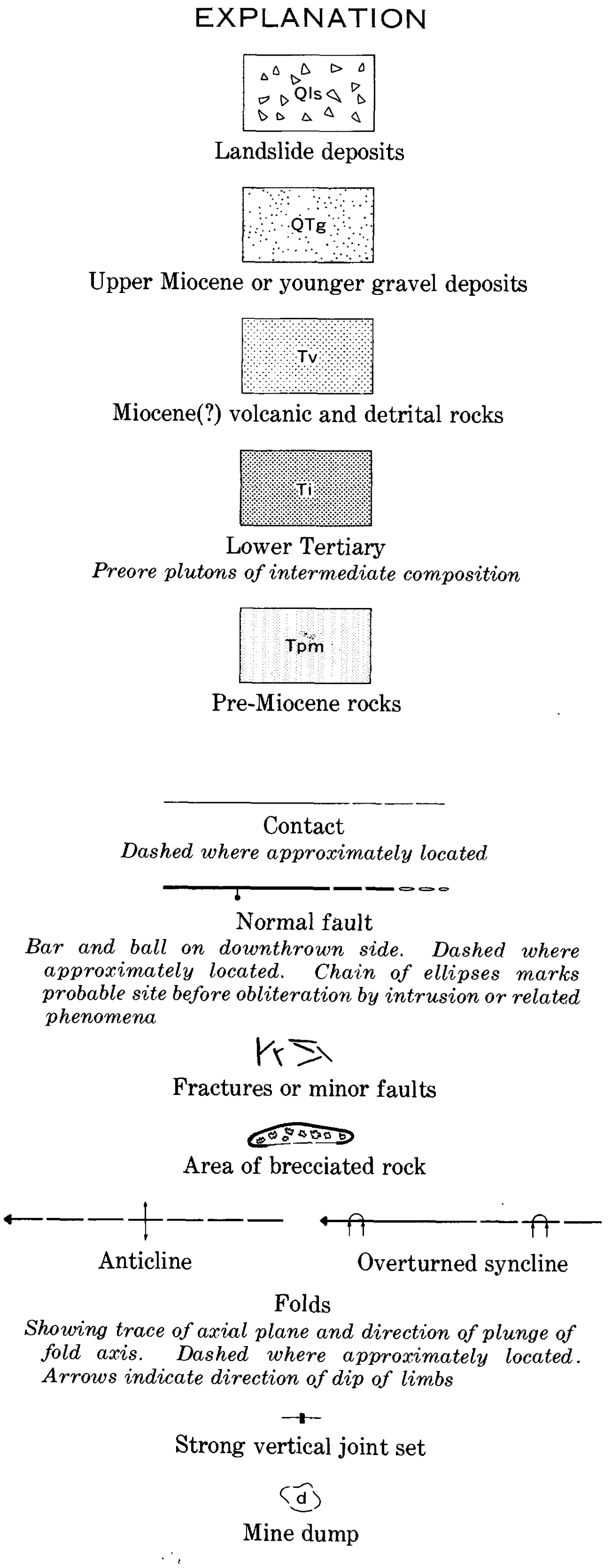


FIGURE 43.—Major structural features in Santa Rita quadrangle.



Consequently, the normal faulting, which may have been initiated by forcible uplift of the south side of the Barringer fault, was probably increased during the time of tensional stresses. That the Barringer fault predates the Hanover–Fierro pluton is proved by the facts that the fault is stoped by the northeast-trending prongs of stock rock and that the northwest contact of the stock is not offset by the Barringer fault. Small movements along the Barringer fault after intrusion of the stock account for the concentration of small closely spaced fractures in the stock rock along the projected course of the fault. This fracture zone later guided fluids that silicified and otherwise mineralized the rock.

Detailed descriptions of all but the Nancy and Hornet faults appear in the published reports by Spencer and Paige (1935) and by Lasky (1936). The principal data on all the major faults of northeast and east-northeast strike are summarized in table 22.

NORTHWEST FAULTS

The northwest set of faults includes only one major fault, the Mimbres, and a set of minor faults in a belt about a mile wide which extends northwest from the Chino mine to the Hanover Hole. Only a few minor northwest-trending fractures are found northwest of the hole, or beyond the Mirror-Hobo fault zone. (The Hanover Hole lies within the northwest belt, but it formed after the intrusion of the stocks and is described on p. 130–132.) Within the northwest belt, from Turnerville to the Chino mine, not only are the rocks broken by conjugate faults into a mosaic of blocks, but within each block the rock is thoroughly brecciated and sheared. The details of the brecciation are given on page 129.

The Mimbres fault, a principal fault of the region, extends from a point in the Allie Canyon quadrangle southeastward for 22 miles, or for 36 miles if the Sarten fault described by Jicha (1954, p. 54) near Cooks Peak is considered an extension of the Mimbres. The trace of the fault is fairly straight except near the town of Lorenzo, due east of Santa Rita, where the trace bulges to the northeast (fig. 42).

The Mimbres fault dips about 70° NE., and the northeast side is downdropped. The direction and amount of slip cannot be determined. In the southeast corner of the Allie Canyon quadrangle, south of the intersection of the Barringer and Mimbres faults, a stratigraphic throw of about 1,300 feet is indicated by the displacement of the Syrena-Abo contact across the Mimbres fault. North of the same intersection the throw on the Mimbres fault is apparently much less, for the base of the Miocene(?) basalt flows is only about 500 feet lower on the hanging-wall side of the

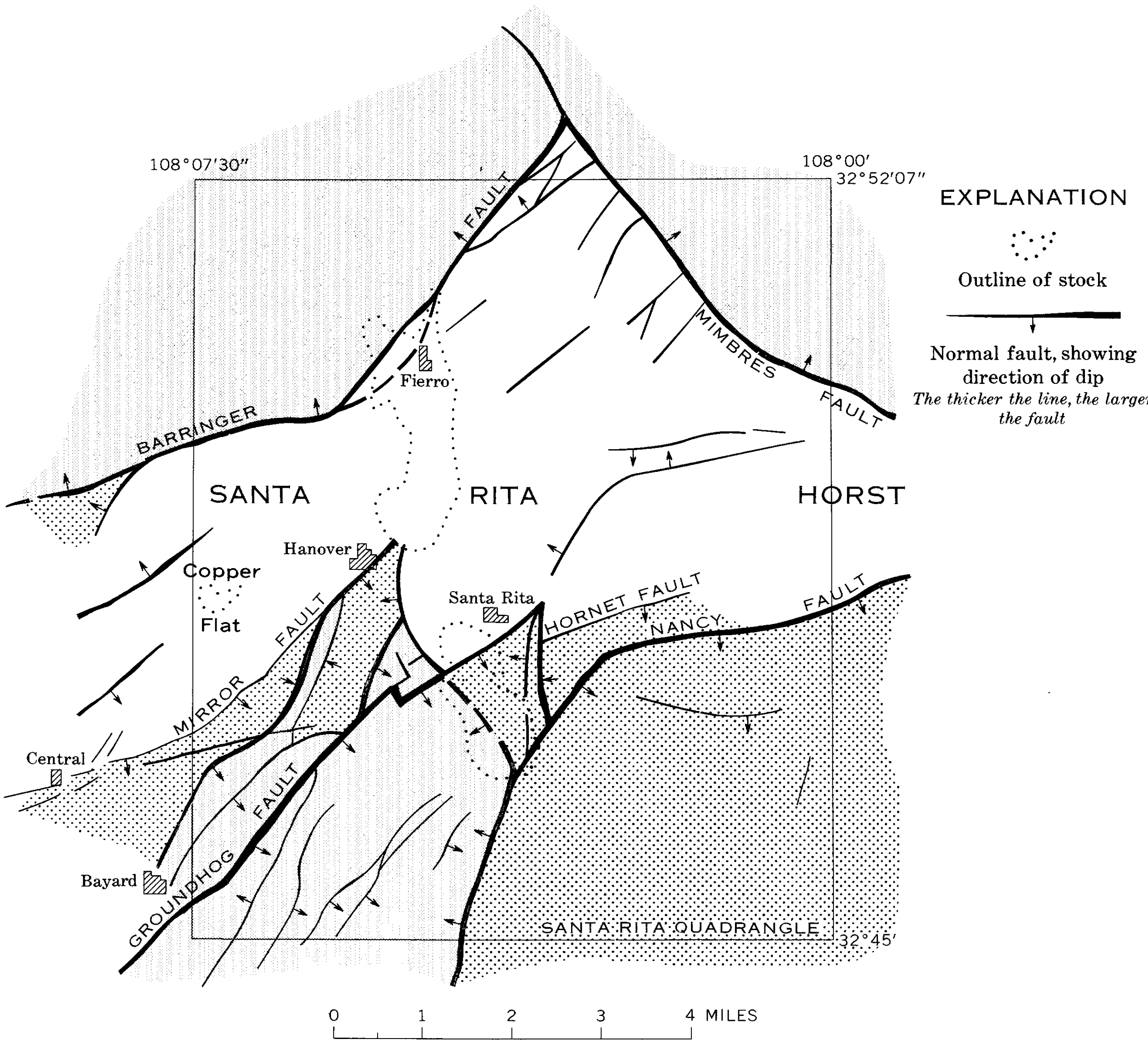


FIGURE 44.—Probable net result of normal faulting in the interval between the intrusion of sills and the intrusion of stocks in the Santa Rita quadrangle. Degree of shading reflects degree of downthrow; solid gray indicates areas of greatest downthrow.

Mimbres than on the footwall side. If 500 feet were taken as an approximation of the postvolcanism throw, the prevolcanism throw south of the intersection would be about 800 feet. Along a northwest-trending fault in the footwall of the Mimbres fault, a mile northwest of Georgetown, a block of the Oswaldo Formation has been dropped to the level of the Percha Shale in the footwall (section *B–B'*). This fault is cut off at both ends by the Mimbres fault and through much of its length has been intruded by trachyte porphyry. If we assume that the full thickness of the Oswaldo Formation, about 400 feet, remains in the downthrown block, a stratigraphic throw of about 1,000 feet is indicated. The throw before intrusion of the sill into the footwall black was about 800 feet, for the sill is about 200 feet thick and the base of the Oswaldo above it has been uplifted by the sill subsequent to the fault action.

Because limestone has proved to be the most favorable rock for zinc-lead replacement ores in the district, the elevation of the limestone beds in the hanging wall of the Mimbres fault is of economic interest. If the throw of the postvolcanism and postcanyon fill is only 500 feet, the base of the Oswaldo should be at an elevation of 5,700 feet on the east side of the fault, and would thus be only 600 feet below the floor of Shingle Canyon. A hole was drilled in the canyon floor to a depth of 570 feet, and it was still in semiconsolidated gravel when discontinued (W. W. Baltosser, oral commun., 1955). If the indicated throw on the Mimbres fault is of the right order of magnitude, the Oswaldo Formation may not be much deeper, unless pregravel erosion cut very deeply along the scarp of the Mimbres fault.

Near the east boundary of the Santa Rita quadrangle the footwall side of the Mimbres fault is silicified for hundreds of feet along the fault. Similarly silicified rock is common along the Joy fault and apparently represents a more distant barren facies of the main period of mineralization and alteration. Silicified rock along the Mimbres fault supports the idea that the Mimbres fault in part coincides with a premineralization fault of early Tertiary age.

Several of the northwest-striking faults mentioned earlier occur within a graben that extends from the Lee Hill area toward Turnerville. The southwest edge of the graben is clearly defined by a northwest-trending dip fault that emerges from under the leaching pond south of Lee Hill. The fault is easily traced for half a mile northwest from the leaching pond, but then it apparently turns in a northerly direction and ends at or has been intruded by a dike of quartz latite porphyry. The amount and direction of displacement cannot be determined, and the stratigraphic throw changes abruptly along the strike, because the walls on both sides of the northwest fault were broken by northeast faults and the blocks thus delimited moved differentially.

TABLE 22.—*Major faults of northeast and east-northeast strike*

Name or designation	Strike	Dip	Maximum determinable stratigraphic throw (feet)	Remarks
Three Brothers fault	N. 50° E.	70°–80° SE.	150	Displaces hornblende quartz diorite sill; mineralized. Intruded by rhyodacite dike; shows post-dike movement.
Apollo fault	N. 58° E.	70°–80° SE.	475+	Displaces quartz diorite porphyry and hornblende quartz diorite sills; mineralized.
Mirror fault	N. 42° E.	80° SE.	100–400	Displaces sills; mineralized; intruded by rhyodacite dikes. Weakens southwestward by splitting.
Hobo fault zone	N. 30° E.	60°–80° SE.	400–1, 000±	Swings to S. 60° E. at south end. Maximum throw at north end only about 400 ft. Mineralized. To north converges with Mirror fault.
Hanover Creek fault	N. 25° E.	75° NW.	150	In hanging wall of Hobo fault zone. Displaces hornblende quartz diorite sill.
Fault in footwall west of Lovers Lane fault.	N. 25° E.	80° NW.	100	Minor fault, west wall down, intruded by quartz monzonite dike.
Lovers Lane fault zone	N. 25°–57° E.	Steep to east and southeast.	500–800	Intersects Copper Glance fault to south. East side down. This downdropped block bounded by faults striking N. 25° E., N. 57° E., and N. 37° W.
Faults of northeast strike, within northwest-trending fault zone; Lee Hill to Turnerville.	N. 15° E., N. 35° E., and N. 50° E.	50°–75° SE.	200–300	See eastern half cross section *F–F'*.
Carbonate fault	N. 55°–65° E.	50°–70° SE.	600±	East end called Romero fault by Spencer and Paige (1935). Mineralized. Stoped by Santa Rita stock. Dies out to northeast at intersection with north-trending west-dipping fault zone. Forms northwest side of graben. See cross sections *D–D'* and *F–F'*.
Fault zone, south slope of Topknot Hill.	N. 35°–45° E.	60°–70° NW.	50–100	Down on northwest side; passes through Oswaldo 2 mine, transecting anticlinal roll. Displaces sill of hornblende quartz diorite.
Bayard (Owl) fault	N. 25° E. (N. 40° E. at north end)	70° SE.	700(?)	Southern extension of Hobo fault zone, south of intersection of Hobo and Slate faults. Throw probably large but insufficient data to estimate closely. Displaces hornblende quartz diorite and older sills. Intruded by granodiorite porphyry dikes.
San Jose Mountain fault	N. 40° E.	65°–75° SE.	300–400	Displaces sills, intruded by granodiorite porphyry dikes; some post-Miocene(?) tuff movement. Splits and weakens northward before intersecting east-northeast fault zone.
Groundhog fault zone	N. 50° E.	20°–70° SE.	1, 700±	Intruded by granodiorite porphyry dikes. Total throw, including post-Miocene(?) movement, about 1,700 ft. Has footwall and hanging-wall splits; fault system linked in plan and section. Splits northward and joins Ivanhoe fault zone on footwall side.

TABLE 22.—*Major faults of northeast and east-northeast strike*—Continued

Name or designation	Strike	Dip	Maximum determinable stratigraphic throw (feet)	Remarks
Fault zone northeast of Chino pits.	N. 10° E.	90°(?)	200–300	Downthrown on west side in hanging wall of Carbonate (Romero) fault. Apparently dies out to south in shallow syncline related to intrusion of Santa Rita stock. See cross section *D–D′*.
Hornet fault	N. 75° E.	Steep to southeast.	200±	Poorly exposed; downdropped on south side. Dies out in Syrena Formation to east, and to west by splitting and intersection with north-trending fault.
Nancy fault	N. 80–85° E.	80° S.	300–500?	South side down; displaces hornblende quartz diorite sill to east. Probably continues 3 miles beyond quadrangle to Mimbres fault. West end turns to south and passes beneath volcanic rocks.
Nancy fault, southwestern extremity.	N. 45° E.	Steep to southeast.	?	Throw indeterminable. See cross section *D–D′*; northward, strike swings to N. 85° E.
South Joy fault (east end).	N. 77° E.	Steep to north.	400	North side down. (See cross section *E–E′*.) Forms south side of narrow graben capped by Syrena Formation. Intersects North Joy fault to east, making acute angle at apex of graben. To west it turns south. Jasperoid along outcrop.
South Joy fault zone (southern extension).	N. 25–40° E.	70° NW.	360–400	Displaces hornblende quartz diorite sill; invaded by granodiorite porphyry dikes. Passes into anticlinal fold southward before reaching Carbonate fault.
North Joy fault	E.	Steep to south.	100+	Down on south side; makes north wall of narrow graben. Turns to southwest course at west end by splitting.
Slate fault	N. 70° E.	70° SE.	100–175?	Cuts hornblende quartz diorite sill; passes at depth into Colorado Formation. Mineralized. Many spurs to hanging wall and footwall. Intersects Apollo fault to west, Bayard-Hobo fault to east.
Copper Glance fault	N. 70° E.	60°–80° SE.	400–450	Strike swings to S. 50° W. at west end. Mineralized. Cut by granodiorite porphyry and younger dikes. Joins Lovers Lane–Ivanhoe fault to east.
Barringer fault (west half).	N. 76° E.	Steep to northwest.	1,400±	Mineralized near Hanover-Fierro pluton. Has split to southwest just west of Santa Rita quadrangle.
Barringer fault (east half).	N. 30°–40° E.	60°–75° NW.	1,600±	Displaces sills of several ages; intruded by apophyses of Hanover-Fierro pluton; some poststock movement. Splits enter footwall block near intersection with Mimbres fault.

The northeast edge of the graben is obscured within a zone of several northwest-trending faults that extends along Lee Hill from the Carbonate fault to Turnerville. The major break in this zone and the one assumed to delimit the graben must lie beneath the leaching ponds just northeast of Lee Hill. Actually, this edge of the graben is probably irregular and follows northeast and northwest faults for short distances. The apparent throw along the northeast edge is much greater at Lee Hill than at Turnerville. This difference results from the progressive downward shift, to the southeast, of blocks within the southeast half of the graben, as shown in cross section *F–F′*.

Part of the Santa Rita stock evidently intruded a northwest fault (fig. 43). The southwest side of the fault is downthrown. The Beartooth Quartzite on the northeast side of the fault is at the same elevation as the upper sill of quartz diorite porphyry on the southwest side. (See section *G–G′*.) The exact stratigraphic throw is difficult to estimate, because the distance at which the upper sill lies above the Beartooth Quartzite depends on the thicknesses of the middle and lower sills, which vary greatly from place to place. For example, in the Groundhog mine, where the middle and lower sills aggregate about 1,700 feet in thickness, the upper sill lies about 2,000 feet above the Beartooth; but northeast of the Chino pit, where the lower sill is absent and the middle sill is only 100–200 feet thick, the upper sill lies only 400 feet above the Beartooth. On this basis we estimate that the stratigraphic throw on the northwest fault engulfed by the Santa Rita stock is at least 400 feet, and possibly as much as 800 feet.

TABLE 23.—*Faults of northwest set*

Name	Strike	Dip	Maximum determinable stratigraphic throw (feet)	Remarks
Mimbres fault	N. 42° W.	60°–70° NE.	Total 1,300 or more	Swings to S. 70° E., east of Santa Rita quadrangle. Pre-Miocene(?) stratigraphic throw about 1,000 feet; total throw, including postvolcanism and post-Quaternary gravel, not determinable because depth to Upper Cretaceous rocks in downthrown block is not known; throw decreases sharply to northwest beyond intersection of Barringer fault.
Faults beneath tailings dump, east of Bull Hill.	N. 5°–10° W.	Steep to west	625	Two closely spaced dip faults offset Syrena-Oswaldo contact 1,800 ft to right and displace sill of hornblende quartz diorite. Faults intruded by granodiorite and quartz monzonite porphyry dikes. Stock contact to north not offset, which indicates faults predate stock. Western fault ends at northeast-striking Hobo fault in Hanover Creek; block in angle of this intersection downdropped. At south end, fault is cut off by Hanover Hole, or marks east wall north of the highway.
Lee Hill–Turnerville fault zone.	N. 40°–45° W.	Vertical	Variable	Northwest-trending zone of conjugate faults; northwest dip faults and northeast strike and oblique faults. Bounding fault on southwest side fairly well defined; northeast limit of fault zone indefinite. Cretaceous beds on north side dip southwest; same beds on south side dip west. Intruded by granodiorite and younger dikes; mineralized and altered.

Data on the northwest-trending faults are summarized in table 23.

In summary, the faults described (tables 22, 23) originated during the intervals between the intrusions of the sills, the Santa Rita and Hanover-Fierro plutons, and probably the composite stock at Copper Flat. The major structural element, the Santa Rita horst, is delineated by members of all three sets of faults. Along the Barringer fault, which marks the northwest limit of the Santa Rita horst, the stratigraphic throw is consistently large, about 1,200–1,600 feet. The stratigraphic throw is less consistent along the jagged south margin of the Santa Rita horst, which is formed by faults striking east-northeast, northeast, and northwest. The bounding faults are the Slate, the Groundhog–Lovers Lane, the northwest-striking fault southwest of Lee Hill, a segment of the Carbonate fault, a northwest-trending fault that has been engulfed by part of the Santa Rita stock, and the Nancy fault. A triangular block, whose apex is near State Highway 90 northeast of the north Chino pit, is relatively less depressed than the part which lies south of the northwest fault that was engulfed by part of the Santa Rita stock. A segment of the Carbonate fault was also engulfed by the Santa Rita stock in the area of the north pit, and it provides additional evidence for the prestock age of the major faults.

DEFORMATION RELATED TO THE INTRUSION OF STOCKS

After formation of the fault sets described in the preceding section, the strata were further disrupted by the forcible intrusion of magma at three centers in the Santa Rita quadrangle—at Copper Flat and at Santa Rita and in the area between Hanover and Fierro. At Copper Flat and especially at Hanover, the early surges of magma expanded upon reaching the present surface elevation. The centrifugal force of the expanding magma produced asymmetrical peripheral folds in the invaded strata and locally caused outward thrusting. Later surges of magma at Copper Flat and between Hanover and Fierro rose vertically beyond the present surface elevation but may have expanded at higher elevations. Evidence of the forcible injection of the main mass of the Hanover-Fierro pluton is found in the sharply upturned and thinned strata along its east and west margins. Reconstruction of the partly eroded roof rocks reveals a slight doming above part of the Santa Rita stock, from which it is inferred that the upward force of the intrusion was relatively weak when the magma reached the present surface elevation.

DEFORMATION RELATED TO THE INTRUSION OF THE HANOVER-FIERRO PLUTON

The south lobe of the Hanover-Fierro pluton is surrounded by a rather gently folded anticline whose inner limb has been curled upward and backward adjacent to the intrusive; the overall structure is shown diagrammatically in figure 45. The structure resulted from outward-directed hydrostatic pressure of the intruding magma, and, as Spencer and Paige (1935, p. 45) pointed out, the "structural features were first formed in advance of the magma and later disrupted by its continued progress." (See section *C–C′*, pl. 2.)

The outcrop of a hornblende quartz diorite sill in the Oswaldo Formation conveniently marks the peripheral folds surrounding the south lobe of the Hanover-Fierro pluton.

FIGURE 45.—Diagrammatic section showing nature of deformation caused by the intrusion of the Hanover lobe of the Hanover-Fierro pluton.

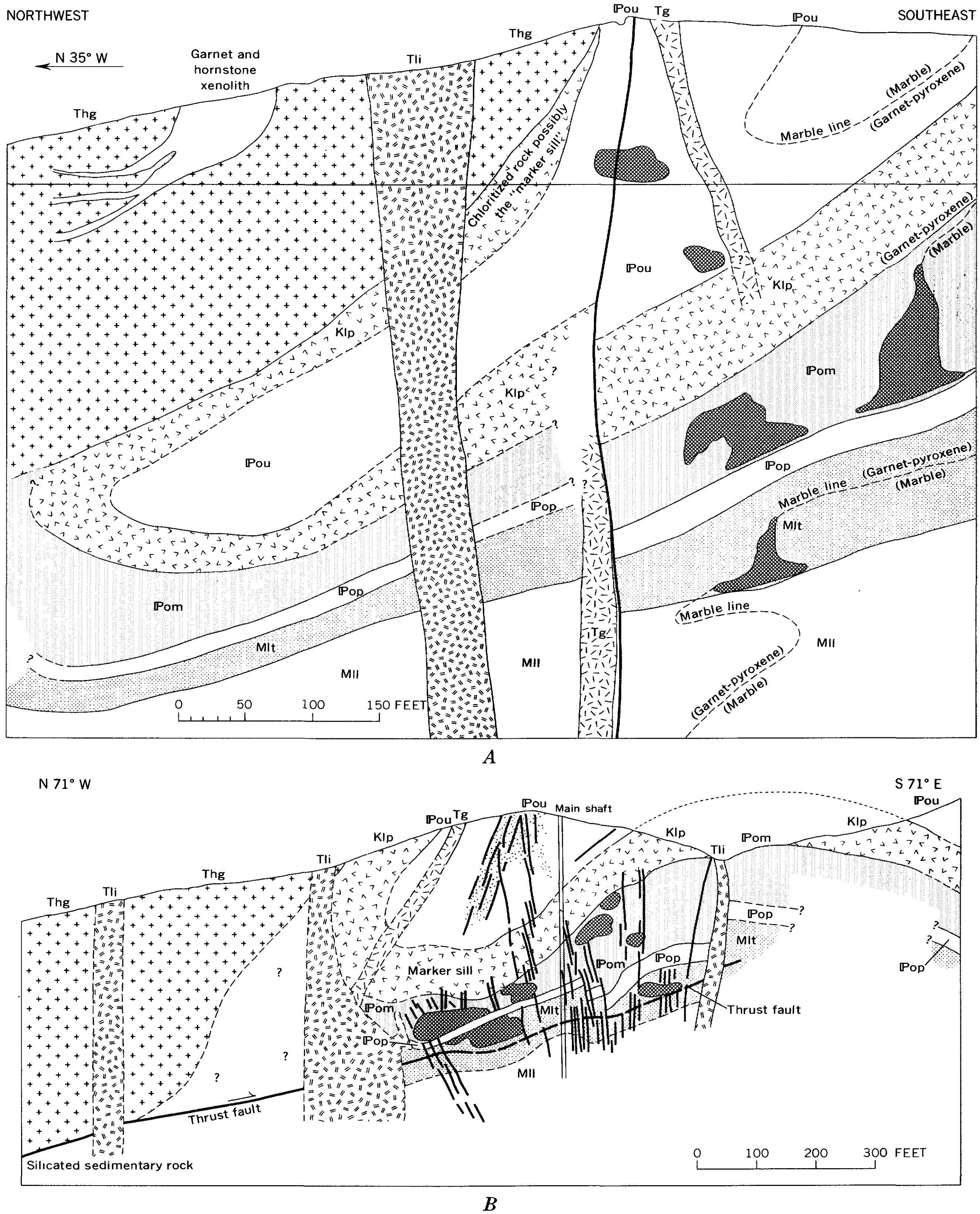
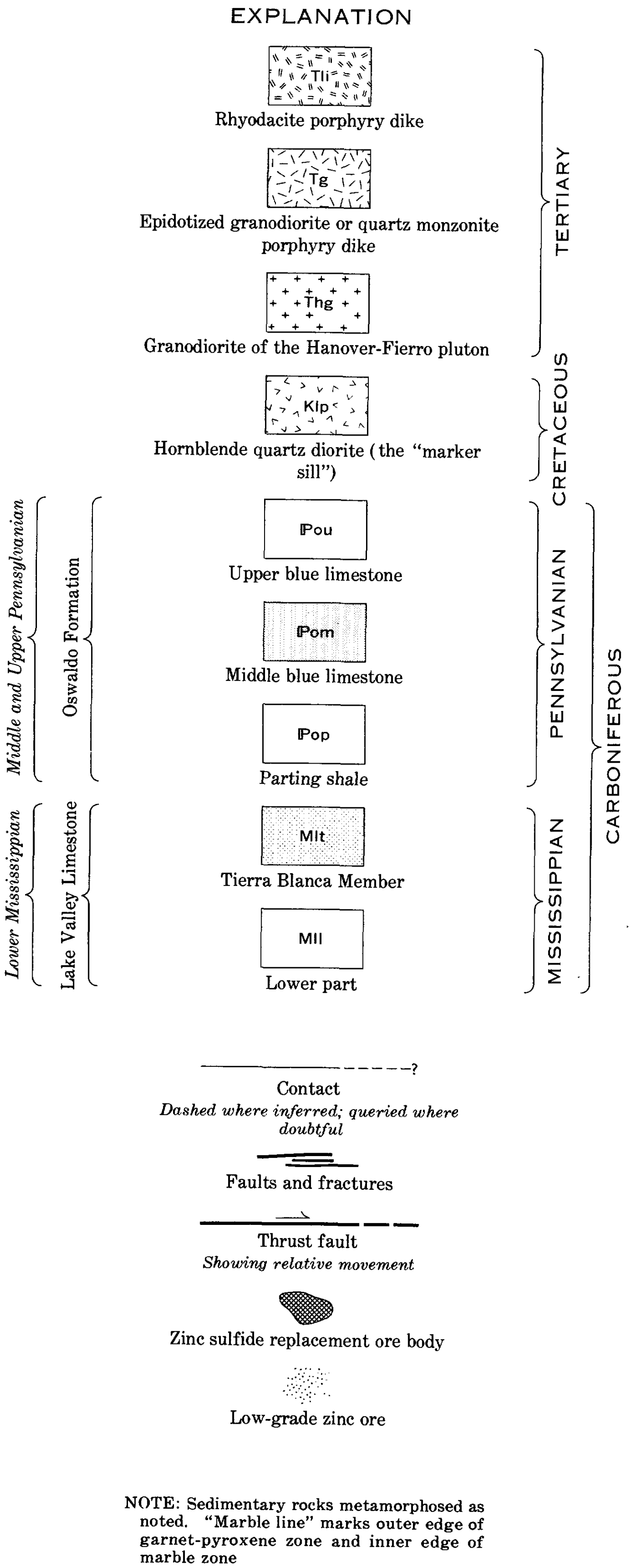


FIGURE 46.—Sections through Thunderbolt and Pewabic mines. *A*, Thunderbolt mine. (Modified from Lasky and Hoagland, 1948.) *B*, Pewabic mine. (Modified from Schmitt, 1939a, pl. 2, section *A–A′*.)



The traces of the axial planes of both the inner and the outer anticlines are curved parallel to the south edge of the pluton. The axial plane of the anticline is almost vertical, and its limbs dip equally, or nearly so, at 15°–25°; locally, the limb closer to the intrusive is steeper—for example, on the hillside east of Hanover Creek the inner limb dips 60° N. and the outer limb dips 25° S. The axial plane of the syncline is inclined away from the intrusive, and the limb closer to the intrusive is steeper in most places. Around the southeast margin of the intrusive the syncline is isoclinally folded, and both limbs dip about 30° N. These relationships are shown in figure 46. Throughout most of their length the peripheral folds plunge very gently in a counterclockwise direction; that is, from Buckhorn Gulch toward the gulch south of the Pewabic mine. North of the latter gulch the trace of the Marker sill shows clearly that the folds plunge gently south, and the axes of the folds are downwarped in the area of the gulch. If the main mass of the Hanover-Fierro pluton was intruded after the intrusion of the south lobe, or even if it simply continued to rise after the south lobe was emplaced, the structures around the northeast half of the south lobe must have been tilted southward as the main mass rose. This tilting would explain the reversal in plunge of the peripheral folds south of the Pewabic mine area.

The continuity of the anticlinal fold is broken in the Bull Hill area by a wedge-shaped graben whose northern apex underlies Hanover Creek south of the synclinal fold. The northwest bounding fault is a continuation of the Mirror and Hobo faults, which, as indicated on previous pages, are considered to have formed as part of a district-wide fracture system prior to intrusion of the stocks. The relations between the faults and the folds suggest that movement was renewed along the faults as the peripheral folds formed.

On the west side of the south lobe the peripheral syncline continues beneath the intrusive rock. In the southeast corner of sec. 16, T. 17 S., R. 12 W. (pl. 1), a tight syncline is parallel to the north margin of the south lobe. The limbs of this syncline dip steeply, as can be seen in cross section *C–C′* on plate 2. This fold is cut off to the east by the main mass of the Hanover-Fierro pluton and apparently ends to the west at a north-trending fault. If the syncline continues beyond this fault and connects with the syncline along the west side of the south lobe, it does so beneath the intrusive rock of the south lobe. On the west side of the north-trending fault in sec. 16, the Lake Valley Limestone is thrust slightly northward and cuts out the uppermost beds of the Percha Shale. The reverse fault along which movement occurred dips 55° S. and dies out westward before reaching Buckhorn Gulch.

A small south-dipping reverse fault is exposed in the creek that cuts across the tight syncline on the east side of the north-trending fault. The attitudes of these minor reverse faults and of the syncline indicate that the intrusive force was directed to the north as well as to the east, south, and west.

The structures within the Pewabic mine area have been described in detail by Schmitt (1939a, p. 786). In that area, and possibly elsewhere around the south lobe, the peripheral syncline lies above a thrust fault that dips 10°–15° toward the intrusive (fig. 46). Updip, the thrust follows the bedding planes in the inner limb of the anticline. In the Pewabic mine the fault is in the Hanover Limestone (called the Tierra Blanca Member of the Lake Valley Limestone in this report), and is marked by breccia and silicified gouge. According to Schmitt (1939a, p. 787), "deep-level development in the Republic mine shows that the beds in the lower plate were nearly flat and unfolded and that the pronounced peripheral anticlinal form so prominent on the surface disappears with depth." Thus the peripheral folds, at least in this area, are superficial.

The main mass of the Hanover-Fierro pluton broke through the Precambrian basement and pierced the overlying strata to form an elongate dome whose axial plane before erosion probably coincided with the medial line of the stock as now exposed. The original center of intrusion apparently was in the vicinity of the Sleeping Beauty shaft, but eventually the magma broke through the south flank of the dome and invaded the somewhat older rock of the south lobe. The present center of the intrusive lies on the axis of the Fort Bayard arch, between the two prominent bulges in the Marker sill, which suggests that the axis of the arch may coincide with a major fissure in the Precambrian basement. The outcrop pattern of the surrounding beds indicates that the axis of the elongate dome plunged northwest and south, and that it was noticeably concave to the west. The existing walls of the intrusive are almost vertical, although locally they dip inward; these dips indicate that the lateral pressure of the magma overcame the confining force of the wallrocks. The Bliss Formation and lower Paleozoic carbonate rocks at the contact were greatly sheared, thinned, and turned sharply upward by the forcible intrusion. Apparently the intrusive made room for itself by lifting a plug of strata. The lower Paleozoic strata were not simply uparched; they were punctured. The overall form before erosion must have been that of a piercement dome. Apophyses of the magma invaded and obliterated segments of the Barringer fault south of Hanover Mountain. The intrusion arched the rocks in a segment of the hanging-wall block of the Barringer fault southwest of Hanover Mountain and injected apophyses into fissures in the arched formations.

DEFORMATION RELATED TO THE STOCK AT COPPER FLAT

Peripheral folds similar to those around the south lobe of the Hanover-Fierro pluton, but much less prominent, occur around the composite stock at Copper Flat. The folds at Copper Flat have no topographic expression and were revealed only by detailed mapping. The folds are in a peripheral belt about 900 feet wide, but tight folds are limited to the inner 150 feet of the belt. The arcuate traces of the fold axes are shown on plate 3, a previously unpublished geologic map of the Copper Flat area by S. G. Lasky. It is clear that the axes are discontinuous within the peripheral belt; the folds apparently were disrupted by the continued progress of magma. In general, however, the tightest fold, a syncline, lies adjacent to the contact; its inner limb is very steep or overturned, and its outer limb is the inner limb of a peripheral anticline. Beyond the anticline the beds are locally downwarped or crinkled into folds of small amplitude. The peripheral belt of folds seems to have been arched over two northeast-trending prominences of the composite stock, so that the axes of the peripheral folds have a sinuous trace around the northeast margin of the composite stock. Underground workings and drill holes reveal that the composite igneous mass narrows with depth, more rapidly in some sectors than in others. (See cross sections on pl. 3.) In summary, the geologic relations indicate that the folds surrounding the Copper Flat stock were formed by the forceful intrusion of magma.

DEFORMATION RELATED TO THE INTRUSION OF THE SANTA RITA STOCK

The intrusion of the Santa Rita stock caused little folding of the intruded strata other than a slight arching over the stock. The northeastward dip of the Syrena, Abo, Beartooth, and Colorado Formations close to the northeast contact of the stock is undoubtedly a result of the intrusion, for away from the contact the attitude of these formations changes to the regional southward dip. Evidence of arching of the strata over the intrusive along the southwest margin is indicated by the southwestward dip of the Colorado Formation as exposed in the southwest wall of the south Chino pit (pl. 2). The southwestward dip, however, may be in part a reflection of the regional southward tilt of the strata. The beds exposed in the northwest corner of the south pit strike northeastward at right angles to the contact with the stock and dip gently northwestward toward the Carbonate fault. If this block of sedimentary rocks were tilted by the intrusion, arching over a northeast-trending axis that passes over the area of the south pit rather than arching along a northwest-trending axis that coincides with the long axis of the intrusion would be indicated. The northwest edge of the Santa Rita stock lies somewhere beneath one of the large leaching ponds, and the attitude of the layers northwest of the pond reflects the doming farther north that was caused by the intrusion of the Hanover-Fierro pluton. A narrow northwest-trending arch in the Oswaldo 2 mine area may be related to the intrusion of the Santa Rita stock, but the structural interpretation of this area is complicated by the presence of northeast-trending flexures and faults.

The axis of the Santa Rita stock coincides with a northwest-trending arch that plunges both northwest and southeast at about 600 feet per mile (Ordóñez and others, 1955, p. 18). Good evidence of arching over the stock is found along part of its northeast margin, where the formations apparently were turned up by the force of the intrusion; there is little evidence of upturn, however, along the southwest or southeast margins. It is clear that the deformation attributable to the intrusion of this stock is much less than that attributable to the intrusion of the smaller composite stock at Copper Flat. Evidently, the magma of the Santa Rita stock had just enough propulsive force to reach the present surface level. The Santa Rita stock, the composite stock at Copper Flat, and the northern extremity of the Hanover-Fierro pluton are all truncated near their apices. The central part of the Hanover-Fierro pluton is truncated at a much deeper level.

BRECCIA PIPES

Six irregular patches of brecciated ground are exposed within the Santa Rita quadrangle. (See fig. 43.) Exploration has shown that the breccia extends for hundreds of feet below the surface; so the brecciated areas are undoubtedly the surface expression of breccia pipes. Three of the breccia areas are close to the margin of the Hanover Hole, which formed later: one of these is northwest of Bull Hill, another is west of the Kearney shaft, and the third, by far the most extensive, is between the Princess mine and Lee Hill. Two of the other three pipes are within the stocks; one is in the south lobe of the Hanover-Fierro pluton, and one, called the Whim Hill breccia, is in the north-central part of the Santa Rita stock. The sixth breccia pipe is in the Colorado Formation north of Hermosa Mountain.

The relative age of brecciation in each of the areas is indicated by the type of igneous rock included in the breccia or intruded into it and by the nature of hydrothermal alteration and metalization. The pipes probably did not all form simultaneously; the oldest may predate the stocks, and two are definitely post-stock—and an unbrecciated quartz monzonite porphyry dike cuts across one of these. The breccia between the Princess mine and Lee Hill and the breccia west of the Kearney shaft contain irregular ramifying stringers and cigar-shaped pods of granodiorite or quartz monzonite porphyry that may be equivalent in age to the magma of the stocks or to the later granodiorite porphyry dikes. Both of these breccias as well as the two pipes in the stocks and the breccia pipe near Bull Hill are altered and contain some galena, sphalerite, and chalcopyrite. The large breccia area north of Hermosa Mountain contains blocks of rock tentatively identified as quartz monzonite porphyry; parts of this breccia are silicified, bleached, and pyritized but are not known to contain any ore minerals. From these relationships we conclude that the six breccia pipes formed over a long span of time—from possibly before the emplacement of the stocks until after the introduction of the quartz monzonite dikes. The relative age of each pipe cannot be deduced with enough certainty to justify describing the pipe in what might be its proper chronologic position; it seems more logical to discuss all the breccia pipes together.

The brecciated areas are irregular in plan, and the margins are poorly defined. The margins are locally marked by faults, as are the southwest margin of the brecciated area south of Turnerville and the north boundary of the breccia area north of Hermosa Mountain. The brecciation varies in intensity both laterally and vertically, and in places seems to extend outward from the main pipe along certain strata. The strata and any enclosed sill rock may be merely cracked, or individual blocks may be rotated so that the bedding in adjacent blocks is haphazard. Rotated blocks of brecciated limestone are well exposed in the creek bottom west of the Kearney mine and at the 1000 level of the Princess mine. At one place in the Princess mine, fragments of limestone, shaly limestone, and shale are set in a matrix of andradite garnet. The fragments are rotated, altered, and mineralized; and both the fragments and the garnet matrix are cut by narrow veins which contain pyrite, chalcopyrite, and sphalerite. The shale fragments are epidotized. The matrix of the breccia was probably calcite before being replaced by andradite. The selective replacement of limestone by garnet and the shale by epidote is typical in the district. Breccia pipes at the Kearney mine and near Bull Hill are locally somewhat altered and metalized. The Whim Hill breccia contains fragments of igneous and sedimentary rock cemented by orthoclase, quartz, and magnetite; and it also contains a little chalcopyrite and molybdenite. The small body of breccia within the south lobe of the Hanover-Fierro pluton, west of the Pewabic mine, has not been studied in detail, but it seems to be thoroughly chloritized. The quartz monzonite dike that cuts through the breccia is not similarly altered or brecciated.

Breccia pipes such as these may be in part the result of solution and collapse, but the authors favor an origin of explosive release of magmatic emanations. Further speculation on their origin must be deferred, however, until the breccias, especially those within the limestone, have been mapped and studied in detail.

DEFORMATION DURING THE INTRUSION OF DIKES AND PLUGS

Deformation in the interval between the intrusion of stocks and the Miocene(?) volcanic episode involved repeated fracturing and the formation of the Hanover Hole. Successive surges of magma filled some of the fractures to form dikes and a few small plugs. Some magma invaded older faults, but for the most part the magma invaded new fractures; thus, the dike pattern largely reflects the poststock fracture pattern. The dike pattern at four stages of development is shown by a sequence of maps in figure 47. Map *A* of figure 47 shows fractures filled with granodiorite porphyry; map *B* shows fractures filled with quartz monzonite porphyry; map *C* shows fractures filed with quartz latite porphry, divided into early and late phases; and map *D* shows fractures filled with a variety of rock types grouped, for simplicity, as rhyodacite. Many of the earlier formed fractures were opened repeatedly; as a result, composite dikes are common. Fracturing and shearing along the walls of granodiorite dikes and within the dikes provided channelways for fluid which caused widespread alteration and metalization in the district. Most of the dikes occupy fractures along which there was evidently little if any vertical or horizontal displacement of the walls; this small displacement and the irregular course followed by most dikes suggest that the fractures resulted from tensional stresses. Variations in the strike of the dikes reveal that the direction of tension ranged from about east-west to north-south, and that during the interval represented by the emplacement of a single magma type the direction of tension changed with time or was different from place to place within the quadrangle at any one time. For example, southwest of Santa Rita granodiorite dikes strike between N. 50° E. and N. 20° E., and northwest of Santa Rita a swarm of granodiorite dikes trends about N. 20° W., although individual dikes strike from N. 50° W. to due north. The northwest swarm coincides with the projected trend of the long axis of the Santa Rita stock, cuts across the south lobe of the Hanover-Fierro pluton, and extends into the Union Hill area. The pattern of the next younger dike swarm (fig. 47*B*) is roughly wishbone-shaped and conforms closely with the preceding fracture pattern. One of the oldest quartz latite dikes (the Republic) strikes due east, whereas later members of the group strike due north and north-northeast (fig. 47*C*). The youngest dike swarm reveals a considerable broadening of the fracture zone and the dominance of northeast trends over earlier more northerly trends (fig. 47*D*).

FORMATION OF HANOVER HOLE

The Hanover Hole was formed in postore time, during or close to the time of intrusion of the quartz latite dikes and plugs. The sedimentary rocks that fill the hole have been described earlier in this report, but the origin of the hole itself is a structural matter.

The term "hole" is commonly used to describe a topographic basin, and although there is such a basin at Hanover, the term is applied not to the basin but to the cavity in the bedrock, which was filled by sand and gravel soon after its formation. There are other terms for holes, such as diatreme, crater, or subsidence cauldron, but each of these terms connotes a definite origin, and the origin of the Hanover Hole is not definitely known; it may have resulted from subsidence, from the expulsion of material by explosive release of gas, or from a combination of these two mechanisms. The origin is of considerable economic significance, because if a block of ground has subsided it may contain replacement deposits of sphalerite, but if the hole is of explosive origin the mineralized rock has been blown out and is lost.

Evidence favors an origin of both subsidence and explosion. The contact between the Lake Valley and Oswaldo Formations, the most favorable horizon for replacement ore bodies, is at an elevation of about 5,250 feet in the vicinity of the Princess mine adjacent to the south wall of the hole. Exploration from the Princess shaft south of Hanover has shown that the filling in the Hanover Hole extends down at least to the elevation of the favorable beds (5,000 ft), or to about 1,200 feet below the surface. To the authors' knowledge, the depth to the bottom of the fill in the Hanover Hole has not been determined.

Evidence of an origin by subsidence is found in the synclinal structure of the sedimentary filling. The subsidence seems to have been greatest south of the long axis of the hole, beneath the trough of the downwarped beds. Subsidence during the filling of the hole does not necessarily mean, however, that the hole originated simply by subsidence of a block overlying a volcanic neck or a cupola of a stock. The filling of

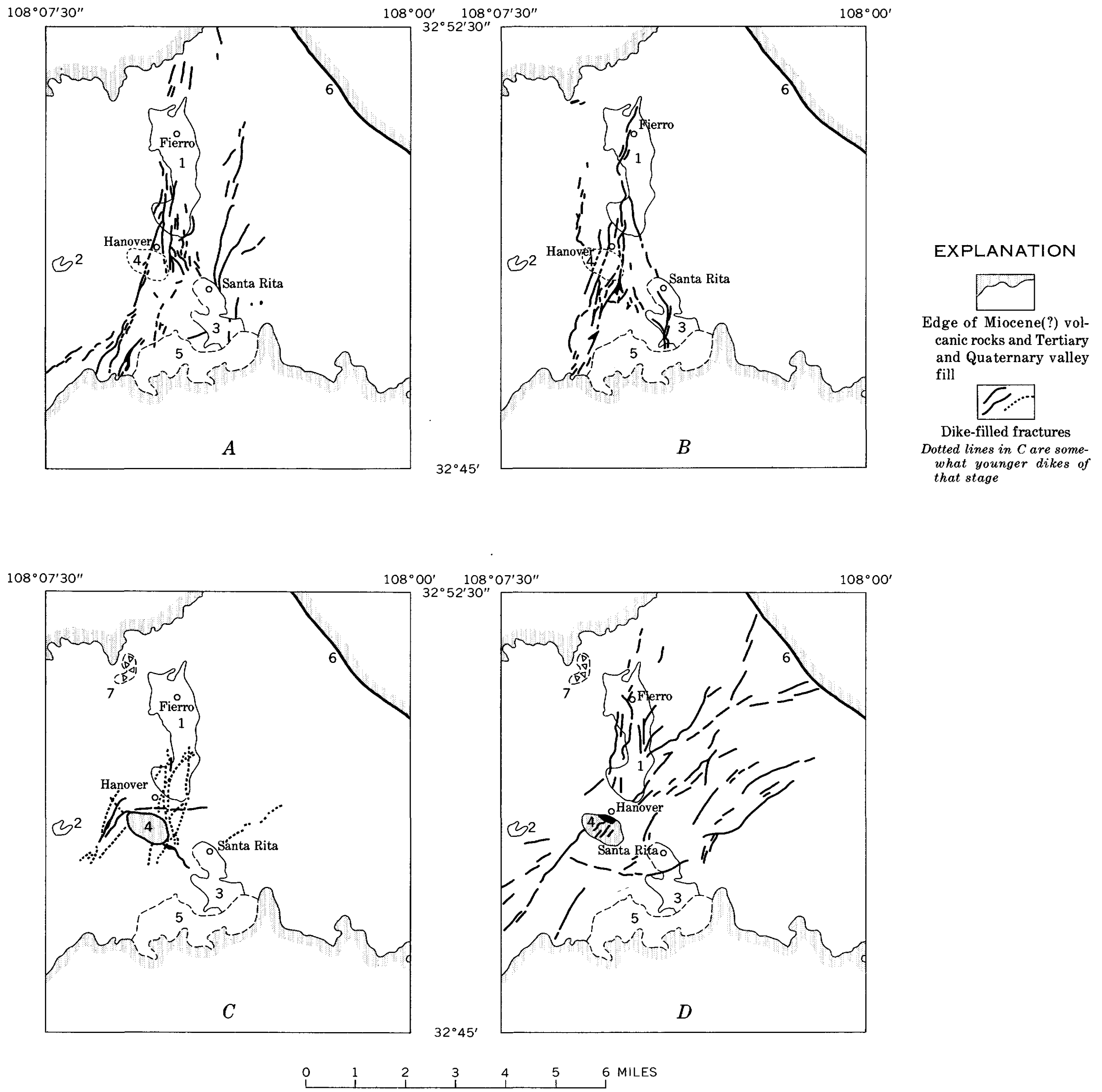


FIGURE 47.—Poststock, pre-Miocene(?) fracture patterns shown by four successive dike swarms, Santa Rita quadrangle, New Mexico *A*, Granodiorite porphyry dikes; *B*, quartz monzonite porphyry dikes; *C*, quartz latite porphyry dikes; *D*, rhyodacite porphyry dikes. 1, Hanover-Fierro pluton; 2, Copper Flat pluton; 3, Santa Rita stock; 4, Hanover Hole (outline dotted in stages *A* and *B*, before formation); 5, Chino mine dump (outline dashed); 6, Mimbres fault; 7, brecciated area.

many diatremes in the Colorado Plateaus province is similarly downwarped. The diatremes are surrounded by explosion debris, so it is clear that an explosion occurred and that subsidence took place during the filling of the diatreme. A similar combination of events may have been responsible for the Hanover Hole. The brecciated bedrock near Turnerville, at Hanover, and west of the Kearney mine is evidence of early explosive activity in the area surrounding the Hanover Hole. The quartz latite dikes and plugs, some of which predated formation of the hole, are intensely altered in most exposures, having apparently been altered by fluids of about the same age as the magma. From this alteration it can be deduced that the magma at that stage was highly charged with volatiles. The explosive release of the volatiles from the magma as it approached the surface could have produced the hole.

In the description of the filling of the Hanover Hole, the possibility was mentioned that the diameter of the hole may have increased toward the surface as the nearly vertical walls sloughed off while the hole was being filled. Any downward decrease in the diameter of the hole means, of course, that there is a corresponding decrease in the area of the favorable beds in the hypothetical downdropped block. On the other hand, if the walls of the hole dip inward, more of the favorable ground remains around the perimeter of the hole at depth than the trace of the hole at the surface would indicate. The walls of the hole appear to be nearly vertical along parts of the north and south sides, but their attitude around the west and east sides has not been determined.

To summarize, the origin of Hanover Hole is in doubt. It may be a filled diatreme, in which there is little hope of finding replacement ore bodies at depth; or it may be a subsidence cauldron, in which ore may exist in the downdropped block. The chance of discovering ore in the Hanover Hole is decreased both by the fact that plugs and postore dikes have invaded the filling, and by the possibility that the plugs may have engulfed any ore bodies that may have existed. A few deep drill holes should yield data that will answer some of the questions.

DEFORMATION OF MIOCENE(?) TO RECENT AGE

Evidence of deformation during and after deposition of the Miocene(?) volcanic rocks is, of course, restricted to areas underlain by Miocene(?) or younger rocks. The deformation is characterized by faulting and jointing; no evidence of folding was found.

Many of the major faults in the Miocene(?) and younger rocks overlie older faults and originated when movement was renewed along the old fractures; the best examples are the Groundhog, San Jose Mountain, and Mimbres faults. The Miocene(?) volcanic rocks have been eroded from the central part of the Santa Rita quadrangle because they were thoroughly broken by movement along the multitude of old faults and fractures and because they were much thinner in that area.

Displacement of units within the Miocene(?) volcanic layers attests to the crustal unrest during the volcanic epoch. Successive steps during the intervolcanic period of faulting were discussed and illustrated by Lasky (1936, p. 51, 52, fig. 8). Some of the faults within the tuffaceous rocks fail to offset the overlying basalt flows; a few faults displace the lower basalt flows but fail to displace an overlying rhyolite tuff; and still others displace the basalt flows above the rhyolite tuff. In places along some faults, the crystal tuffs of the Kneeling Nun Tuff have been displaced more than younger tuffs. The Kneeling Nun Tuff is much more severely jointed, both vertically and at low angle, than the tuff above it, and even the upper part of the Kneeling Nun Tuff is much less jointed than its lower part. This difference is explained rather by greater compaction of the lower part than by greater tectonic stress. Joints and faults are sparse in the overlying basalt flows, which are separated from the crystal tuffs by a conspicuous unconformity within the Miocene(?) volcanic rocks. A belt of northwest-trending joints within the Kneeling Nun Tuff extends from near the south Chino pit southeastward for about 3 miles. Rustler Canyon and the northeast escarpment of the massive crystal tuffs are controlled by northwest joints. The landslide just east of the south pit contains blocks from an area that was broken by sets of northwest and northeast joints.

The sparsity of northeast-trending faults in the east half of the southern volcanic field is noteworthy. This part of the field lies southeast of the prominent belt of northeast faults that is in the underlying pre-Miocene(?) rocks; evidently no new faults of any magnitude developed in this area during or after the volcanic episode. South of the Chino mine dump, where the volcanic rocks overlie the northeast belt of faults in pre-Miocene(?) rocks, the volcanic layers are broken by several persistent northeast-trending faults. These postore faults in the volcanic rocks may reflect mineralized faults in the underlying rocks and are therefore promising sites for deep exploration.

All these facts clearly point to several intervolcanic periods of faulting, and to faulting later than the youngest volcanic units now preserved. Renewed movements on individual faults are indicated by greater displacement of the lower units than of the upper units.

Faulting that involves the Miocene(?), Pliocene, and Pleistocene gravels which fill the valleys and lap onto the sides of the ranges has been described by Paige (1916, p. 11, 12). The faults of this period are typical of those formed in the Basin and Range province. This late faulting was of great magnitude, and northwest-trending faults delineate the large horst block which contains the Santa Rita and adjoining quadrangles. The northeast-bounding fault of this large horst, the Mimbres fault, passes through the northeast corner of the Santa Rita quadrangle. Evidence has been given on preceding pages that the

Mimbres fault in part followed an older, premineralization fault. Late movement is best indicated in a small valley 3,800 feet from the east edge of the quadrangle, where the upper Tertiary and lower Quaternary valley fill is separated from the Paleozoic limestone of the footwall by ½–2 feet of gouge that contains pebbles of rock derived from conglomerate of the valley fill. Were it not for this evidence, the contact of the valley fill with the Paleozoic limestones might be interpreted as a depositional rather than a fault contact.

The youngest faults recognized in the quadrangle cut older alluvium (of Pleistocene age) that is cemented by iron oxides and calcium carbonate; the stratigraphic throw is a few feet at most. The best exposures of such faults are on the rather flat-topped ridge just north of the Keystone shaft, west of the Chino mine. The offsets are due to renewed movement on much older faults. No offsets of younger alluvium were recognized, and no evidence of faulting in historic time was found in the quadrangle.

PHYSIOGRAPHY

In the Santa Rita quadrangle and adjoining areas there are three general types of physiography: (1) dissected plateaus, underlain by flat-lying volcanic rocks in the northwestern and southern parts of the quadrangle and by gravel in the northeast corner; (2) broad gently rolling uplands underlain by flat-lying limestone near the west-central edge of the quadrangle and in much of the eastern part; and (3) irregular topography underlain by many kinds of igneous and folded sedimentary rocks in the rest of the quadrangle. Within these three broad types, individual land forms are dependent upon original lithologic differences and upon differences related to degree and kind of metamorphism. Thus, the volcanic plateaus are composed chiefly of basaltic andesite and tuffs; flows erode to a smooth rolling surface that is in striking contrast to the precipitous slopes that form on the massive indurated tuffs. Where volcanic rocks of greatly different resistances are interlayered, or where resistant volcanic rocks are interlayered with thick gravel deposits, cliff-and-bench topography has resulted. In the broad limestone upland east of Hanover Creek valley, elongate shallow trenches have formed in virtually unaltered dikes of rhyodacite. In the rest of the quadrangle the hills are underlain by syenodiorite porphyry, hornblende granodiorite, silicified granodiorite of the Hanover-Fierro pluton, limestone capped by quartzite, silicated limestone, and silicated limy shale. Some masses of igneous types do not form hills, which suggests that the arrangement of the hills and valleys resulted in part from the superposition of a drainage pattern as well as from the relative resistance of the rocks. Topographic lows are underlain by unaltered parts of quartz monzonite and granodiorite stocks, by conglomerate and sandstone in the Hanover Hole, and by shale and sandstone of the Colorado Formation.

The most active streams drain the northeast corner of the quadrangle and the mountainous areas underlain by the volcanic rocks of Miocene(?) age. These streams drain areas of higher elevation and greater precipitation, and some have steeper gradients; they drain directly into the Mimbres River, which is by far the largest stream that affects erosion in the Santa Rita quadrangle.

OLDER EROSION SURFACES

Transcending the land forms of Recent erosion are two recognizable older erosion surfaces: the pre-Miocene(?) surface and the younger Bayard surface. The oldest erosion surface sufficiently preserved to be recognizable in the present land forms is that which formed just before deposition of the Miocene(?) volcanic rocks. This surface may have been bared in the Silver City–Santa Rita region for a short time during the epoch of erosion that removed the Miocene(?) volcanic cover from parts of the region, but as erosion continued it soon was reburied by deposits of gravel and boulders derived from nearby highlands. Somewhat later, in late Pliocene or early Pleistocene time, erosion carved a pediment, called the Bayard surface, across the semiconsolidated conglomerate and older rocks. Close to the northern mountains the pre-Miocene(?) surface was reexposed and probably somewhat beveled by the Bayard surface; in that area the two surfaces cannot be distinguished. In the area west of the divide that passes through the Santa Rita quadrangle, erosion since Pleistocene time has been relatively slow. The streams, flowing close to base level, have carved broad valleys through the Bayard surface and through the deeper, pre-Miocene(?) surface; and some ridges and flat uplands are capped by a thin veneer of upper Tertiary or lower Quaternary conglomerate, and some by remnants of Miocene(?) volcanic rocks. Some ridge crests not so covered may be only a few feet lower than the pre-Miocene(?) surface. The pre-Miocene(?) surface east of the Mimbres fault was downdropped several hundred feet after being covered by Miocene(?) volcanic rocks and has not been reexposed. In that area the eastward extension of the Bayard surface is several hundred feet above the older, pre-Miocene(?) surface.

PRE-MIOCENE(?) SURFACE

The pre-Miocene(?) surface is now exposed only where the Miocene(?) volcanic rocks have been removed or in canyons that cut sufficiently deep to expose the base of the volcanic pile. A topographic high on the pre-Miocene(?) surface probably existed in the central part of the Santa Rita quadrangle, because resistant rocks stand structurally higher there than in adjoining areas. Direct evidence of the highland is obtained by comparison of the surface underlying the Miocene(?) volcanic rocks, as exposed in the escarpments in the northern and southern parts of the quadrangle, with the crests of the prominent hills in the intervening area. The crests are as much as a few hundred feet higher than the high points of the surface exposed in the north and south escarpments, and they probably represent the minimum height of pre-Miocene(?) hilltops. At the margin of the southern area of Miocene(?) volcanic rocks, the elevation of the pre-Miocene(?) surface ranges from about 6,000 feet near the west and east margins of the quadrangle to about 6,900 feet southeast of the Chino mine, at the crest of a buried highland. At the margin of the northern area of Miocene(?) volcanic rocks, the old erosion surface is at an elevation of about 7,300 feet; this fact and the absence of the lower units of the Miocene(?) volcanic rocks from the area show that a highland probably extended northward from the Chino mine area.

Just east of the Chino mine, a hill crest at an elevation of 6,800 feet coincides with the base of the adjacent Miocene(?) volcanic rocks. The crests of the hills west of the Chino mine are at an elevation of 6,400–6,500 feet; and although they could be remnants of the pre-Miocene(?) surface, they more probably represent the later Bayard surface. The hill crests in the north half of the quadrangle stand about 500 feet above the level of the Bayard surface and are probably relicts of the pre-Miocene(?) surface (fig. 48). However, the surface of the highland once buried by Miocene(?) rocks may have been surmounted by peaks and ridges whose elevations were as much as several hundred feet above the general level. Present topographic highs, such as Hanover and Hermosa Mountains and the ridge crest east of the Hanover-Fierro pluton, probably existed as prominences on the pre-Miocene(?) surface.

The pre-Miocene(?) surface, including the central highland, was completely buried and preserved by Miocene(?) volcanic rocks, but much of it has been destroyed or so modified by later erosion that its detailed character is difficult to determine. Some things about it can be inferred, however. The pre-Miocene(?) surface slopes steeply to the southeast from the highland. Elston (1957) showed that the Rubio Peak Formation (basal formation of the volcanic pile) thickens to thousands of feet thick southeast of the Santa Rita quadrangle. North of the quadrangle the tuff and gravel beneath the basaltic andesite thickens abruptly. The highland, later buried by Miocene(?) volcanic rocks younger than the Rubio Peak Formation, was bounded on the southeast and north by a steep slope, whereas the slopes to the west and east within the quadrangle were comparatively gentle. The surface seems to have reached late maturity on the western slope and probably on much of the eastern slope; in the southeastern part of the quadrangle and north of the quadrangle it seems to be in a more youthful stage.

BAYARD SURFACE

After deposition of the Miocene(?) volcanic rocks, movement was renewed on many of the older faults (for example, the Mimbres, the Groundhog, and the San Jose). Erosion was undoubtedly accelerated in the uplifted areas and in areas where the layers of volcanic rock had been broken by the faults; hence, the volcanic rocks in the Silver City–Santa Rita region, a relatively high area and one of concentrated faulting, were rapidly eroded. The detritus was carried eastward into the Mimbres River valley, and south toward the Deming Basin. In time, the relief of the mountains was reduced and the level of the areas being aggraded rose; the rate of erosion declined as streams slowed, and the line marking the transition between areas of degradation and aggradation advanced toward the highland. Then, possibly because of regional uplift or as a natural continuation of the erosional cycle, the transition line reversed its movement and retreated basinward, and the worn mountains and the upper part of the area of aggradation were beveled to a nearly flat surface. This surface, which slopes southward at about 100 feet per mile, is a prominent physiographic feature west and southwest of the Santa Rita quadrangle. It is here named the Bayard surface because of its prominence near the town of Bayard. (See fig. 49.) The surface extends northward to the steep flank of the Pinos Altos Range. Ridge crests in the Mimbres River valley are roughly concordant and are probably remnants of the same pediment. The relations of the Bayard surface to the underlying rocks and to the older, pre-Miocene(?) surface are shown diagrammatically in figure 50.

FIGURE 48.—View north-northeast from a point south of Copper Flat, showing difference between the elevation of the Bayard surface (foreground and middle ground) and that of the crests of Hermosa and Humbolt Mountains, which are believed to be remnants of the pre-Miocene(?) highland.

The age of the Bayard surface is not precisely known, but it must be Pliocene or even Pleistocene. Pleistocene fossils have been found in somewhat-consolidated alluvium 175 feet below the Bayard surface.

PRESENT EROSION SURFACE

The Bayard surface in the Santa Rita quadrangle has now been partly or largely destroyed by renewed downcutting and lateral erosion. Rejuvenation of the streams apparently resulted principally from an uplift; it may have resulted partly from regional upwarping, but locally it is more plausibly explained as the result of renewed movement on the Mimbres and other faults of the region.

Rejuvenation in the Mimbres River valley area has resulted in dissection of the upper Tertiary conglomerate in the Santa Rita quadrangle to maximum depths of about 500 feet. This dissection has lowered the local base level and has accelerated downcutting by the tributaries of the Mimbres River that head west of the Mimbres fault; thus, youthful valleys—for example, Myers and Willow Springs Canyons—that interrupt the older, mature topography have formed. The relatively deep dissection in the southeast corner of the Santa Rita quadrangle was probably accomplished by tributaries of the Mimbres River. The headwaters of these tributaries, however, seem to have been captured by the stream that follows Lampbright Draw, which passes southward through the Hurley East quadrangle and empties into Deming Basin.

The uplands underlain by Miocene(?) basaltic andesite flows apparently were eroded, during development of the Bayard surface, to a nearly mature topography. The parts of the present valleys that are deep in the massive rhyolite tuff present a more youthful aspect, owing partly to the massiveness of the tuff and to its continuous position above local base levels, and partly to rejuvenation. The erosion of the volcanic areas, which has been continuous since the end of Miocene(?) volcanic activity, has recently been accelerated by rejuvenation.

The east margin of the massive rhyolite tuffs, which extends southeastward from the Kneeling Nun landmark, is marked by cliffs free of any major transverse canyons. This absence of canyons probably resulted from the south to southwest dip of the volcanic layers and the abundance of northwest-trending joints, both of which favor formation of drainage parallel to the scarp. Thus, the intermittent streams of the uplands drain down the dip from the crest and into Rustler Canyon, which is controlled by the northwest jointing; this pattern of drainage was apparently no different in the past.

The north- or northwest-trending canyons that drain part of this area of Miocene(?) volcanic rocks widen in the weak Sugarlump Tuff, as in Lucky Bill Canyon near the Groundhog mine and in the next valley northeast. Most of this widening may have taken place while the Bayard surface was being cut, but much of it occurred during recent rejuvenation.

The area of volcanic rocks in the mountainous northwestern part of the quadrangle is in a late youth or early maturity stage, but the lower part of some of the valleys appears more youthful, suggesting mild rejuvenation. Because of the thinness or absence of the massive crystal tuff, no steep cliffs are present, as in the southern part of the quadrangle, but the topography is rolling, like that formed on basaltic andesite in the southern part. Accordant ridge crests in the northwest area of volcanic rocks may represent remnants of a high dissected erosion surface well above the Bayard surface, or they may be remnants of a resistant flow surface of basaltic andesite from which an ash or gravel layer was rapidly removed.

The partial destruction of the Bayard surface is probably the result of only one major period of rejuvenation. Unpaired deposits of older alluvium occur at various elevations, from the Bayard surface to the bottoms of the valleys. Southwest of the quadrangle, paired terraces indicate rejuvenation in more than one stage.

The presence in the quadrangle of somewhat-consolidated Pleistocene alluvium at or near the bottom of present valleys on the west side of the divide shows that lateral cutting rather than downcutting has been dominant in that area since Pleistocene time. Tectonic stability and the domination of lateral erosion over downcutting have resulted in widening of valleys and in deposition of younger alluvium, in places overlying the Pleistocene alluvium, on the valley floors.

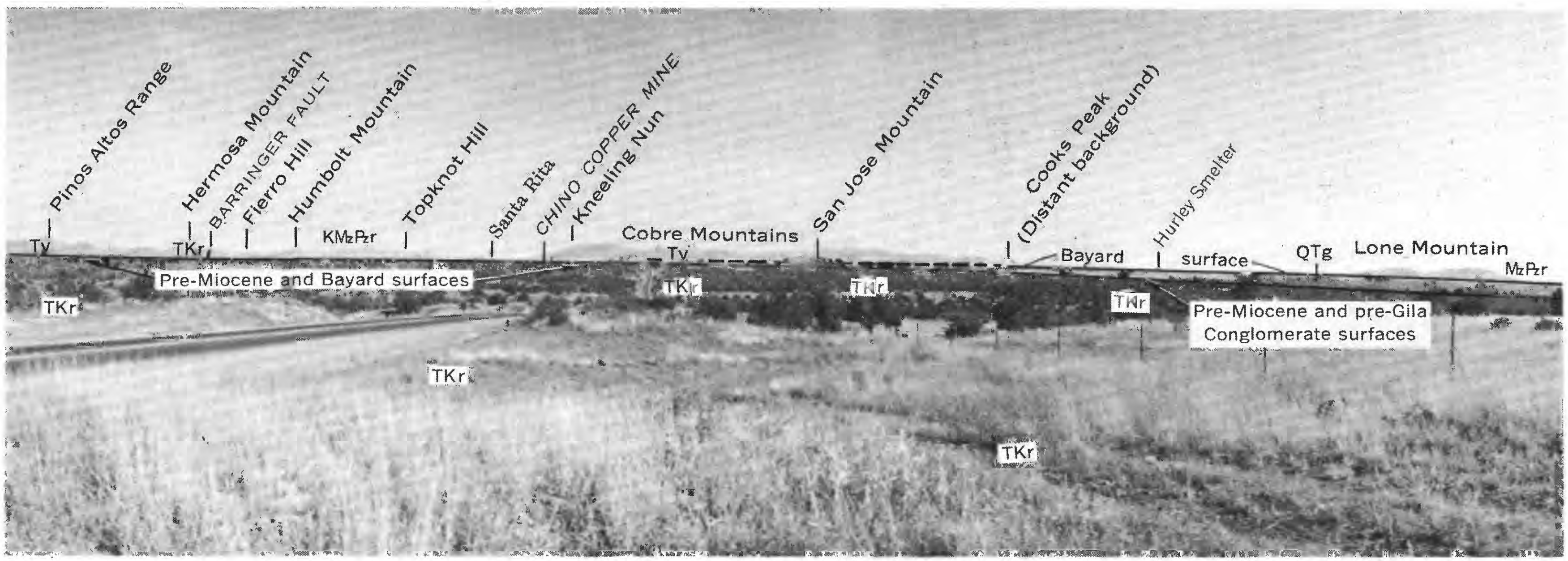


FIGURE 49.—View east from west edge of Fort Bayard quadrangle, showing the somewhat-dissected Bayard surface mainly underlain by rocks of the Upper Cretaceous Colorado Formation and the Upper Cretaceous or lower Tertiary andesite breccia and swarms of mafic dikes. Throughout most of the area north of the highway the Bayard surface and the pre-Miocene surface probably coincide and are indistinguishable. QTg, upper Tertiary and lower Quaternary valley fill, in part equivalent of Gila Conglomerate; Tv, Miocene(?) volcanic rocks; TKr, Upper Cretaceous and lower Tertiary rocks; KMzPzr, Cretaceous, Mesozoic, and Paleozoic rocks; MzPzr, Mesozoic and Paleozoic rocks.

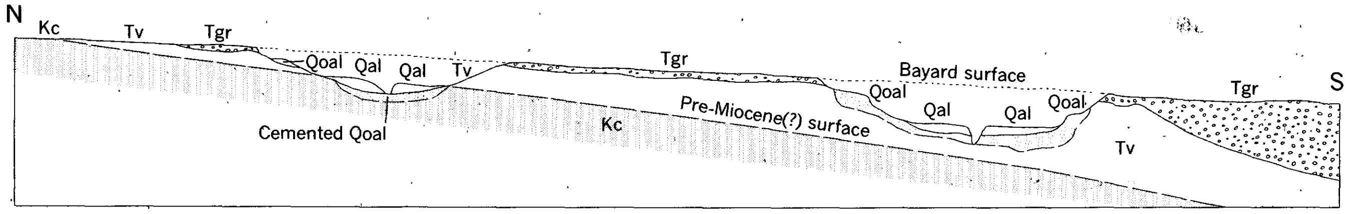


FIGURE 50.—Relations of the Bayard surface and the pre-Miocene(?) surface in area southwest of Santa Rita quadrangle. Qal, Recent alluvium; Qoal, older (Pleistocene) alluvium; Tgr, upper Tertiary gravel; Tv, Miocene(?) volcanic rocks; Kc, Colorado Formation.

East of the main divide, however, downcutting has been nearly continuous, because the base level there is controlled by the Mimbres River.

Trenching of later alluvium in historic times is common throughout the Santa Rita–Silver City region. Much of this trenching has been caused by overgrazing and by torrential rains, particularly rains that interrupt long droughts. Breaking of the sod cover by wagon roads contributed locally to gullying; many roads between Fort Bayard and Pinos Altos, in use since about 1900, are now marked by gullies 3–5 feet deep. Alluvium on the valley floors of the region has been trenched in the past 75 years to depths as great as 40 feet, causing lowering of the water table and consequent destruction of meadows, as well as erosion of the soil.

REFERENCES CITED

Ballmer, G. J., 1953, Geology of the Santa Rita area, *in* New Mexico Geol. Soc. Guidebook 4th Field Conf., Southwestern New Mexico, 1953: p. 130–132.

Bateman, P. C., Clark, L. D., Huber, N. K., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith—A synthesis of recent work across the central part: U.S. Geol. Survey Prof. Paper 414–D, 46 p.

Belt, C. B., Jr., 1955, A petrographic and alteration study of the Hanover-Fierro intrusive, New Mexico: Columbia Univ. M.A. thesis.

Bowen, N. L., 1956, The evolution of the igneous rocks: New York, Dover Publications, Inc., 257 p.

Bushnell, H. P., 1955, Mesozoic stratigraphy of south-central New Mexico, *in* New Mexico Geol. Soc. Guidebook 6th Field Conf., South-central New Mexico, 1955: p. 81–87.

Callaghan, Eugene, 1951, Distribution of intermediate and basic igneous rocks in the Tertiary of western United States [abs.]: Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1428.

Chayes, F. A., 1949, A simple point counter for thin-section analysis: Am. Mineralogist, v. 34, no. 1, 2, p. 1–11.

Cloud, P. E., Jr., and Barnes, V. E., 1946, The Ellenburger group of central Texas: Texas Univ. Bur. Econ. Geol. Pub. 4621, 473 p. [1948].

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1043.

Cope, E. D., 1882, Geological age of the Lake Valley mines of New Mexico: Eng. Mining Jour., v. 34, p. 214.

Dane, C. H., and Bachman, G. O., 1961, Preliminary geologic map of the southwestern part of New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I–344.

Darton, N. H., 1917, Description of the Deming quadrangle [New Mexico]: U.S. Geol. Survey Geol. Atlas, Folio 207. 15 p.

——— 1928, "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 356 p. [1929].

Duriez, Leo H., and Neuman, J. V., Jr., 1948, Geology and mining practice at the Bayard, New Mexico, property: Mining and Metallurgy, v. 29, no. 502, p. 559–561.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 38, 86 p.

——— 1960, Reconnaissance geologic map of Virden thirty-minute quadrangle: New Mexico Bur. Mines and Mineral Resources Geol. Map 15.

Entwistle, L. P., 1944, Manganiferous iron-ore deposits near Silver City, New Mexico: New Mexico School Mines Bull. 19, 70 p.

Epis, R. C., and Gilbert, C. M., 1957, Early Paleozoic strata in southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2223–2242.

Epis, R. C., Gilbert, C. M., and Langenheim, R. L., Jr., 1957, Upper Devonian Swisshelm formation of southeastern Arizona: Am. Assoc. Petroleum Geologists Bul., v. 41, no. 10, p. 2243–2256.

Fenneman, N. M., 1931, Physiography of western United States: McGraw-Hill Book Co., 534 p.

Flower, R. H., 1953, Paleozoic sedimentary rocks of southwestern New Mexico, *in* New Mexico Geol. Soc. Guidebook 4th Field Conf., Southwestern New Mexico, 1953: p. 106–112.

——— 1955, Pre-Pennsylvanian stratigraphy of southern New Mexico, *in* New Mexico Geol. Soc. Guidebook 6th Field Conf., South-Central New Mexico, 1955: p. 65–70.

——— 1958, Cambrian-Mississippian beds of southern New Mexico, *in* Roswell Geol. Soc. Guidebook 11th Field Conf., 1958: p. 61–78.

George, W. O., 1924, The relation of the physical properties of natural glasses to their chemical composition: Jour. Geology, v. 32, no. 5, p. 353–372.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U.S. Geog. and Geol. Survey west of 100th Meridian (Wheeler), v. 3, p. 503–567.

Gillerman, Elliot, and Whitebread, D. H., 1956, Uranium-bearing nickel-cobalt-native silver deposits, Black Hawk district, Grant County, New Mexico: U.S. Geol. Survey Bull. 1009–K, p. 283–313.

Gilluly, James, 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Gilluly, James, Cooper, J. R., and Williams, J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 266, 49 p.

Gordon, C. H., 1907, Notes on the Pennsylvanian formations in the Rio Grande Valley, New Mexico: Jour. Geology, v. 15, p. 805–816.

Gordon, C. H., and Graton, L. C., 1906, Lower Paleozoic formations in New Mexico: Jour. Geology, v. 15, p. 91–92.

Graf, D. L., and Kerr, P. F., 1950, Trace-element studies, Santa Rita, New Mexico: Geol. Soc. America Bull., v. 61, no. 10, p. 1023–1052.

Hague, Arnold, Iddings, J. P., Weed, W. H., and others, 1899, Descriptive geology, petrography, and paleontology, pt. 2 *of* Geology of the Yellowstone National Park: U.S. Geol. Survey Mon. 32, 893 p.

Hayden, F. V., 1876, Eighth annual report of the United States Geological and Geographical survey of the territories, embracing Colorado and parts of adjacent territories, being a report of progress of the exploration for the year 1874: Washington, D.C., 515 p.

Heindl, L. A., 1952, Gila conglomerate, *in* Arizona Geol. Soc. Guidebook, Southern Arizona, 1952: p. 113–116.

Hemley, J. J., and Jones, W. R., 1964, Chemical aspects of hydrothermal alteration with emphasis on hydrogen metasomatism: Econ. Geology, v. 59, no. 4, p. 538–569.

Hernon, R. M., Jones, W. R., and Moore, S. L., 1953, Some geological features of the Santa Rita quadrangle, New Mexico: New Mexico Geol. Soc. Guidebook 4th Field Conf., Southwestern New Mexico, 1953: p. 117–130.

Hewitt, Charles H., 1959, Geology and mineral deposits of the northern Big Burro Mountains-Redrock area, Grant County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 60, 151 p.

Howell, B. F., and others, 1944, Correlation of the Cambrian formations of North America [Chart 1]: Geol. Soc. America Bull., v. 55, no. 8, p. 993–1003.

Hulin, C. D., 1929, Metallization from basic magmas, a theory of genesis for hydrothermal and emanation types of ore deposits: California Univ. Dept. Geol. Sci. Bull., v. 18, no. 9, p. 233–274.

Jicha, H. L., Jr., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 37, 93 p.

Jones, W. R., 1956, The Central mining district, Grant County, New Mexico: U.S. Geol. Survey open-file report.

Jones, W. R., Case, J. E., and Pratt, W. P., 1964, Aeromagnetic and geologic map of part of the Silver City mining region, Grant County, New Mexico: U.S. Geol. Survey Geophys. Inv. Map GP–424.

Jones, W. R., Hernon, R. M., and Pratt, W. P., 1961, Geologic events culminating in primary metallization in the Central mining district, Grant County, New Mexico, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C11–C16.

Kelley, V. C., 1949, Geology and economics of New Mexico iron-ore deposits: New Mexico Univ., Pubs. Geology, no. 2. 246 p.

——— 1951, Oolitic iron deposits of New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 10, p. 2199–2228.

Kelley, V. C., and Silver, Caswell, 1952, Geology of the Caballo Mountains: New Mexico Univ. Pubs. Geology, no. 4, 286 p.

Kerr, Paul F., Kulp, J. L., Patterson, C. M., and Wright, R. J., 1950, Hydrothermal alteration at Santa Rita, New Mexico: Geol. Soc. America Bull., v. 61, no. 4, p. 275–347.

Kindle, E. M., 1909, The Devonian fauna of the Ouray limestone: U.S. Geol. Survey Bull. 391, 60 p.

King, P. B., 1942, Permian of west Texas and southeastern New Mexico, pt. 2 *of* DeFord, R. K., and Lloyd, E. R., eds., West Texas-New Mexico symposium: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 4, p. 535–763.

King, P. B., and Flawn, P. T., 1953, Geology and mineral deposits of pre-Cambrian rocks of the Van Horn area. Texas: Texas Univ. Pub. 5301, 218 p.

King, P. B., and others, 1944, Tectonic map of the United States (scale 1:2,500,000), with text: Am. Assoc. Petroleum Geologists; prepared under direction of Tectonics Comm., Div. Geology and Geography, Natl. Research Council.

Knechtel, M. M., 1936, Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., 5th ser., v. 31, no. 182, p. 81–92.

Kniffin, L. M., 1930, Mining and engineering methods and costs of the Hanover Bessemer Iron and Copper Co., Fierro, New Mexico: U.S. Bur. Mines Inf. Circ. 6361, 20 p.

Kottlowski, F. E., 1957, High-purity dolomite deposits of south-central New Mexico: New Mexico School Mines, State Bur. Mines and Mineral Resources, Circ. 47, 43 p.

——— 1958, Pennsylvanian and Permian rocks near the late Paleozoic Florida islands [New Mexico], *in* Roswell Geol. Soc. Guidebook 11th Field Conf., 1958: p. 79–87.

——— 1962, Reconnaissance of commercial high-calcium limestones in New Mexico: New Mexico School Mines Circ. 60.

Kuellmer, F. J., 1954, Geologic section of the Black Range at Kingston, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 33, 100 p.

——— compiler, 1956, Geologic map of Hillsboro Peak thirty-minute quadrangle: New Mexico Bur. Mines and Mineral Resources, Thirty-minute Quad. Ser., no. 1 [Geol. Map 1].

Landon, R. E., 1929, Metamorphism and ore deposition in the Santa Rita-Hanover-Fierro area, New Mexico—a study of igneous metamorphism: Chicago Univ., unpub. Ph.D. thesis.

——— 1932, Desericitization, a process operative during high-temperature mineralization: Am. Mineralogist, v. 17, no. 9, p. 449–454.

Larsen, E. S., 1938, Some new variation diagrams for groups of igneous rocks: Jour. Geology, v. 46, no. 3, pt. 2, p. 505–520.

Lasky, S. G., 1930, Geology and ore deposits of the Ground Hog mine, Central district, Grant County, New Mexico: New Mexico School Mines, State Bur. Mines and Mineral Resources, Circ. 2, 14 p.

——— 1936, Geology and ore deposits of the Bayard area. Central mining district, New Mexico: U.S. Geol. Survey Bull. 870, 144 p.

——— 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalog and Grant Counties, New Mexico: U.S. Geol. Survey Prof. Paper 208, 101 p.

Lasky, S. G., and Hoagland, A. D., 1948, Central mining district, New Mexico, *in* Dunham, K. C., ed., Symposium on the geology, paragenesis, and reserves of the ores of lead and zinc: Internat. Geol. Cong., 18th, London 1948, p. 97–110. Reprinted 1949 in West Texas Geol. Soc. Guidebook Field Trip 3, p. 7–24.

Laudon, L. R., and Bowsher, A. L., 1941, Mississippian formations of Sacramento Mountains, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 25, no. 12, p. 2107–2160.

——— 1949, Mississippian formations of southwestern New Mexico: Geol. Soc. America Bull., v. 60, no. 1, p. 1–87.

Leroy, P. G., 1954, Correlation of copper mineralization with hydrothermal alteration in the Santa Rita porphyry copper deposit, New Mexico: Geol. Soc. America Bull., v. 65, no. 8, p. 739–767.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, The ore deposits of New Mexico: U.S. Geol. Survey Prof. Paper 68, 361 p.

Lloyd, E. R., 1949, Pre-San Andres stratigraphy and oil-producing zones in southeastern New Mexico—a progress report: New Mexico Bur. Mines and Mineral Resources Bull. 29, 79 p.

Lovering, T. G., 1953, Geology of the western portion of the Santa Rita quadrangle, New Mexico: Arizona Univ., M.S. thesis.

McKee, E. D., 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, no. 5, p. 481–505.

Miller, A. K., and Parizek, E. J., 1948, A Lower Permian ammonoid fauna from New Mexico: Jour. Paleontology, v. 22, no. 3, p. 350–358.

Moore, J. G., 1959, The quartz diorite boundary line in western United States: Jour. Geology, v. 67, no. 2, p. 198–210.

Needham, C. E., 1937, Some New Mexico *Fusulinidae*: New Mexico School Mines Bull. 14, 88 p.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007–1032.

Ordóñez, Georges, Baltosser, W. W., and Martin, Keith, 1955, Geologic structures surrounding the Santa Rita intrusive, New Mexico: Econ. Geology, v. 50, no. 1, p. 9–21.

Paige, Sidney, 1909, The Hanover iron-ore deposits, New Mexico: U.S. Geol. Survey Bull. 380–E, p. 199–214.

——— 1912, The geologic and structural relations at Santa Rita (Chino), New Mexico: Econ. Geology, v. 7, p. 547–559.

——— 1916, Description of the Silver City quadrangle, New Mexico: U.S. Geol. Survey Geol. Atlas, Folio 199, 19 p.

——— 1935, Santa Rita and Tyrone, New Mexico, *in* Copper resources of the world, v. 1: Internat. Geol. Cong., 16th, Washington, p. 327–335.

Pike, W. S., Jr., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Mem. 24, 103 p.

Pratt, W. P., 1967, Geology of the Hurley West quadrangle, Grant County, New Mexico: U.S. Geol. Survey Bull. 1241–E (in press).

Pratt, W. P., and Jones, W. R., 1961, Montoya dolomite and Fusselman dolomite in Silver City region, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 4, p. 484–500.

Pray, L. C., 1953, Upper Ordovician and Silurian stratigraphy of Sacramento Mountains, Otero County, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 8, p. 1894–1918.

——— 1958, Stratigraphic section, Montoya Group and Fusselman Formation, Franklin Mountains, Texas, *in* West Texas Geol. Soc. Guidebook, 1958: p. 30–42.

Ransome, F. L., 1904, The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

Richardson, G. B., 1908, Paleozoic formations in trans-Pecos Texas: Am. Jour. Sci., 4th ser., v. 25, p. 474–484.

Richardson, G. B., 1909, Description of the El Paso quadrangle, Texas: U.S. Geol. Survey Geol. Atlas, Folio 166, 11 p.

Rove, O. N., 1947, Some physical characteristics of certain favorable and unfavorable ore horizons: Econ. Geology v. 42, no. 1, p. 57–77.

Schmitt, H. A., 1933a, Structural associations of certain metalliferous deposits in southwestern United States and northern Mexico: Am. Inst. Mining Metall. Engineers Contr. 38, 23 p.; 1935a, Trans,. v. 115, p. 36–58.

——— 1933b, The Central mining district, New Mexico: Am. Inst. Mining Metall. Engineers Contr. 39, 22 p.; 1935b, Trans., v. 115, p. 187–208.

——— 1939a, The Pewabic mine [New Mexico]: Geol. Soc. America Bull., v. 50, no. 5, p. 777–818.

——— 1939b, Outcrops of ore shoots [Southwestern United States and Mexico]: Econ. Geology, v. 34, no. 6, p. 654–673.

——— 1942, Certain ore deposits in the Southwest, Central mining district, New Mexico, *in* Newhouse, W. H., ed., Ore deposits as related to structural features: Princeton Univ. Press, p. 73–79.

——— 1948, The contact pyrometasomatic aureoles: Am. Inst. Mining Metall. Engineers Tech. Pub. 2357, v. 12, no. 3, 9 p.

——— 1954, The origin of the silica of the bedrock hypogene deposits: Econ. Geology, v. 49, no. 8, p. 877–890.

Skinner, J. W., 1946, Correlation of Permian of West Texas and southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 30, no. 11, p. 1857–1874.

Spencer, A. C., and Paige, Sidney, 1935, Geology of the Santa Rita mining area, New Mexico: U.S. Geol. Survey Bull. 859, 78 p.

Stainbrook, M. A., 1947, Brachiopoda of the Percha shale of New Mexico and Arizona: Jour. Paleontology, v. 21, no. 4, p. 297–328.

Stevenson, F. V., 1945, Devonian of New Mexico: Jour. Geology, v. 53, no. 4, p. 217–245.

Stoyanow, A. A., 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 47, no. 4, p. 459–540.

Sun, Ming-Shan, 1957, The nature of iddingsite in some basaltic rocks in New Mexico: Am. Mineralogist, v. 42, no. 7–8, p. 525–533.

Thompson, M. L., 1942, Pennsylvania system in New Mexico: New Mexico School Mines Bull. 17, 90 p.

Thornton, C. P., and Tuttle, O. F., 1960, Chemistry of igneous rocks—[Pt.] 1, Differentiation index: Am. Jour. Sci., v. 258, no. 9, p. 664–684.

Twenhofel, W. H., chm., Ordovician Subcommittee on Stratigraphy, Natl. Research Council, 1954, Correlation of the Ordovician formations of North America: Geol. Soc. America Bull., v. 65, no. 3, p. 247–298.

Weller, J. M., chm., and others, 1948, Correlation of the Mississippian formations of North America [Chart 5]: Geol. Soc. America Bull., v. 59, no. 2, p. 91–107.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954. Petrography—an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

INDEX

[Italic page numbers indicate major references]