Petrography of xenolith zones in the Black Face-Ames plutons, western San Juan Mountains, Colorado

Richard B. Moore

University of North Dakota

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PETROGRAPHY OF XENOLITH ZONES
IN THE BLACK FACE-AMES PLUTONS,
WESTERN SAN JUAN MOUNTAINS, COLORADO

by
Richard B. Moore
Bachelor of Science, Tufts University 1967

A Thesis
Submitted to the Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Science

Grand Forks, North Dakota

December
1970
This thesis submitted by Richard B. Moore in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

________________________
Dean of the Graduate School
Permission

Title  Petrography of Xenolith Zones in the Black Face-Ames
Plutons, Western San Juan Mountains, Colorado

Department  Geology

Degree  Master of Science

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Signature  Richard B. Moore

Date  18 December 1970
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ABSTRACT

The middle to late Tertiary Black Face-Ames plutons are irregularly-shaped, intrusive bodies located in the San Miguel Mountains of southwestern Colorado. The Ames pluton is generally a composite sill; the Black Face pluton is an asymmetric laccolith. The two plutons are probably joined at depth, and together they form a crudely annular outcrop pattern, open toward the west. The principal rock type within the plutons is granodiorite porphyry, although part of the Ames pluton consists of porphyritic rhyodacite.

Two major zones of xenoliths of Precambrian rock occur within the Black Face-Ames plutons; scattered xenoliths are found at widely separated locations. One zone, located near the summit of Black Face, contains xenoliths of shale, quartzite, and granitic rocks, ranging in diameter from 2 cm to 5.4 m. The other zone is exposed near Ames, where xenoliths of amphibole-pyroxene rocks, mafic schists, and occasional granites occur, ranging in diameter from 2 cm to 3.6 m.

Measurements near Ames indicate that the xenoliths of high specific gravity have tended to sink to the lower parts of the granodiorite porphyry sill, whereas the lighter granitic rocks have generally remained in the middle portions.
In contrast, the xenoliths on Black Face, which are generally of lower specific gravity than the host granodiorite porphyry, have apparently floated to the top of the magma chamber.

Xenolith orientation measurements near Ames suggest imbricate structure, which may indicate the direction of magmatic flow.

Microscopic study of contact zones between xenoliths and host rocks indicates that granitic xenoliths have reacted with their hosts to a greater degree than have xenoliths of other rock types. In the contact zone, pyroxene in both mafic xenoliths and in the granodiorite porphyry is usually converted to amphibole and amphibole is generally altered to chlorite. Concentration of mafic minerals at the contact is common.

The presence of a small mafic-rich intrusive cutting the granodiorite porphyry near the summit of Black Face, as well as the zone of concentrated xenoliths in this area, suggest that a zone of weakness existed, through which first the xenolith-bearing granodiorite porphyry and later the mafic-rich plug intruded.

The zone of xenoliths and Ophir stock-Ames pluton contact phenomena near Ames is located near the intersection of two major structures: the northeast-trending monoclinal flexure associated with the San Juan domal uplift during Laramide time, and a west-trending fracture radiating from...
the middle to late Tertiary Silverton caldera. The concentration of xenoliths in this area is believed to be a product of this apparent conduit from the Precambrian basement.
INTRODUCTION

Scope and Objectives

Cross and Purington (1899), Bromfield (1967), and the writer observed several features of the xenolith zones in the Black Face-Ames plutons which appeared to warrant further study:

1. The great variety of rock types present among the xenoliths.
2. The enormous concentration of xenoliths.
3. The unusual outcrop pattern of the Black Face-Ames plutons and their varying relationships to the intruded country rocks.
4. The evidence of possible liquid mixing or liquid immiscibility phenomena near the contact between the Ophir stock and the Ames pluton adjacent to one of the inclusion zones.
5. The apparent difference in amount of chemical reaction which occurred between different xenolith rock types and their hosts.
6. The presence of textural, and perhaps compositional, variations in the granodiorite porphyry throughout the Black Face-Ames plutons.
7. Other evidence for important magmatic processes bearing on geneses of various rock types and on the history of a
Figure 1.--View southeast across Bilk Basin from summit of Wilson Peak (14,017 feet) in eastern San Miguel Mountains. Lizard Head (Silverton Volcanic Series) at right, Black Face pluton in shadow at center.
given rock body, including, in addition to the liquid mixing phenomena mentioned above, sinking or floating in the fluid magma, chilling against invaded rocks, and formation of rocks different in composition from two adjacent magmatic bodies.

The objective of the present investigation is the determination of the origin of these xenoliths and their relation to the host magma.

Previous Investigations

According to Bromfield (1967, p. 6-8), the San Miguel Mountains were first investigated in 1874 by F. M. Endlich, who merely recognized the presence of both igneous and sedimentary rocks in the area, and in 1876 by W. H. Holmes, who visited the San Miguels and described several laccolithic features similar to those of the Ute and Abajo Mountains.

Prior to U. S. Geological Survey studies conducted intermittently from 1953 to 1968, the most important contributions to an understanding of the geology in the western San Juan Mountains were the investigations of Cross and his co-workers. In particular, Cross and Purington in 1899 described the Black Face-Ames plutons and discussed the xenoliths along the railroad grade near Ames, suggesting that they might be the product of "magmatic differentiation."

As a result of field and laboratory examinations, Bromfield (1967) and others mapped the outcrops of the
Black Face-Ames plutons at a scale of 1:24,000, identified the two major rock types present in the Ames pluton, discussed the magnascopic and microscopic details of the rocks, described the structural features associated with the plutons, and established their approximate age. He discussed the various rock types found among the inclusions, described their general size and degree of roundness, and suggested that they originated from rocks present in the buried Precambrian basement.

Field Investigations

Field investigations were conducted during the summer of 1968. All previously mapped (Bromfield, 1967) outcrops of the Black Face-Ames plutons were examined, intrusive relationships to the host sedimentary rocks were studied, and samples were taken at 169 localities.

Because of the varied lithologic units present in the Ames area, a geologic map (Plate 1) of that area was drawn on U. S. Geological Survey topographic sheets photographically enlarged to a scale of 1:6000. Short and Mason 16,000-foot altimeters and Brunton compasses were used to establish locations. In addition, part of the adjoining Ophir quadrangle was mapped in the field on aerial photographs (scale 1:24,000) and subsequently transferred to the topographic sheet.

Within one of the two principal xenolith zones, along the abandoned narrow gauge railroad track near Ames, samples
illustrating contact relations between the Ames pluton and the Ophir stock were collected. In the same area and near the summit of Black Face, samples of xenolith-host contacts were taken.

In the zone of xenoliths near Ames, quantitative data were obtained on: (1) the relative proportions of each inclusion rock type within the two hosts, porphyritic rhyodacite and granodiorite porphyry, (2) the possible presence of an imbricate structure in the orientation of the xenoliths, which might demonstrate the direction of flow of the host magma, and (3) the sinking of various xenolith rock types in the magma and subsequent concentration of heavier types toward the bottom of the magma.

Outcrops of Precambrian rocks in areas adjacent to the San Miguel Mountains were examined in an effort to identify possible source areas for the xenoliths on Black Face and at Ames. Specifically, amphibolites, granites, gneisses, and mafic schists were observed and, in many cases, collected in the Needle Mountains and in the Black Canyon uplift, and siliceous schists were observed in the Rico Mountains.

Laboratory Investigations

Thin sections of ninety-four specimens were studied in order to determine textural and compositional variations throughout the Black Face-Ames plutons, as well as to
investigate reaction relationships between the xenoliths and their host magmas. Modal analyses were performed using a mechanical stage and counting one thousand points for each thin section. Optically determined modal analyses are included in the Appendices. In several cases, counts on a thin section were repeated to check reproducibility of results, which averaged about 97 percent. Aside from determinate errors, variations in modal analyses for rocks of megascopically similar appearance are due principally to variations in mineral composition.

Compositions of plagioclase were determined by the Wright extinction angle method (Moorhouse, p. 57).

Fifty-five samples were X-rayed using a Philips high angle diffractometer in order to determine mineralogical compositions, especially for the fine-grained or extensively altered rocks, to examine reaction relationships between xenoliths and host magmas, and to compare diffraction patterns with microscopically determined modal analyses. A summary of the X-ray diffraction analyses is included in Appendix A.

**Topography**

The Black Face-Ames plutons lie in the eastern San Miguel Mountains (Figure 1), an erosional outlier of the San Juan Mountains. The San Juans, consisting of rugged, glaciated peaks and magnificent intermontane valleys, are a
westward extension of the southern Rocky Mountains, about one hundred miles long and sixty to seventy miles wide.

Although the highest peaks in the San Miguel Mountains reach well over 14,000 feet, outcrops of the Black Face-Ames plutons range in elevation from 12,147 feet on Black Face to about 8800 feet near Ames.

Regional Geography

The Black Face-Ames plutons are located almost entirely within the Mount Wilson 7½-minute quadrangle (Figure 2) in the San Juan and Uncompahgre National Forests of eastern San Miguel and Dolores Counties in southwestern Colorado; a thin sill of rhyodacite, considered to be part of the Ames pluton, extends about four hundred feet into the adjoining Gray Head 7½-minute quadrangle to the north; and another part of the Ames pluton, consisting of xenolith-bearing granodiorite porphyry and porphyritic rhyodacite, extends about five hundred feet into the Ophir quadrangle to the east.

Access to outcrops of the Black Face pluton is mostly by means of a few trails, although an old usable jeep road runs into Bilk Basin from the south. Much of the Ames pluton is exposed near an abandoned narrow-gauge railroad grade, upon which cars can be driven.

Summer temperatures in the area are variable, largely depending on elevations. Temperatures in the valley of the
Figure 2.--Index map of Colorado showing location of Mount Wilson Quadrangle. Based on map by Bromfield (1967).
South Fork of the San Miguel River near Ames may approach 90° while simultaneously snow and sleet are falling above 12,000 feet a few miles away. May and June are relatively dry months, but in July and August heavy thunderstorms occur almost every day. The winters are long and cold with heavy snow, much of which remains on the ground until July.

Three vegetation zones are found in the area of the Black Face-Ames plutons. Aspen and ponderosa pine dominate the montane zone, ranging in elevation from 6000 to 9000 feet. Engelmann’s spruce and alpine fir are the typical trees of the subalpine zone, ranging from 9000 feet to timberline (11,000 to 11,500 feet). The alpine zone consists of many open meadows where grasses and beautiful wildflowers grow, and of, above 12,000 feet, only lichen-covered rocks.
The San Juan Mountains in southwestern Colorado are composed of Tertiary volcanic rocks overlying Paleozoic and Mesozoic sediments and Precambrian gneisses, schists, and intrusives. Late Tertiary stocks, laccoliths, dikes, and sills ranging from gabbro to adamellite intrude the volcanic and sedimentary sequence.

The San Miguel Mountains consist principally of several of these intrusions, including the Black Face-Ames plutons.

According to Bromfield (1967, p. 64-5),

The primary tectonic feature of the western San Juan Mountains is a broad dome which was formed principally in Laramide time. . . . From the plateaus province to the west of the San Juan Mountains, Mesozoic and older strata rise gently but steadily toward the San Juan dome. Just to the east of the (Mount Wilson) quadrangle, they bend upward along the San Juan monoclinal fold on the flank of the dome . . . .

Probably during early Tertiary time, erosion beveled the western part of the San Juan dome to a surface of low relief, and upon this surface piedmont alluvial gravel was deposited which today forms the Telluride Conglomerate. Upon this conglomerate, beginning perhaps in middle Tertiary time, a thick pile of volcanic rocks accumulated and formed a volcanic plateau some 100 miles across which contained well over 6000 cubic miles of volcanic rocks (Larsen and Cross, 1956). During later Tertiary and Quaternary time this volcanic pile was deeply dissected to form the present rugged San Juan Mountains. Erosion by the San Miguel and Dolores Rivers and their tributaries has nearly isolated the stock-cored San Miguel Mountains from the main San Juan Mountain region to the east.
A major tectonic feature superimposed on the dome in the western San Juan Mountains is the linked Silverton-Lake City calderas of middle to late Tertiary age. The Silverton caldera, located about 10 miles east of the Wilson Peak stock area, is approximately 10 miles in diameter and is bounded by concentric and radial fractures that were the locus for numerous important mineral deposits of gold, silver, and base metals. Stocks intruding the volcanic rocks include the Sultan Mountain, Stony Mountain, the Grizzly Peak, and in a straight line, the Ophir, Wilson Peak, and Dolores Peak stocks.

The Black Face-Ames plutons occupy the area between the Ophir and the Wilson Peak stocks.
FORMATIONS intruded by the Black Face-Ames plutons include the Mancos Shale, the Dakota Sandstone, and the Brushy Basin Shale Member of the Morrison Formation. Within the western San Juan Mountains, however, sedimentary and volcanic rocks ranging in age from Cambrian to Oligocene are exposed. The unexposed Paleozoic rocks in the Mount Wilson quadrangle include, according to Bromfield (1967), the Upper Cambrian Ignacio Quartzite, the Upper Devonian Ouray Limestone and Elbert Formation, the Mississippian Leadville Limestone, the Pennsylvanian Hermosa and Molas Formations, the Permian and Pennsylvanian Rico Formation, and the Permian Cutler Formation.

Exposed sedimentary units in the Mount Wilson quadrangle include, in ascending order: the Upper Triassic Dolores Formation, consisting of interbedded red sandstones and mudstones ranging in thickness from 300 to 600 feet; the Upper Jurassic Entrada Sandstone, a 100-foot thick, friable, light-colored sandstone; the Upper Jurassic Wanakah Formation, consisting of one to three feet of the fresh-water Pony Express Limestone Member, 25 to 35 feet of the Bilk Creek Sandstone Member, and 70 to 120 feet of the uppermost marl member; the Upper Jurassic Morrison Formation, subdivided in the area into the lower Salt Wash
Sandstone Member, about 400 feet thick, and the upper Brushy Basin Shale Member, 325 to 400 feet thick; the Lower Cretaceous Burro Canyon Formation, present only locally, where it ranges up to 40 feet in thickness; the Upper Cretaceous Dakota Sandstone, consisting of interbedded sandstone, conglomeratic sandstone, carbonaceous shale, and coal ranging in total thickness from 150 to 200 feet; the Upper Cretaceous Mancos Shale, a deep marine black shale 1500 to 2500 feet thick; and the Oligocene (?) Telluride Conglomerate, 200 to 1000 feet of red to light-gray conglomerate, sandstone, and mudstone.

The Paleozoic, Mesozoic, and early Tertiary sedimentary units in the San Miguel Mountains are overlain by volcanic rocks of middle to late Tertiary age. The oldest of these is the San Juan Formation, consisting of 600 to 3000 feet of tuffaceous sandstone, probably deposited partly by water, and tuff breccia. The Silverton Volcanic Group, up to 700 feet thick in this area, overlies the San Juan Formation; it consists of welded ash flow tuffs, tuff breccia, and porphyritic pyroxene andesite flows. In much of the western San Juan Mountains the Silverton Volcanic Group is overlain by welded ash flow tuffs of the Potosi Volcanic Group, but these rocks are absent from the Mount Wilson quadrangle.

Above the consolidated rocks are Quaternary glacial, landslide, talus and alluvial deposits.
STRUCTURAL RELATIONS

According to Bromfield (1967), the Black Face pluton is an asymmetric laccolith. On its north side it is relatively concordant with the intruded Mancos Shale, but the Mancos on the south side "is at steep angles, commonly vertical to overturned, and probably in part is faulted parallel to the contact" (Bromfield, 1967, p. 67). To the west of the summit of Black Face, just east of Cross Mountain, the pluton becomes more sill-like, but on the west side of Cross Mountain the granodiorite porphyry occurs generally as a dike. At its eastern exposures the Black Face pluton apparently merges with the Ames pluton, although their connection is buried. Therefore, the "boundary" between the two plutons is drawn somewhat arbitrarily.

The Ames pluton is generally a thick composite sill, although in its western exposures north of Sunshine Mountain it is apparently discordant. According to Bromfield, the intruding magma was apparently highly viscous, for it "made room for itself by both lifting and crumpling the beds as it pushed forward in 'snowplow' fashion through the incompetent Mancos Shale" (Bromfield, 1967, p. 69). The pluton usually intrudes various stratigraphic horizons within the Dakota Sandstone or the Mancos Shale, but in the
vicinity of the inclusion zone near Ames the Brushy Basin Shale Member of the Morrison Formation apparently forms the floor of the sill; Mancos Shale is found above the sill, and the Dakota Sandstone is apparently covered.
CONTACT METAMORPHISM

The Black Face-Ames plutons have metamorphosed the Mesozoic sediments into which they have intruded. The Mancos Shale has been baked to a hornfels near the top of Black Face (Figure 3) and on its south side (where it is also commonly contorted), the Brushy Basin Shale has been converted to an extremely indurated hornfels in the vicinity of Ames (Figure 4), and the Dakota sandstone has locally been baked by the same intrusive to a quartzite. An extensive contact metamorphic aureole surrounding the Wilson Peak stock and part of the Ophir stock has been mapped by Bromfield (1967), who states that the stocks were the principal agents of contact metamorphism of the Mancos Shale, the Telluride Conglomerate, and the volcanic formations in the area.
Figure 3.--View of summit of Black Face from the west. Light gray area near center is "hornfelsed" Mancos Shale.
Figure 5.--Porphyritic adamellite of the Ophir stock. Phenocrysts of plagioclase, alkali feldspar, biotite, and augite are set in a groundmass of the same minerals and quartz, magnetite-ilmenite, and apatite. Crossed nicols. Magnification 10X.
OPHIR STOCK

In the vicinity of the Ames inclusion zone the Ophir stock consists of at least two separate rock types, microgranodiorite and porphyritic adamellite. The microgranodiorite is often in contact with the granodiorite porphyry of the Ames pluton, and in some areas liquid-mixing relationships along the mutual contact between the two plutons are suggested (see p. 42). The porphyritic adamellite apparently is not in contact with the Ames pluton. Like the Wilson Peak and Dolores Peak stocks to the west, the Ophir stock is probably also composite, although in the principal study area the contact between the porphyritic adamellite and the microgranodiorite is covered by alluvium and glacial deposits.

Only one thin section of the porphyritic adamellite (Figure 5), which forms the spectacular cliffs known as the Ophir Needles, was obtained. Modal analysis shows that it consists of about 37 percent plagioclase, 17 percent K-feldspar, 24 percent quartz, 6 percent augite, and 13 percent biotite. Plagioclase occurs chiefly as euhedral to subhedral phenocrysts reaching 1 cm in length and occasionally in the groundmass. It shows oscillatory normal zoning with cores of about An$_{55}$ and rims of An$_{35}$, with an average
Figure 4.—Ames. View from north of "hornfelsed" Brushy Basin Shale in lower right corner. Mixed granodiorite porphyry and microgranodiorite zone at center.
of about $\text{An}_{42}$. Alkali feldspar is perthitic and is found chiefly as anhedral grains in the groundmass and more rarely as euhedral to subhedral phenocrysts reaching 2 cm in diameter. Quartz occurs solely as small anhedral grains interstitial to the groundmass feldspar. Biotite is found in large (to 8 mm) grains and is pleochroic from light yellow to dark brown. Augite is generally colorless to light brown or green and is found as euhedral grains up to 3 mm in diameter. This medium-grained rock has a hypidiomorphic granular texture and is distinctly porphyritic. In hand specimen and in thin section its appearance and mineral content are quite similar to the porphyritic adamellite of the Wilson Peak stock six miles to the west.

The microgranodiorite (microgranogabbro of Bromfield, 1967) of the Ophir stock is a fine-grained gray rock with a hypidiomorphic granular texture (Figure 6). Modal analyses indicate an average mineral composition of about 50-65 percent plagioclase, 8-15 percent quartz, 6-12 percent K-feldspar, 8-12 percent augite, 4-6 percent hornblende, 8-12 percent biotite, and 6-8 percent magnetite. Subhedral plagioclase, often occurring as Carlsbad twins, shows oscillatory normal zoning with cores of $\text{An}_{62}$ to rims of $\text{An}_{38}$, with an average of about $\text{An}_{48}$. Alkali feldspar and quartz are anhedral and interstitial to plagioclase. Augite is found as light green, faintly pleochroic, subhedral crystals which alter to hornblende, biotite, and chlorite. Hornblende
Figure 6.--Microgranodiorite of the Ophir stock. Highly altered hornblende phenocrysts are scattered through a groundmass of plagioclase, K-feldspar, quartz, augite, hornblende, biotite, and magnetite. Crossed nicols. Magnification 9X.
is found in the groundmass, where it often mantles augite, and in rare phenocrysts up to 3 mm long. It is pleochroic from dark yellow to medium brown. Red-brown biotite occurs as discrete crystals and as an alteration product of augite and hornblende. Accessory minerals are magnetite, apatite, and zircon.

From the dump of the Silver Bell Mine at Ophir a specimen of a third rock type occurring within the Ophir stock was obtained. Modal analysis of a single thin section shows that this coarse-grained gabbro (Figure 7) consists of about 55 percent plagioclase, 3 percent enstatite, 8 percent augite, 12 percent magnetite, 10 percent hornblende, 2 percent biotite, and 10 percent chloritic and sericitic alteration of mafic minerals and plagioclase. The plagioclase is generally unzoned and has a composition of about 52-62 percent anorthite.

According to R. G. Luedke of the U. S. Geological Survey (oral communication, 1969), gabbro is an important phase of the Ophir stock, although he has not mapped it in detail as yet. According to C. S. Bromfield (oral communication, 1969), syenitic rocks have also been identified in the Ophir stock.

As mentioned before, contact relations between the microgranodiorite of the Ophir stock and the granodiorite porphyry of the Ames pluton are somewhat unusual and will be discussed in a later section.
Figure 7.--Photomicrograph of gabbro of the Ophir stock. The section contains labradorite, orthopyroxene, clinopyroxene, and magnetite, with minor amounts of biotite, hornblende, and alteration products. Crossed nicols. 10X.
BLACK FACE MINOR INTRUSIVE

Strikingly exposed near the summit of Black Face is a small intrusive plug of microgranodiorite (Figure 8), formerly described by Cross and Purington as a camptonite and included by Bromfield (1967) in his minor intrusions of intermediate composition. Modal and X-ray analyses of this dark gray-green to black, extremely fine-grained rock show that it is composed of about 44 percent plagioclase, 11 percent alkali feldspar, 23 percent quartz, 4 percent ferromagnesian minerals, 6 percent magnetite, and 12 percent chlorite. Rare, widely scattered phenocrysts of plagioclase, augite, and hornblende occur in a somewhat chloritized groundmass of feldspar, quartz, magnetite, and ferromagnesian minerals (Figure 9). The rock contains many inclusions of Mancos Shale and of granodiorite porphyry from the Black Face pluton.

Near the east end of the Black Face ridge, overlooking Trout Lake, is another irregular plug somewhat similar to the microgranodiorite described above. In the granodiorite porphyry near this intrusive are a few xenoliths similar to the silicic types exposed on Black Face adjacent to the microgranodiorite plug. The presence of these xenoliths near the small intrusives is believed to suggest the
existence of zones of weakness in the basement rock, through which first the xenolith-bearing granodiorite porphyry and later the microgranodiorite magmas moved.
Figure 8.--Contact between minor Black Face intrusive (left) and Black Face pluton (right). Note zone of monite-stained granodiorite porphyry. Rico Mountains in instance at left.
PETROGRAPHY OF BLACK FACE PLUTON

The granodiorite porphyry of the Black Face pluton is a holocrystalline medium-grained porphyritic rock with hypidiomorphic granular texture (Figure 10). Seriate porphyritic texture frequently occurs as a result of increasing size of the groundmass.

Modal analyses (Appendix B) of the granodiorite porphyry show that this medium gray rock consists of about 34-45 percent plagioclase, 8-25 percent quartz, 11-22 percent alkali feldspar, 6-8 percent pyroxene, 1-12 percent biotite, and 1-14 percent alteration products.

Subhedral to euhedral phenocrysts (up to 5 mm long) of zoned plagioclase range from cores of about An55-70 to rims of An18-35, the overall average being approximately An48. Plagioclase of similar composition and habit is found in the groundmass. The crystals are often strongly altered to sericite or clay minerals.

Augite, occasionally titaniferous and commonly glomeroporphyritic, usually occurs as euhedral phenocrysts 1-3 mm in diameter, ranging in color from light green to brown or colorless. Rarely, grains of enstatite reaching 0.5 mm in length are seen.

Quartz is always anhedral and confined to the groundmass.
Figure 10.--Photomicrograph of granodiorite porphyry of Black Face pluton, plane polarized light. Phenocrysts of plagioclase, augite, and biotite are set in a groundmass of plagioclase, alkali feldspar, quartz, magnetite-ilmenite, accessory minerals, and alteration products. 7X.
K-feldspar is subhedral to euhedral, strongly altered, and confined to the groundmass.

Anhedral to subhedral biotite occurs chiefly as phenocrysts ranging from 1 to 3 mm in length. It is strongly pleochroic from light yellowish-brown to dark red.

Magnetite-ilmenite occurs generally as anhedral to subhedral grains 0.1 to 0.3 mm in diameter, and accessory apatite and zircon are euhedral and less than 0.1 mm in size.

The principal alteration products include widespread sericitic and clay-mineral alteration of feldspars; reddish-brown "iddingsite," often pseudomorphous after pyroxene and perhaps hornblende; green chlorite, altering from biotite and augite; and calcite, perhaps a product of the disintegration of hornblende.

Hornblende itself is rarely seen in the Black Face granodiorite porphyry. It is more common in the otherwise similar granodiorite porphyry of the Ames pluton.
PETROGRAPHY OF AMES PLUTON

Lithology

A greater variation in rock types is present in the Ames pluton than in the Black Face granodiorite porphyry. The dominant lithology is also granodiorite porphyry, but a large portion of the thick sill west of Ames is composed of porphyritic rhyodacite. In addition, decrease of quartz in certain areas of the Ames pluton, such as near its western contact with the Wilson Peak stock near the Morning Star Mine, results in a monzonite porphyry. Among phenomena associated with the Ophir stock-Ames pluton contact zone is a porphyritic granite with large (2.5 cm diameter) alkali feldspar phenocrysts—a rock megascopically similar to the granodiorite porphyry except for the conspicuous K-feldspar phenocrysts and the decrease in plagioclase. In addition, a dike of granite 15 cm wide and 3 meters long, possibly genetically related to the granodiorite porphyry, intrudes the latter near the Silver Hat mill.

The porphyritic rhyodacite of the thick sill west of Ames has been interpreted by Bromfield (1967) as somewhat older than the granodiorite porphyry on the basis of dilation and alteration of the rhyodacite by the granodiorite. However, the porphyritic rhyodacite of the Ames inclusion
zone is interpreted by this writer as a chill zone, formed by rapid cooling of the granodiorite porphyry magma against the enclosing wall rock.

Mineralogy and Texture

With a few exceptions, the dominant granodiorite porphyry of the Ames pluton is a highly porphyritic, holocrystalline, medium-grained rock with hypidiomorphic granular texture (Figure 11). In scattered areas along the large sill west of Ames, the rock is nonporphyritic near its upper and lower contacts with either the rhyodacite or with the Dakota Sandstone.

Modal analyses (Appendix B) of the Ames granodiorite porphyry indicate that its composition is quite similar to that of the Black Face rock: 36-49 percent plagioclase, 9-24 percent K-feldspar, 3-25 percent quartz, 6-10 percent pyroxene, 0-12 percent biotite, and 1-20 percent alteration products. The only significant variation in mineralogy is the presence of 1-7 percent hornblende in the Ames granodiorite porphyry. As mentioned before, quartz may decrease to as low as 2.6 percent in the Ames granodiorite porphyry, making this rock a monzonite porphyry, but these local variations are relatively insignificant and these rocks are included with the granodiorite porphyry.

Plagioclase occurs as subhedral to euhedral phenocrysts up to 5 mm long, zoned from cores of An$_{54-65}$ to rims
Figure 11.—Photomicrograph of granodiorite porphyry of Ames pluton, crossed nicols. Phenocrysts of plagioclase, augite, and hornblende in a groundmass of plagioclase, alkali feldspar, quartz, biotite, magnetite-ilmenite, accessory minerals, and alteration products. Magnification 5X.
of An$_{28-34}$ and averaging about An$_{48}$. Similar plagioclase from 0.01 to 0.2 mm in length is found in the groundmass. Sericitic and clay-mineral alteration of both phenocrysts and groundmass is common.

Alkali feldspar, as in the Black Face pluton, is euhedral to subhedral, strongly altered, and confined to the groundmass, where its size varies from about 0.01 to 0.2 mm in diameter.

Anhedral quartz occurs in the groundmass in grains 0.01 to 0.2 mm in diameter.

Phenocrystals of augite, hornblende, and occasionally biotite are often clustered together. The augite is light brown or green, sometimes titaniferous, weakly pleochroic, invariably euhedral, often twinned, and reaches 3 mm in diameter.

Hornblende occurs generally as subhedral phenocrysts reaching 2 mm in diameter. Pleochroism ranges from light yellowish-brown to greenish- or reddish-brown, and reaction rims of biotite, magnetite-ilmenite, and augite are common.

Anhedral to subhedral biotite is found in grains reaching 3 mm in length. It is strongly pleochroic from light yellowish-brown through chestnut to dark red.

Magnetite-ilmenite occurs as discrete grains or as masses altered from hornblende. It is generally anhedral and ranges from 0.01 to 0.3 mm in diameter. Accessory
apatite, zircon, and rarely sphene and pyrite occur as euhedral inclusions in plagioclase or as separate grains associated with pyroxene.

As in the Black Face granodiorite porphyry, alteration products include sericite and clay minerals from feldspars; "iddingsite," pseudomorphous after hornblende and augite; chlorite, altering from biotite, augite, and hornblende; and calcite, occurring both as an alteration product of hornblende and as highly assimilated xenoliths.

The porphyritic rhyodacite of the Ames pluton is a holocrystalline, fine-grained rock with an allotriomorphic to hypidiomorphic granular groundmass and euhedral phenocrysts (Figure 12).

Modes (Appendix C) of the porphyritic rhyodacite show that this green to gray rock is composed of about 38-68 percent plagioclase, 2-23 percent K-feldspar, 11-21 percent quartz, 1-25 percent hornblende, and 3-20 percent alteration products. Through decrease in quartz and alkali feldspar and corresponding increase in plagioclase, the rhyodacite grades into dacite, quartz andesite, and andesite.

Plagioclase occurs as euhedral phenocrysts reaching 3 mm in diameter and as subhedral grains from 0.01 to 0.1 mm long in the groundmass. Oscillatory normal zoning, with cores ranging from An45 to An60 and rims ranging from An32 to An38, is present in both types. Alteration of both
Figure 12.--Photomicrograph of Ames porphyritic rhyodacite. Note reaction rims of magnetite-ilmenite surrounding or completely replacing hornblende phenocrysts. Crossed nicols. 90X.
phenocrysts and groundmass to epidote, sericite, and clay minerals is common.

K-feldspar varies considerably in volumetric percentage. Subhedral phenocrysts range from 1 to 3 mm and anhedral groundmass grains range from 0.01 to 0.1 mm. The crystals are always strongly altered to clay minerals and often are almost unrecognizable.

Anhedral quartz occurs as phenocrysts, often embayed, reaching 0.3 to 6 mm, and as grains in the groundmass 0.01 to 0.08 mm in diameter.

Hornblende occurs as euhedral to subhedral phenocrysts, often twinned, 1 to 4 mm in length and pleochroic from light greenish-brown to dark green. Reaction rims of chlorite, calcite, and magnetite-ilmenite are common.

Biotite was noted in one thin section of porphyritic rhyodacite, occurring as scattered anhedral to subhedral phenocrysts up to 0.75 mm long and surrounded by reaction rims of chlorite and magnetite-ilmenite. Pleochroism varies from light to dark reddish-brown.

In the same thin section (which came from a small, unmapped zone of rock somewhat transitional between the porphyritic rhyodacite and the granodiorite porphyry near Ophir Loop, east of the main inclusion zone), two subhedral phenocrysts of augite 0.4 mm in diameter and showing pleochroism from light brown to light green were noted. This rock is the only one found resembling rhyodacite which
contains biotite and augite. The two minerals are absent from all other specimens of porphyritic rhyodacite examined.

Magnetite-ilmenite occurs as discrete euhedral to anhedral grains and in reaction rims. Total replacement of hornblende phenocrysts by opaque material is occasionally observed.

Accessory minerals include euhedral apatite and zircon, both reaching 0.2 mm in length.

Chlorite, epidote, calcite, and clay minerals are the most common alteration products in the porphyritic rhyodacite. Chlorite occurs as green, faintly pleochroic subhedral to anhedral phenocrysts reaching 1 mm in length and pseudomorphous after hornblende, in very fine-grained reaction rims surrounding hornblende, and as discrete anhedral grains scattered throughout the rock. Epidote occurs as very small anhedral blebs associated with plagioclase and scattered throughout the rock. Calcite occurs as an anhedral alteration product of hornblende and also fills small cracks. Clay minerals result from the alteration of feldspars.

The porphyritic granite phase of the Ames pluton is a holocrystalline, medium-grained rock with a hypidiomorphic granular texture. (Figure 13).

Modal analysis of the porphyritic granite shows that this rock consists of about 36 percent alkali feldspar,
26 percent plagioclase, 29 percent quartz, 3 percent biotite, and 6 percent accessory minerals and alteration products.

Alkali feldspar occurs in subhedral to anhedral phenocrysts reaching 2 cm in diameter and extensively altered to clay minerals. Exsolution of plagioclase has occurred in some grains, suggesting that the alkali feldspar may have crystallized as cryptoperthite.

Plagioclase occurs in subhedral to anhedral phenocrysts reaching 4 mm in diameter and in the groundmass. Carlsbad twins are common. The anorthite content of these slightly zoned crystals averages about An_{24}.

Quartz is found as subhedral to anhedral phenocrysts up to 7 mm in diameter and in the groundmass (0.05 to 0.1 mm). Biotite is pleochroic from light yellowish-brown to chestnut and generally forms clots, with a few euhedral grains reaching 0.35 mm in length scattered among smaller subhedral to anhedral grains. Alteration of biotite to chlorite and magnetite-ilmenite is common.

Anhedral hornblende grains reaching 0.3 mm in length are pleochroic from light brown to medium green to very light yellow (almost colorless).

Magnetite-ilmenite occurs as euhedral to anhedral grains reaching 0.4 mm in diameter and associated with biotite, hornblende, apatite, and chlorite.
Accessory minerals include euhedral apatite (up to 0.2 mm long) and zircon.

Alteration products include light green, slightly pleochroic chlorite up to 0.35 mm long and associated with biotite and other mafic minerals, and clay-mineral alteration of the feldspars.

**Ophir Stock-Ames Pluton Contact Phenomena**

As previously discussed, the xenoliths near Ames are located in and adjacent to a zone of mixed granodiorite porphyry of the Ames pluton and microgranodiorite (formerly known as microgranogabbro) of the Ophir stock. Xenoliths of microgranodiorite are found within the granodiorite porphyry; inclusions of inclusion-bearing granodiorite porphyry are found within the microgranodiorite (Figure 14); and dikelets of each cut the other.

The previously described porphyritic granite is developed in the contact zone between these two intrusives. This rock often contains xenoliths similar to those found in the granodiorite porphyry; it is therefore considered to be a phase of the Ames pluton. Similar Precambrian xenoliths are absent from the Ophir stock, except where such inclusions occur in the granodiorite porphyry which in turn is included in the microgranodiorite.

The relations described above suggest contemporaneity of the Ophir stock and the Ames pluton. The Ames pluton
Figure 14.--Photomicrograph of granodiorite porphyry xenolith (left) in Ophir stock microgranodiorite right). The microgranodiorite has invaded and almost surrounded the larger plagioclase phenocrysts of the granodiorite porphyry. Note slight alignment of plagioclase laths in the microgranodiorite parallel to the contact. Crossed nicols. 75X.
is truncated at its westernmost exposure (where, coincidentally, a few banded amphibolite inclusions are found) by the composite Wilson Peak stock; since the Ophir, Wilson Peak, and Dolores Peak (in the quadrangle immediately to the west of the Mount Wilson quadrangle) stocks all have similar compositions, migration of stock intrusion westward with time is suggested. These three stocks, the Black Face-Ames plutons, and several laccoliths are all aligned along an east-west fracture radiating from the Silverton caldera.
Xenolith Distribution

Xenoliths are scattered throughout much of the Black Face pluton; however, they are concentrated in a small area approximately 400 feet long, 100 feet wide, and 30 feet high near the summit of Black Face (Figure 15). Rock types exposed in this zone are dominantly silicic types: granite, aplite granite, pegmatitic granitic gneiss, quartzite, porphyritic granophyre, shale, and rarely, mafic schist and porphyritic rhyodacite.

Most of the xenoliths are subangular to rounded, indicating probable reaction with the granodiorite porphyry magma; they range in diameter up to 6 m and average 0.5 m.

Petrography of Xenoliths

Granite, Aplitic Granite, Pegmatitic Granitic Gneiss, and Porphyritic Granophyre

Xenoliths of these four rock types are characterized by similar mineralogy and modal analyses: 15-36 percent quartz, 12-31 percent alkali feldspar, 25-48 percent plagioclase, 1-6 percent biotite, 0-5 percent hornblende, and 1-10 percent chlorite.
Figure 15.--Black Face from the east. Scattered xenoliths are found in the granodiorite porphyry in the foreground; the principal zone of Black Face xenoliths is near the crest of the ridge at the center of the photograph.
Anhedral quartz grains range in size from less than 0.1 mm in the aplitic granite to 15 mm in the pegmatitic granitic gneiss. Alkali feldspar is subhedral, invariably strongly altered to clay minerals, and ranges from 0.1 mm to 1 cm in diameter. Plagioclase, usually oligoclase-andesine (An$_{22-38}$), is subhedral, slightly altered to sericite and epidote, and also ranges from 0.1 mm to 10 mm. Anhedral to subhedral biotite laths are pleochroic from light yellow to dark brown and range from less than 0.1 mm to 1 mm in length. Subhedral hornblende is pleochroic from dark green to medium brown and ranges in diameter from 0.1 mm to 0.8 mm. Greenish-yellow chlorite replaces all or part of most hornblende and biotite crystals and is thus similar to them in size and habit. Magnetite is generally anhedral and about 0.1-0.3 mm in diameter, and accessory minerals include euhedral apatite, zircon, and sphene.

Quartzite

Quartzite xenoliths consist almost entirely of sub-rounded quartz grains ranging in size from 0.3 to 1.5 mm. Rarely, grains of alkali feldspar, plagioclase, hornblende, biotite, and magnetite are observed.

Shale

Mancos Shale xenoliths are composed of anhedral grains of quartz, alkali feldspar, plagioclase, magnetite, chlorite,
and, rarely, biotite, hornblende, and apatite. According to Bromfield (1967), X-ray analyses of Mancos Shale indicate that illite and calcite are also present in the unmetamorphosed rock.

Mafic Schist

Mafic schist xenoliths (Appendix D) consist of about 0-14 percent quartz, 2-9 percent alkali feldspar, 18-52 percent plagioclase, 12-26 percent hornblende, 14-37 percent augite, 1-8 percent biotite, 2-15 percent chlorite, and 4-18 percent magnetite. All mineral grains are anhedral to subhedral and range from 0.05 to 0.25 mm in diameter. Segregation into bands of light and dark minerals results in a foliation apparent in hand specimen and in thin section.

Porphyritic Rhyodacite

A few xenoliths of rhyodacite similar to that of the Ames pluton were collected. This very light gray rock consists of about 40-65 percent plagioclase, 3-25 percent alkali feldspar, 10-20 percent quartz, 1-15 percent hornblende, and 4-22 percent alteration products. Individual mineral descriptions are identical to those of the Ames porphyritic rhyodacite and are included in that section.

Reaction Relationships

Reaction relationships between the xenoliths and their host granodiorite porphyry are rather difficult to determine
because of the intense pyrite-limonite mineralization concentrated in the same area of the Black Face pluton. However, several effects of reaction can be observed.

In the porphyritic granophyre xenoliths, quartz phenocrysts are rounded near the granodiorite porphyry contact and tend to group together. Mafic minerals such as biotite and hornblende (both strongly altered to chlorite) are concentrated near the contact. Plagioclase grains in both the xenoliths and their host are more greatly altered to sericite, epidote, and clay minerals near the contact than they are 2-4 millimeters away. Alkali feldspar is generally strongly altered throughout both rocks. Otherwise, little reaction has occurred between the porphyritic granophyre xenoliths and the granodiorite porphyry host.

In the granite, aplite granite, and pegmatitic granitic gneiss xenoliths, alkali feldspar in the inclusions has been much more strongly altered to clay minerals than has the plagioclase. Biotite grains in the host granodiorite porphyry have been converted to chlorite in the vicinity of the contact. Xenolith mineral grains at the contact have been broken off and slightly incorporated into the granodiorite porphyry.

Quartz grains at the margins of quartzite xenoliths are usually rounded, embayed, and partially assimilated into the granodiorite porphyry.
Figure 16.—Photomicrograph of shale xenolith (right) in granodiorite porphyry (left). Biotite has developed in the xenolith. Note concentration of magnetite in the xenolith at the contact (bottom right). Plane polarized light. Magnification 6.8X.
Mancos Shale xenoliths show the effects of considerable reaction with the granodiorite porphyry magma (Figure 16). A margin of iddingsite and chlorite surrounds each xenolith. Feldspar grains in the xenoliths are highly altered to epidote. Quartz grains have migrated from the inclusion into the granodiorite porphyry, and the entire xenolith has been rounded.

Mafic schist xenoliths also reacted considerably with the granodiorite porphyry magma. Magnetite tends to be concentrated in the xenoliths at the contact. Hornblende and augite in the xenoliths are altered to chlorite close to the contact. Hornblende, augite, and biotite in the granodiorite porphyry are completely altered to chlorite several centimeters from the contact. Alkali feldspar in the xenoliths is generally more altered than is plagioclase. Grains of all minerals at the contact have been separated from the xenolith and incorporated into the granodiorite porphyry.

Porphyritic rhyodacite xenoliths show little or no reaction with their host, and their mutual contacts are often texturally gradational. Mineralogy and alteration are similar on both sides of these contacts. These data suggest to this writer that the porphyritic rhyodacite may be a chill zone of the granodiorite porphyry which was soon after emplacement shattered by the viscous granodiorite porphyry magma and incorporated into it.
Origin of Xenoliths

Quartzite fragments in the Black Face xenolith zone may have been derived from the underlying Upper Cambrian Ignacio Formation, and shale xenoliths originated in the enclosing Upper Cretaceous Mancos Shale. The origin of the porphyritic rhyodacite xenoliths has been discussed in the previous section. The remainder of the xenoliths in this zone were undoubtedly derived from the Precambrian basement; they closely resemble rock types observed in the Precambrian of the Needle Mountains fifteen miles southeast of Black Face.

According to Bromfield (1967, p. 36), the xenoliths are concentrated near the summit of Black Face because this area is "just under the roof of the Black Face intrusive mass." The xenoliths, generally of lower specific gravity than their host, evidently were buoyed up by the magma. Further evidence for the presence of vertical movements of light or volatile material within the magma is the area of quartz-pyrite-limonite mineralization which covers the Black Face ridge crest, extending downward only 20 to 30 feet (Figure 17).
Figure 17.--Central San Miguel Mountains from the southeast. The high peaks are, from left to right, Mount Wilson (14,246 feet), Gladstone Peak (13,913 feet), Lizard Head (13,113 feet), and Wilson Peak (14,017 feet). Note zone of limonite-stained Black Face granodiorite porphyry in the foreground.
Xenolith Distribution

As in the Black Face pluton, xenoliths are scattered throughout the Ames pluton; however, a vast number of them are concentrated in a relatively small zone 1000 feet long and 50 feet high in the granodiorite porphyry and porphyritic rhyodacite along the abandoned narrow gauge railroad grade near Ames (Figures 18 and 19). In addition, xenolith-bearing granodiorite porphyry mixed with microgranodiorite of the Ophir stock occurs for another 2000 feet southward to State Highway 145. Similar concentrations of xenoliths (Bromfield, 1967, p. 35) are found about 1 mile south in a small exposure of granodiorite porphyry in the river bottom (east) of the San Bernardo mine and at the base of the granodiorite porphyry outcrop on the west side of the river opposite Ophir Loop. Because the area between these three localities is covered by glacial drift, continuity of the inclusion zone between these outcrops is uncertain.

In a nearly vertical cliff 45-50 feet high and 200 feet long within the principal xenolith zone near Ames, studies were made of the amounts of each rock type represented in the xenoliths. In addition, the 40-foot high segment of granodiorite porphyry was subdivided into four 10-foot high and 200-foot long portions and the number of each rock type counted.
Figure 21.--Ames xenolith zone. Head of hammer at contact between lower porphyritic rhyodacite and upper granodiorite porphyry. Xenoliths of banded amphibolite and mafic schist can be seen.
Figure 20.--Ames xenolith zone, showing concentration of xenoliths in the lower half of the cliff.
Figure 19. -- Ophir-Ames area. Sill of Ames pluton at right center, showing contact between upper porphyritic rhyodacite and lower granodiorite porphyry. Part of Ames xenolith zone in left foreground along railroad grade.
Figure 18.--Ophir-Ames area. Ophir Needles at left, Ophir Valley at center, and Ames xenolith zone at right center. Porphyritic adamellite of Ophir stock sends intrusive wedge into Telluride Conglomerate below the Needles.
Table 1 shows the amount of each xenolith rock type found in the porphyritic rhyodacite chill zone at the base of the cliff. The percentages of each rock type in the rhyodacite and in the granodiorite porphyry plus the rhyodacite are also indicated. Finally, the percentage of the total number of xenoliths in the study area which are found in the porphyritic rhyodacite segment is indicated.

Table 2 shows the numbers of each xenolith rock type found in successive 10-foot vertical segments of the granodiorite porphyry. The percentages of each rock type in the given segment, in the whole granodiorite porphyry outcrop studied, and in the entire outcrop of porphyritic rhyodacite and granodiorite porphyry are indicated. In addition, the number of xenoliths in the segment relative to the total number in the granodiorite porphyry and in the porphyritic rhyodacite plus the granodiorite porphyry is expressed as a percentage.

The table indicates that virtually all xenoliths are concentrated toward the bottom of the granodiorite porphyry magma body (Figure 20). In particular, over 72 percent of the xenoliths are found in the lower 40 percent of the exposure, and the lowest 10-foot segment of the granodiorite porphyry has almost half (46 percent) of the xenoliths.

Lighter xenoliths, especially granitic types, have generally remained in the middle portions of the exposure. The high percentage of granitic inclusions in the lower
Table 1.—Number and Type of Xenoliths in Porphyritic Rhyodacite, Ames Xenolith Zone

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Number in this Segment</th>
<th>Percentage of 244 Xenoliths in Porphyritic Rhyodacite Segment</th>
<th>Percentage of 919 Xenoliths in Porphyritic Rhyodacite and Granodiorite Porphyry Segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banded amphibolites</td>
<td>84</td>
<td>34.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Hornblendite and augite-actinolite rocks</td>
<td>26</td>
<td>10.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Mafic schists</td>
<td>50</td>
<td>20.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Granites, pegmatitic and aplite granites, and gneissic granites</td>
<td>84</td>
<td>34.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Totals</td>
<td>244</td>
<td>100.0</td>
<td>26.6</td>
</tr>
</tbody>
</table>
Table 2.—Number and Type of Xenoliths in Successive Segments of Granodiorite Porphyry,\(^1\) Ames Xenolith Zone

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Number in Segment</th>
<th>Percentage of This Rock Type Relative To:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Xenoliths in Each Segment</td>
<td>675 Xenoliths in All Four Segments</td>
</tr>
<tr>
<td></td>
<td>Segment 1 2 3 4</td>
<td>Segment 1 2 3 4</td>
</tr>
<tr>
<td>Banded amphibolites</td>
<td>255 102 15 3</td>
<td>60.8 58.6 26.3 12.5</td>
</tr>
<tr>
<td>Hornblende and augite-actinolite rocks</td>
<td>48 9 3 0</td>
<td>11.4 5.2 5.3 0.0</td>
</tr>
<tr>
<td>Mafic schists</td>
<td>111 57 30 12</td>
<td>26.4 32.8 52.6 50.0</td>
</tr>
<tr>
<td>Granites, pegmatitic and aplitic granites, and gneissic granites</td>
<td>6 6 9 9</td>
<td>14 3.4 15.8 37.5</td>
</tr>
<tr>
<td>Totals</td>
<td>420 174 57 24</td>
<td>100.0 100.0 100.0 100.0</td>
</tr>
</tbody>
</table>

\(^1\)The granodiorite porphyry was divided into four 10-foot segments, Segment 1 the lowest.
rhyodacite chill zone is interpreted as an indication of lesser reaction with their host than similar xenoliths in the granodiorite porphyry.

Xenoliths of heavier specific gravity than their hosts, such as the amphibolites, are particularly concentrated toward the bottom of the exposure (Figure 21).

**Xenolith Orientation**

Within the steep cliff along the narrow gauge railroad grade near Ames, measurements of xenolith orientation were made, in an attempt, first suggested by C. S. Bromfield, to determine if an imbricate structure existed. The measurements were conducted in the vicinity of the vertical variability studies, but at a different time and in a slightly different area, and thus there is a difference in the total number of xenoliths examined. Detailed studies were confined to an area of the cliff 200 feet long and about 50 feet high, within which the xenoliths are best exposed and their orientation is thus best determined. In this nearly vertical cliff, three-dimensional views of individual xenoliths are generally difficult to find, but 87 such xenoliths were measured. Two-dimensional views are far more common, and measurements were made on 1026 xenoliths so exposed. Most xenoliths have a long axis and thus the orientation of the fragment can be determined; those which are equidimensional are, however, included.
Table 3 shows the results of measurements on the 87 xenoliths whose three dimensions are visible. No separation between xenoliths in the porphyritic rhyodacite and those in the granodiorite porphyry was made in this part of the study. The percentages of xenoliths in each orientation relative to the total number of three-dimensionally oriented xenoliths and relative to the number of three-dimensionally oriented xenoliths elongated in an east-west direction are indicated.

Table 4 shows the results of measurements on xenoliths in the granodiorite porphyry with two dimensions exposed, and Table 5 records similar measurements on xenoliths in the porphyritic rhyodacite chill zone. Table 6 summarizes the data from Tables 4 and 5. Percentages of each xenolith orientation relative to the total number of two-dimensionally oriented xenoliths and to the number of two-dimensionally oriented xenoliths in the specific host rock (granodiorite porphyry or porphyritic rhyodacite) are indicated. The percentage of xenoliths in each host relative to the total number of two-dimensionally oriented xenoliths is also recorded.

The above data are interpreted as an indication that the granodiorite porphyry magma in this portion of the Ames pluton probably moved laterally from east to west (Figure 22). The xenolith-bearing magma possibly welled up in the vicinity of the intersection of the east-west trending fracture radiating from the Silverton caldera and the northeast-
Table 3.—Orientation Measurements on Xenoliths with Three Exposed Dimensions

<table>
<thead>
<tr>
<th>Orientation of Xenoliths</th>
<th>Number</th>
<th>Percentage of Total Xenoliths with Three Exposed Dimensions</th>
<th>Orientation of Xenoliths</th>
<th>Number</th>
<th>Percentage of Total Xenoliths with Three Exposed Dimensions</th>
<th>Total Xenoliths Elongated in an East-West Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongated in east-west direction</td>
<td>71</td>
<td>81.6</td>
<td>Dipping west 10° or more</td>
<td>9</td>
<td>10.3</td>
<td>12.7</td>
</tr>
<tr>
<td>Elongated in north-south direction</td>
<td>6</td>
<td>6.9</td>
<td>Dipping east 10° or more</td>
<td>53</td>
<td>61.0</td>
<td>74.6</td>
</tr>
<tr>
<td>Equidimensional and thus unoriented</td>
<td>10</td>
<td>11.5</td>
<td>Dipping less than 10°</td>
<td>9</td>
<td>10.3</td>
<td>12.7</td>
</tr>
<tr>
<td>Totals</td>
<td>87</td>
<td>100.0</td>
<td>Totals</td>
<td>71</td>
<td>81.6</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 4.—Orientation Measurements on Xenoliths with Two Exposed Dimensions in Granodiorite Porphyry

<table>
<thead>
<tr>
<th>Orientation of Xenoliths</th>
<th>Number</th>
<th>Percentage of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>865 Xenoliths in Granodiorite Porphyry</td>
</tr>
<tr>
<td>Horizontal</td>
<td>120</td>
<td>13.9</td>
</tr>
<tr>
<td>Vertical</td>
<td>55</td>
<td>6.4</td>
</tr>
<tr>
<td>Unoriented</td>
<td>165</td>
<td>19.1</td>
</tr>
<tr>
<td>Dipping east 10° or more</td>
<td>435</td>
<td>50.2</td>
</tr>
<tr>
<td>Dipping west 10° or more</td>
<td>90</td>
<td>10.4</td>
</tr>
<tr>
<td>Totals</td>
<td>865</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 5.—Orientation Measurements on Xenoliths with Two Exposed Dimensions in Porphyritic Rhyodacite

<table>
<thead>
<tr>
<th>Orientation of Xenoliths</th>
<th>Number</th>
<th>161 Xenoliths in Porphyritic Rhyodacite</th>
<th>1026 Xenoliths Granodiorite Porphyry and Porphyritic Rhyodacite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>30</td>
<td>18.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Vertical</td>
<td>3</td>
<td>1.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Unoriented</td>
<td>50</td>
<td>31.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Dipping east 10° or more</td>
<td>60</td>
<td>37.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Dipping west 10° or more</td>
<td>18</td>
<td>11.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Totals</td>
<td>161</td>
<td>100.0</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Table 6.—Orientation Measurements on All Xenoliths with Two Exposed Dimensions

<table>
<thead>
<tr>
<th>Orientation of Xenoliths</th>
<th>Number</th>
<th>Percentage of Total Xenoliths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>150</td>
<td>14.6</td>
</tr>
<tr>
<td>Vertical</td>
<td>58</td>
<td>5.7</td>
</tr>
<tr>
<td>Unoriented</td>
<td>215</td>
<td>21.0</td>
</tr>
<tr>
<td>Dipping east 10° or more</td>
<td>495</td>
<td>48.2</td>
</tr>
<tr>
<td>Dipping west 10° or more</td>
<td>108</td>
<td>10.5</td>
</tr>
<tr>
<td>Totals</td>
<td>1026</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Figure 22.—Diagram Illustrating Xenolith Orientation and Concentration Process in the Ames Pluton near Ames, Colorado.

EXPLANATION

Ames Pluton

Tgdpl
Granodiorite porphyry

Trd
Porphyritic rhyodacite

Km
Mancos Shale

Kd
Dakota Sandstone

Jmb
Morrison Formation

Jms
Brushy Basin Shale Member

Solt Wash Sandstone Member

Xenoliths

Direction of Magmatic Flow

Contact

Expanded view of blocked area—note orientation of Xenoliths.

200 feet
trending axis of the western San Juan monoclone. Approximately half of all xenoliths in the granodiorite porphyry portion of the study area are dipping 10 or more degrees to the east, suggesting, in an analogy with rivers or streams, that the upper portions of the xenoliths are inclined opposite to the direction that the "current" (magma) flowed. Imbricate structure is not apparent after a cursory examination of the outcrop; indeed, the xenoliths appear to be quite randomly oriented. However, the relatively high percentage of xenoliths dipping toward the east suggests that the magma moved from this direction. Xenoliths oriented in other directions might have arrived at their positions merely by "bumping" against other inclusions or against the wall rock. In other areas of the pluton, the granodiorite porphyry magma may well have moved in an entirely different direction than it apparently did at the Ames xenolith zone.

Petrography of Xenoliths

Rock types occurring in this major zone of xenoliths are generally much more mafic than those on Black Face and include amphibolite, hornblendite, mafic schist, augite-actinolite rocks, hornblende-biotite gneiss, granite, gneissic granite, aplitic and pegmatitic granite, magnetite-rich rocks, and, rarely, hornblende diorite and phyllite.
Amphibolite

The amphibolite (Figure 23) is by far the most common of the xenoliths; modal analyses of this foliated ("spotted") rock show that it consists of about 10-40 percent plagioclase, 18-50 percent amphibole, 1-12 percent quartz, 1-8 percent alkali feldspar, 1-10 percent pyroxene, and 4-18 percent magnetite-ilmenite.

The plagioclase is anhedral labradorite (An_{67-58}), often showing strain effects probably associated with dynamic metamorphism. Crystals are elongated and may reach 3 cm in length.

Amphibole is invariably extremely fine-grained, appearing crushed or granulated, probably by dynamic metamorphic processes. The anhedral grains are generally 0.01 mm or less in diameter. Pleochroism is from dark green to medium brown. X-ray diffractometry indicates that this amphibole is actinolite.

Quartz is anhedral and concentrated in small stringers scattered throughout the large plagioclase grains. It appears to have been added to the amphibolite, probably during the metamorphic process.

Alkali feldspar varies somewhat in volumetric percentage; its presence is probably related to the amount of reaction which occurred between xenolith and host magma, for it is concentrated near the contact between the amphibolite and its host. The alkali feldspar is a microperthite,
Figure 23.--Photomicrograph of interior of banded amphibolite xenolith. Large strained labradorite laths are surrounded by fine-grained actinolite and magnetite crystals. Note small quartz stringer above the plagioclase. Crossed nicols. 12X.
generally unaltered, anhedral in form, and consisting of about 60 percent K-feldspar and 40 percent plagioclase.

Augite is not always found in the amphibolite; where it is present, it occurs as subhedral grains up to 0.1 mm in diameter associated with the actinolite.

Magnetite-ilmenite is similar in size and habit to actinolite and is usually associated with that mineral.

Apatite occurs as euhedral laths up to 0.5 mm in length.

Hornblendite

Spectacular rocks consisting largely of hornblende are occasionally found in the Ames inclusion zone. Modal analyses (Appendix D) show that this rock is composed of about 37-58 percent hornblende, 0-11 percent K-feldspar, 9-17 percent plagioclase, 10-26 percent chlorite, 7-20 percent magnetite-ilmenite, 0.4-6 percent apatite, and 0-4 percent quartz.

The hornblende crystals, reaching 3.75 cm long, are euhedral and pleochroic from amber to dark brown. The K-feldspar occurs in strongly altered subhedral crystals reaching 1 mm in diameter. Plagioclase (An_{66-59}) occurs in elongate subhedral laths reaching 4 mm in length. Chlorite occurs in green anhedral grains as an alteration product of hornblende. The magnetite-ilmenite is found in anhedral masses up to 8 mm in diameter. Apatite occurs as
typical euhedral laths up to 2.5 mm long. Quartz is rare and found only as anhedral grains 0.1 mm in diameter.

Augite-Actinolite Rocks

Another relatively common rock found in the Ames xenolith zone consists largely of actinolite and augite. Modes (Appendix D) indicate a composition of about 44-51 percent actinolite, 28-33 percent augite, 10-23 percent magnetite-ilmenite, 0.2-10 percent chlorite, and 0-2 percent plagioclase. The actinolite occurs as subhedral grains, pleochroic from medium green to medium brown, up to 1 mm in diameter. Augite of similar size and habit is colorless to light greenish-brown. Green chlorite, altering from actinolite, occurs as anhedral grains up to 0.5 mm in diameter.

Mafic Schist

Xenoliths of mafic schists vary somewhat in their modal composition (Appendix D), but the general mineralogy is about 5-49 percent plagioclase, 5-27 percent pyroxene, 1-32 percent amphibole, 2-35 percent quartz, 9-12 percent magnetite-ilmenite, 1-9 percent chlorite, 1-16 percent alkali feldspar, and 1-7 percent biotite.

The foliation of these mafic schists is caused by the segregation into separate bands of dark and light minerals. Occasional megacrysts (probably porphyroblasts) of hornblende are seen, but most grains range from 0.2 to 0.6 mm in diameter.
Plagioclase is generally subhedral and ranges from $\text{An}_{52}$ to $\text{An}_{25}$, with an average of about $\text{An}_{38}$. The pyroxene is generally a light brownish-green augite. The amphibole is usually subhedral hornblende, occasionally actinolite, and is pleochroic from medium green to medium yellowish-brown. Quartz and magnetite-ilmenite are anhedral. Green, slightly pleochroic chlorite occurs as an alteration product of amphibole. K-feldspar is anhedral to subhedral and generally less altered than is the K-feldspar in the host rock. Subhedral to anhedral biotite is pleochroic from light yellow to dark brown, and apatite occurs as typical small euhedra.

Granite, Gneissic Granite, and Aplitic and Pegmatitic Granite

Similar mineralogy characterizes these three rock types occurring among the xenoliths near Ames. Modal analyses indicate that they consist of about 18-34 percent quartz, 9-28 percent alkali feldspar, 16-43 percent plagioclase, and 1-6 percent hornblende.

Anhedral quartz occurs as grains up to 7 mm in diameter. Alkali feldspar and plagioclase are altered to almost unrecognizable masses of sericite and clay minerals. Anhedral magnetite-ilmenite and euhedral apatite, zircon, and rare sphene occur as grains up to 0.08 mm long. Hornblende is generally absent from the granite, pegmatitic
granite, and aplite granite, but it is present as subhedral grains, pleochroic from medium green to dark brown, up to 0.5 mm in diameter in the gneissic granite.

Hornblende-Biotite Gneiss

The hornblende-biotite gneiss xenoliths are quite similar to the granitic gneisses except for the greater percentage of mafic minerals in the former. Relative mineral abundances are: 31-45 percent plagioclase, 7-12 percent alkali feldspar, 12-26 percent quartz, 11-23 percent hornblende, and 7-19 percent biotite. The biotite is subhedral and pleochroic from light yellow to chestnut. All other minerals are similar in size and habit to those of the granitic gneisses.

Magnetite-rich Rocks

Rocks megascopically identified as rich in magnetite were scanned by the X-ray diffractometer in an attempt to determine the minerals present and, if possible, their relative abundances. However, the only minerals positively identified are magnetite and ilmenite, and their relative abundances are unknown.

Reaction Relationships

Reaction relationships between the xenoliths and their two host rocks, granodiorite porphyry and porphyritic
rhyodacite, range widely and are largely dependent on the mineralogy of the xenoliths and on the type of host rock. In general, xenoliths found in the porphyritic rhyodacite chill zone show the effects of considerably less reaction with their host than do the xenoliths in the granodiorite porphyry. These observations suggest that the xenoliths had more time to react with the more slowly cooling interior portions of the granodiorite porphyry sill than they did with the magma adjacent to the contact with the wall rock.

Xenoliths in Porphyritic Rhyodacite

Granite (Figure 26), aplitic and pegmatitic granite, and gneissic granite xenoliths in the porphyritic rhyodacite generally show rounding of quartz grains, complete alteration of feldspars to clay minerals and epidote, and intense chloritization of the mafic minerals (originally hornblende and biotite). In the outcrop, the inclusions appear subrounded.

In most cases, the chief effect of these granitic xenoliths on the host rock is the addition of quartz to the latter and the chloritization of its hornblende phenocrysts.

Banded amphibolite (Figures 24-26), hornblendite (Figure 27), and augite-actinolite xenoliths appear generally subrounded when observed in the outcrop; microscopic examination of the contacts, however, reveals that very little reaction has occurred.
Figure 27. Hornblendite xenolith (right) in porphyritic rhyodacite (left), crossed nicols. The rhyodacite has invaded the xenolith and broken off a few crystal fragments, but little reaction has occurred. Magnification 30X.
Figure 26.--Photomicrograph of granite (left) and spotted amphibolite (right) xenoliths in porphyritic rhyodacite. The granite xenolith has been extensively invaded by the rhyodacite; its mineral grains are disaggregated and at an advanced stage of assimilation into the rhyodacite. In contrast, the amphibolite xenolith has been only slightly affected by the rhyodacite magma. Crossed nicols. 7X.
Figure 25.—This large actinolite crystal has broken off from a banded amphibolite xenolith (left) and has been partially incorporated into the porphyritic rhyodacite (right). However, a small fragment of the grain, still in optical continuity with the main mass, remains in the xenolith. Crossed nicols. 110X.
Figure 24.--Photomicrograph of contact between banded amphibolite xenolith (left) and porphyritic rhyodacite (right). Note alignment of hornblende and plagioclase phenocrysts in the rhyodacite parallel to contact. Little or no reaction appears to have occurred. Crossed nicols. Magnification 10X.
Mafic schist xenoliths are generally rather angular, and thin sections across contacts show that little or no reaction has occurred.

Xenoliths in Granodiorite Porphyry

Granitic xenoliths in the granodiorite porphyry react with their host in a similar manner as do those in the rhyodacite: rounding of quartz grains and their even more extensive incorporation into the granodiorite, alteration of feldspars to clay minerals and epidote, and chloritization of mafic minerals. The lower amount of granitic xenoliths in the granodiorite porphyry suggests that many of them, especially the smaller ones, may have been totally assimilated into the host magma.

Augite in the augite-actinolite xenoliths in the granodiorite porphyry has reacted with the melt to produce actinolite at the contact, and the amphibole in turn has been converted to chlorite (Figures 28 and 29). Pyroxene is absent from the contact with the granodiorite porphyry.

Hornblende crystals in hornblendite xenoliths are extensively altered to chlorite at their contact with the granodiorite porphyry (Figures 37 and 38).

Mafic schist xenoliths are generally subangular in shape and microscopic examination shows that little reaction between xenolith and host magma has occurred, with the exception of amphibole crystals in the xenolith, which are
Figure 38.---Hornblendite xenolith in granodiorite porphyry. Note extensive conversion of hornblende to chlorite at the contact. Plane polarized light. 100X.
Figure 37.--Hornblendite xenolith in granodiorite porphyry. Note extensive conversion of hornblende to chlorite at the contact. Plane polarized light. 70X.
Figure 36.—Enlargement of hornblende megacryst in upper left corner of Figure 35. Note conversion of hornblende to chlorite at the contact. Plane polarized light. Magnification 80X.
Figure 35.—Hornblende schist xenolith (lower left) in granodiorite porphyry (upper right). Note concentration of fine-grained amphibole in xenolith close to contact. Plane polarized light. 6.4X.
Figure 34.—Banded amphibolite xenolith (lower center) in granodiorite porphyry. This xenolith is surrounded by a reaction halo consisting of recrystallized plagioclase, alkali feldspar, quartz, actinolite, and chlorite. Quartz and alkali feldspar have developed in the interior of the xenolith. Plane polarized light. 7X.
Figure 33.—Photomicrograph of banded amphibolite xenolith (top) in granodiorite porphyry (lower quarter). Alkali feldspar and quartz have developed in the xenolith. Note concentration of magnetite and actinolite in the xenolith adjacent to the contact. Crossed nicols. 25X.
Figure 32.—Banded amphibolite xenolith (top) in granodiorite porphyry (bottom). Alkali feldspar and quartz have developed in the xenolith. Note alignment of plagioclase laths in the granodiorite porphyry parallel to the contact. Crossed nicols. 7.5X.
Figure 31.--Hornblende-augite schist (right) in granodiorite porphyry (left). Stringers of chlorite penetrate the xenolith. Note concentration of mafic minerals adjacent to the contact. Plane polarized light. 7X.
Figure 30.—Photomicrograph of hornblende schist xenolith (right) in granodiorite porphyry (left). Hornblende grains at the contact have been slightly chloritized, broken off, and incorporated into their host. Note concentration of hornblende grains adjacent to the contact. Plane polarized light. Magnification 7.5X.
Figure 29.--Augite-actinolite xenolith (right) in granodiorite porphyry (left), plane polarized light. Augite is absent from the contact. Actinolite at the contact has been largely converted to chlorite (note pseudomorph of chlorite after actinolite near center). Note resorbed quartz phenocrysts in granodiorite porphyry at the left. 38X.
Figure 28.—Augite-actinolite xenolith (top) in granodiorite porphyry (bottom), plane polarized light. Augite is absent from the contact, and actinolite at the contact has been partially converted to chlorite. Some actinolite grains have been broken off and incorporated into the granodiorite porphyry. 7X.
often frayed or corroded and converted into chlorite (Figures 30, 31, 35, and 36). Mafic minerals in these xenoliths occasionally tend to cluster near their contact with the granodiorite porphyry.

The most common xenoliths in the Ames zone, the banded amphibolites, show considerable reaction with the granodiorite porphyry magma (Figures 32-34). The fine-grained actinolite crystals are generally converted to chlorite, patches of labradorite are replaced by microperthite, and quartz stringers often penetrate the xenolith. Hornblende and magnetite-ilmenite crystals tend to concentrate along the contact, and little or no labradorite is found there.

From the granitic xenoliths the granodiorite porphyry magma received quartz grains, altered feldspar fragments, and chloritized mafic minerals. Quartz grains properly belonging to the granodiorite are resorbed and embayed in the vicinity of the banded amphibolite and augite-actinolite xenoliths (Figure 29). Plagioclase laths are commonly aligned parallel to xenolith contacts (Figure 32). Pyroxene grains are entirely absent from the vicinity of all xenolith-granodiorite porphyry contacts; pyroxenes in this area have been converted to hornblende, chlorite, or both.

Origin of Xenoliths

Rock types observed in the Ames xenolith zone were undoubtedly derived from the Precambrian basement, as were
many of those on Black Face. Mafic schists, granites, aplite and pegmatitic granites, gneissic granites, and augite-actinolite rocks were all observed in Precambrian outcrops in the Needle Mountains fifteen miles to the southeast of Ames. Only the banded amphibolite was not observed in these Precambrian exposures; it is unquestionably Precambrian, for no other regional metamorphic events, required for formation of this amphibolite, have occurred in the region of the San Juan Mountains.
APPENDICES
granodiorite porphyry (Tgdp?). X-ray diffraction patterns of this rock show, however, that it is highly altered porphyritic rhyodacite. It seems probable, therefore, that this outcrop represents a northward extension of the thick rhyodacite sill on the south side of the South Fork of the San Miguel River.

In addition, two small dikes in southeastern Bilk Basin mapped by Bromfield (1967) as a granodiorite porphyry have less alkali feldspar and quartz than does the Black Face intrusive. They may be a type of extensively altered granodiorite porphyry, but their higher content of mafic minerals, their medium to dark gray color, and the above-mentioned lower alkali feldspar and quartz content suggest to this writer that they are not part of the Black Face pluton.

A similar situation exists about one kilometer north of Trout Lake, where Bromfield (1967) has mapped a dike-like arm of the Black Face pluton extending down to State Highway 145. This rock actually contains more alkali feldspar and less plagioclase than does the Black Face granodiorite porphyry. Scattered 1 cm phenocrysts of alkali feldspar and actinolite occur in a fine-grained dark gray matrix. This dike may be composed of porphyritic granodiorite, but it is not the Black Face granodiorite porphyry.

Determination of relative mineral content by X-ray diffraction is generally impossible because:
1. Deuteric alteration of the feldspars and mafic minerals tends to lower those individual mineral peaks.
2. Mafic mineral content is somewhat variable. In general, the higher the mafic mineral content, the more the quartz and feldspar peaks are depressed.
3. Reproducibility of diffraction patterns from the same granodiorite porphyry, porphyritic rhyodacite, or xenolith hand specimen is often not possible, probably because of the internal mineral variations within that specimen.

Changes in heights of mineral peaks in the zone of reaction between xenoliths and hosts are generally subtle and difficult to determine. A few significant trends, however, can be observed:
1. Increase of amphibole in the porphyritic rhyodacite adjacent to its contact with spotted amphibolite and augite-actinolite xenoliths.
2. Decrease of plagioclase in the porphyritic rhyodacite in the same area as (1).
3. Increase in actinolite and decrease in plagioclase and alkali feldspar in granodiorite porphyry close to the contact with spotted amphibolite and augite-actinolite xenoliths.
4. Depletion of quartz in granodiorite porphyry close to its contacts with biotite schist xenoliths initially poor in quartz.
5. Depletion of actinolite in granodiorite porphyry adjacent to its contacts with granitic xenoliths.

6. Concentration of actinolite in spotted amphibolite xenoliths near their contact with porphyritic rhyodacite and granodiorite porphyry hosts.
APPENDIX B

Table 7.—Modes of Granodiorite Porphyry

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\(^1\) Generally hornblende, occasionally actinolite
\(^2\) Includes very rare orthopyroxene
\(^3\) Chiefly apatite, zircon, and sphene
\(^4\) Chiefly chlorite, rarely calcite, epidote, sericite, and clay minerals
### APPENDIX C

#### Table 8.--Modes of Porphyritic Rhyodacite

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<td>Magnetite-</td>
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\(^1\)Generally hornblende, occasionally actinolite  
\(^2\)Chiefly apatite and zircon  
\(^3\)Chiefly chlorite, occasionally epidote and calcite.
## APPENDIX D

### Table 9.—Modes of Xenoliths

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¹Chiefly actinolite, rarely hornblende
²Chiefly apatite, rarely zircon
³Chiefly chlorite
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</tbody>
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¹Chiefly actinolite, rarely hornblende
²Chiefly apatite, rarely zircon
³Chiefly chlorite


Kelley, V. C. "General Geology and Tectonics of the Western San Juan Mountains, Colorado." New Mexico Geological Society Guidebook, 8th Field Conference, 1957.


EXPLANATION

PLEISTOCENE

Qal Alluvium
Qt Talus
Qd Glacial drift
Qr Landslide deposits

UNCONFORMITY

Tpa Porphyritic adamellite
Tgd Granodiorite
Tt Telluride Conglomerate

MIDDLE TO LATE TERTIARY

Tgdpx Xenolith-rich granodiorite porphyry
Trd Porphyritic rhyodacite

OLIGOCENE

Tgg Microgranodiorite and gabbro, undifferentiated (m=mixed microgranodiorite and granodiorite porphyry)

LATE CRETAUCEOUS

Km Mancos Shale
Kd Dakota Sandstone

UNCONFORMITY

LATE JURASSIC

Jmb Brushy Basin Shale Member of Morrison Formation
Jms Salt Wash Sandstone Member of Morrison Formation

5 Strike and dip of beds
.17 Sample location

Contact, dashed where approximately located

Mine