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GEOLOGY OF THE

GUFFEY AREA, COLORADO

by
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of the requirements for the degree of
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ABSTRACT

The region geologically mapped as the Guffey area lies within the southern Front Range adjacent to and to the south of South Park. The area is underlain chiefly by pre-Cambrian rocks covered to the east, north and west by Tertiary extrusives. Paleozoic sediments on the western, down-faulted block of the Chumway fault crop out in the area.

The pre-Cambrian rocks include the metamorphic rocks (schists, lime-silicate rocks, hornblende gneiss and biotite gneiss) and the granitic intrusives and associated units. Probably all the metamorphic rocks may be correlated with the Idaho Springs formation, the oldest exposed in the Front Range, but some may be Swandyke hornblende gneiss and quartz monzonite gneiss. Within this area it is concluded that all hornblende gneiss has been derived through metamorphism of dolomitic, chloritic shales. Elsewhere it may be of partially meta-igneous origin. Unusual cordierite-anthophyllite rocks were derived through the Fe-Mg metasomatism of impure limestones or dolomitic limestones. These are extremely similar to the famous occurrences at Orijärvi, Finland and Kenidjack, Cornwall, England. The Fe and Mg were supplied in part by material withdrawn from the metamorphic column. Widespread and intimate lit-par-lit injection of the Idaho Springs formation by the granitic intrusives formed the migmatitic portion of the biotite gneiss, whereas the paragneiss sections represent meta-arkoses. The granitic intrusives are affiliated almost exclusively with the Boulder Creek

granite which is closely related to the Pikes Peak batholith, although a few may be Silver Plume granite affiliates. Associated with these intrusions are pegmatite, gneissic aplite and possibly diabase sills and dikes.

Paleozoic sediments are exposed only in a relatively limited area in the west-central section. They are correlated with the Lower Pennsylvanian Fountain formation, and are typically arkosic and conglomeratic.

Oligocene extrusive rocks are here named the Guffey volcanics with the upper section correlated with the Thirty-nine Mile andesite series, and the lower section here designated the Chumway rhyolite. They covered most of the area with flows and tuffs thousands of feet thick, but have been extensively removed by erosion following a Miocene-Pliocene uplift. Two volcanic breccia necks that served as feeders for the flow material and a monzonitic stock are present.

A very small area of post-extrusive sandstone crops out near the Rowe ranch west of Currant Creek, and two small recent travertine deposits occur on the Guffey road. Pleistocene and Recent sands and gravels are present in stream channels.

The major economic potentialities in the area lie in the pegmatite deposits. Some of these have been mined for mica, feldspar and beryl and by-product rare-element minerals. The detailed paragnesis of the Meyers Ranch pegmatite is described. Quartz-muscovite symplectites and quartz-magnetite symplectites, the latter at the Whopper pegmatite, have been found to be of

exclusively replacement origin. Sillimanite is abundant but is not economic under existing price conditions. Complex copper ores and scheelite mineralization occur in metasomatic lime-silicate deposits. These have had very modest development as sub-marginal deposits in the past, but may be indicative of more significant yet undiscovered ore-bodies. Although the area has been extensively prospected for gold, there is little promise for production.

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INTRODUCTION

Statement of Problem

The Guffey district, in the south-central part of the Front Range of Colorado, is underlain mainly by pre-Cambrian rocks. It was chosen by the author for geologic investigation because it contains exposures of the contact zone between pre-Cambrian schist and gneisses derived predominantly from sedimentary rocks, and pre-Cambrian intrusives probably associated with the Pikes Peak batholith (see pl. 1 and 2). It thus provided an excellent opportunity to study the structural and lithological relations between these two important rock types. It is also intended that this information be integrated into a projected long-range research program in which the University of Michigan proposes to study the large unmapped pre-Cambrian area extending from the Guffey district southward through the Twelve Mile Park and Eight Mile Park districts into the Wet Mountains.

The Guffey area was considered an excellent area for the inauguration of this program as it represents the most northwesterly exposure of the pre-Cambrian complex in the large area outlined, although other pre-Cambrian blocks separated from the Guffey area by extrusive rocks occur to the east and north in the Front Range. As the pre-Cambrian exposures here are bounded on the north, east and west by Tertiary extrusive rocks, only the southern boundary was

arbitrarily chosen.

Details of the Investigation

Several days were spent making an examination and reconnaissance of the area in September of 1949. The field work was done in the summers of 1950 and 1951 and laboratory work in the Mineralogical Laboratory at the University of Michigan from 1950 through the spring of 1954.

Mapping was recorded on U. S. Forest Service aerial photographs, and a base map was constructed using these in conjunction with U. S. Department of Agriculture Soil Conservation Service maps and the U. S. Geological Survey Cover Mountain quadrangle.

Acknowledgements

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facilities, and paid the cost of shipping hand specimens from Colorado to Ann Arbor for further study, and of some of the photographic work. Fred Anderegg of the University Photographic Services and Derwin Bell of the Department of Geology yielded invaluable technical assistance. Without the financial aid received under the G. I. Bill this work would have been impossible.

The writer extends special thanks to Dr. A. A. Levinson who assisted him in the field during the month of August 1950, to Mr. and Mrs. G. A. Bumgarner, Jr. of Guffey for their many kindnesses during his stay there, and to other residents and claim owners of the Guffey area who were very helpful in many ways.

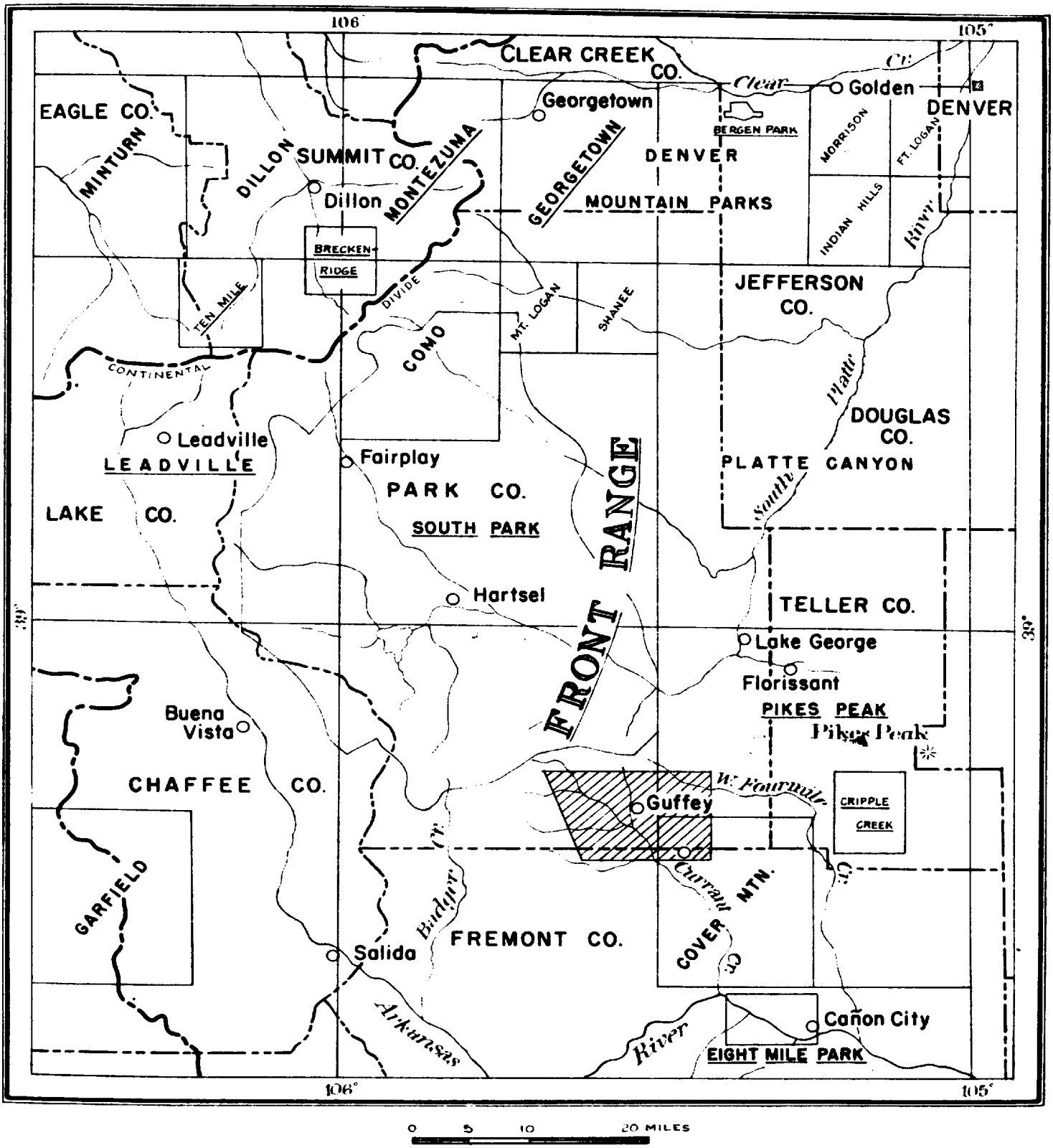


FIG. 1 Index map showing location of the Guffey and related geologically mapped areas. Area names not underlined are topographic maps; names underlined are geologic maps.

GEOGRAPHY

Location

The Guffey district is in the southeastern corner of Park County and the north-central part of Fremont County, Colorado (see fig. 1). Its center (pl. 3, fig. A) is approximately 30 miles northwest of Cañon City. The nearest railroad loading point is about 20 miles by road from Guffey at Parkdale where there is a station on the Denver and Rio Grande Western Railroad line from Cañon City to Salida. The area described by this report covers about 110 square miles in the Front Range about 40 miles west of the Great Plains, including T. 15 S., R. 73 W. and parts of adjoining townships. The northwest corner is at 38° 49' 22" N., 105° 39' 45" W., the northeast corner at 38° 49' 22" N., 105° 25' 00" W., the southeast corner at 38° 41' 25" N., 105° 25' 00" W., and the southwest corner at 38° 41' 25" N., 105° 35' 40" W. To the west and north is the Pike National Forest, of which approximately six square miles is included in the mapped area.

Accessibility

The area is easily accessible by secondary roads, because it is crossed from northwest to southeast by Colorado State Highway 9, and also there are county roads leading from Guffey to Cripple Creek and Florissant. In addition ranch roads, logging roads, and mining roads provide access

Plate 3.

Figure A: The village of Guffey. Population 21.

Figure B: Cover Mountain from atop Stag Mountain. The cap-rock is andesite. It lies on trachyte (center), and sillimanite schist and granodiorite (right background).







Plate 4.

Figure A: Thirty-one Mile Mountain from the west, taken from north of Thirty-one Mile Creek.

Figure B: Thirty-one Mile Mountain from the east, taken from the top of Stag Mountain.





Plate 5.

Figure A: Black Mountain taken looking to the west across Chumway Park.

Figure B: Dicks Peak taken looking to the west from near Sheep Gulch.





Plate 6.

Figure A: Thirty-nine Mile Mountain, taken looking to the northeast from near Dicks Gulch.

Figure B: Chumway Park taken from its northern boundary. Thirty-one Mile Mountain is in the background.





to many parts of the area.

Topography, Culture and History

Elevations range from about 7500 feet in the canyon of Currant Creek near Mac Gulch to 10,165 feet at the top of Cover Mountain (pl. 3, fig. B). Hammond Peak, Stag Mountain, Thirty-one Mile Mountain (pl. 4, fig. A and B) and Dicks Peak (pl. 5, fig. B) all rise to nearly 10,000 feet, and Black Mountain to the west (pl. 5, fig. A) and Thirty-nine Mile Mountain (pl. 6, fig, A), which is just to the north of the mapped area, are approximately 11,000 feet high.

All of the area west of Currant Creek, with the exception of Chumway Park (pl. 6, fig. B), is characterized by deep, steep-sided valleys and high, sharp dividing ridges or peaks as is the area near and south of Guffey but east of Currant Creek. The region east of Currant Creek and north of Guffey has shallower valleys and lower divides, which extend at a low angle from the base of the high cliffs of Thirty-nine Mile Mountain down to Currant Creek. The topography also is gentle generally in the vicinity of West Four Mile Creek with the exception of the prominent, steep-sided peaks of Wicher Mountain and the Castle. In general the topography is rugged in the pre-Cambrian outcrop areas and gentle in the regions of Tertiary lava outcrops as a result of the differences in structure and resistance to erosion of the two rock types.

Mesas capped by dense extrusive rocks, such as Cover

Mountain, Thirty-one Mile Mountain, Wicher Mountain, The Castle, Dicks Peak and Baldy are dominant topographic features.

Near the center of the district lies the village of Guffey which now (1953) has a population of about 20 (pl. 3, fig. A). The first settlement was about one mile to the north and was called Freshwater. This was established about 1895, soon after the Cripple Creek boom caused greatly expanded prospecting activity. The village later was moved to its present location and subsequently the name was changed to Guffey. The presence of rock types similar to those at Cripple Creek resulted in large numbers of prospectors coming into the area, and the population approached 2000 in 1900. When no significant ore deposits were discovered the population started a decline which has continued until reaching its present nearly static level.

About 5 miles southeast of Guffey another village and post office, Micanite, existed from about 1904 to 1908. Its residents, who numbered approximately 100 at the time of greatest activity, were occupied chiefly with the mining and processing of mica from a number of pegmatites in the vicinity. Shortly after mining operations on these deposits ceased the workers left, and subsequently all evidences of the town have vanished. For a short time the post office continued operations at a new location on West Wilson Creek, but soon it was closed.

Drainage

Run-off water in the Guffey area all drains into the Arkansas River and thence into the Mississippi River. There are two dominant drainage systems within the area; the Currant Creek system and the West Four Mile Creek system. The main tributaries to Currant Creek from the west are Sheep Gulch, Dicks Creek, Spring Gulch, and Thirty-one Mile Creek, and from the east are Wildcat Creek, Moonlight Gulch, Lues Gulch and Mac Gulch. The principal tributaries to West Four Mile Creek, all from the west, are High Creek, City Creek and West Wilson Creek. Currant Creek and West Four Mile Creek generally contain water throughout the year although the flow may be very small. All of the other streams mentioned must be classed as intermittent.

Currant Creek empties into the Arkansas River near Parkdale. West Four Mile Creek empties into Oil Creek which enters the Arkansas River near Canon City.

South Park, which is adjacent to the north beyond the Thirty-nine Mile Mountain divide, is in an entirely different drainage system. Water here flows into the South Platte River which eventually enters the Mississippi River by way of the Missouri River.

Vegetation

The distribution of the patchy vegetation of the area is closely related to chemistry and texture of the soil as well as to water supply and altitude. Where the soil is

regolithic, as is generally the case, the type of underlying rock and degree of weathering determine the soil character. Soil developed from the extrusive rocks seems better adapted to supporting heavy vegetation than soil developed from the pre-Cambrian crystalline rocks. Groves of aspen are almost entirely limited to the soils derived from extrusive rocks, particularly where there is topographic shelter and an adequate water supply, for example in grassy hollows or at the upper ends of box canyons. Western pine and Douglas spruce are common on the tops and steep sides of ridges, but occur in densest growth on the flat, lava-capped plateaus. These trees also seem to grow larger and more abundantly on soil of extrusive rock derivation.

At lower elevations the vegetation generally tends to be of a much sparser and scrubbier nature than at higher elevations. Nowhere in the area do peaks rise above the timberline. Slopes with a northerly trend commonly support heavier vegetation than slopes trending in the other compass directions as a result of longer preservation of snow on such slopes.

Climate and Precipitation

No weather records have been kept within or near the Guffey region. The precipitation occurs principally in the summer months characteristically in the form of thundershowers, which are of considerably longer duration than the

same type of storm on the Great Plains. The yearly total is highly erratic; for example, the rainfall for one month may be several times as great as that for a typical year.

Temperature records are not available for any location close to Guffey. However, maxima and minima of approximately 80° F. and -20° F. may be expected, with a yearly average of about 35° F.

The average growing season is perhaps 50 days. Consequently agricultural endeavors are strictly limited and crop failure is common. With the exception of a few small rather unsuccessful truck gardens belonging to individual farmers, only potatoes and a few grain hay crops can be grown with a reasonable expectation of any harvest.

Physiographic Development

The Front Range is a large anticlinal uplift that has been considerably truncated and dissected by streams and glaciers. It consists of crystalline pre-Cambrian and Tertiary rocks with the exception of a few down-faulted or in-folded sedimentary remnants, and a few minor capping Cenozoic gravels and other sediments. These crystalline rocks have been interpreted as showing as many as eleven interrupted erosion cycles of Tertiary age affecting the physiographic development (Van Tuyl and Lovering, 1935, p. 1295). Early writers believed that fewer Tertiary cycles had occurred, Lee (1923) suggesting two, Little (1925) suggesting two, Mather (1925) suggesting two and

Worcester (1931) suggesting three.

In the Guffey area, the erosion surfaces have been assigned to the Cheyenne Mountain peneplain of Upper Eocene age, and the upper and lower Overland Mountain peneplains of Lower and Middle Oligocene age by Van Tuyl and Lovering (1935, p. 1347). In the opinions of the earlier authors cited above, these surfaces would in most cases correspond to what has been designated the Rocky Mountain peneplain cycle, which generally they considered to be younger (Lower Oligocene to Upper Pliocene).

Of the two peneplains observed in this area, the older one can be seen at elevations of from 9200 to 9500 feet as a relatively flat surface onto which the Miocene (?) lavas were poured out. This lies on the flanks of Cover Mountain and Dicks Peak. The younger surface can be observed at elevations of from 8700 to 9200 feet as a flat plain in the southeast portion of the mapped area in the vicinity of the Skyline and Nash ranches (pl. 7, fig. A and B), and also on the flanks of Thirty-one Mile Mountain where it is covered with Miocene (?) lavas. Patches of lava also rest on this surface in the vicinity of the Nash ranch.

Van Tuyl and Lovering (1935, p. 1336) suggest that both of these erosion periods were terminated by orogenic uplift. This conclusion is supported by general physiographic evidences in the Guffey region.

Minor deposits of rounded gravels, pebbles and sand occur chiefly in the valley of Currant Creek, but also to a

lesser extent in some of its tributaries and in the West Four Mile Creek drainage system. These may be related to outwash during the Wisconsin glaciation as found elsewhere by Atwood and Mather (1932) and Lovering and Goddard (1950, p. 42), serving as evidence in this region of this period of glaciation otherwise unrecorded.

Comparatively recently a new erosion cycle has operated in the stream channels, cutting steep banks as much as 20 feet high (pl. 8, fig. A). Many of these gulches extend far up the flanks of the mountains, and have dissected what were grassy pasture areas within the last few decades.

Currant Creek, through which the largest volume of water flows, has the characteristics of a subsequent stream. Its course follows the strike of the pre-Cambrian rocks quite closely. Nearly all of its tributaries such as Dicks Creek, Thirty-one Mile Creek and Mac Gulch are generally nearly perpendicular to the strike of the rocks throughout their courses and are classified as consequent streams.

Pegmatite, aplite, and aplitic migmatite have been the most resistant to weathering, and these commonly occur as ridges and knobs. Where these resistant bodies are of large size, or occur as many small closely associated discrete units, they commonly divert the channels of even the largest streams and control their courses. Zones of the greatest concentration of these rock types are present as high steep-sided ridges, which commonly have relatively

Plate 7.

Figure A: Overland Mountain peneplain on left skyline. Taken from across Currant Creek valley on Thirty-one Mile Mountain.

Figure B: Overland Mountain peneplain in vicinity of Nash Ranch taken looking southwest from Cover Mountain.



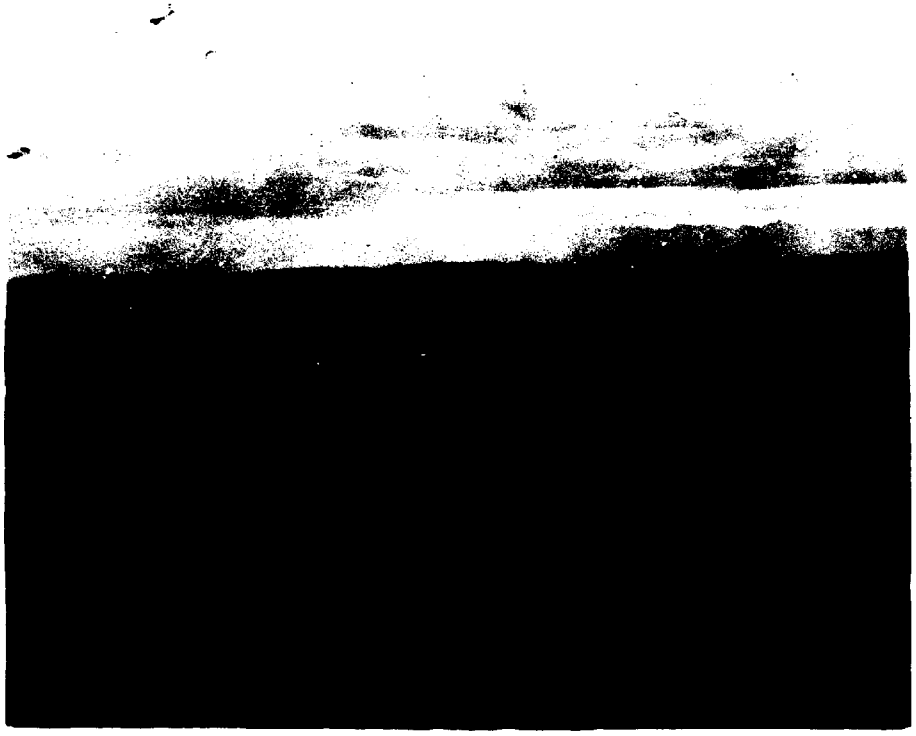


Plate 8.

Figure A: Steep-sided channel of intermittent stream, typical of those now developing throughout the area.

Figure B: Fault breccia boulder of pre-Cambrian fragments. A number of these occur along the east margin of Chumway Park.





soft rock types outcropping on their flanks. Ridges of this type can be observed on the west side of Currant Creek extending all the way from the Meyers Ranch pegmatite on the north to the south end of Thirty-one Mile Mountain on the south, and on the east side of Currant Creek from near the entrance of Thirty-one Mile Creek on the north to the southern boundary of the district. Also the high southwest peneplain surface (Lower Overland Mountain) is held up by the swarms of pegmatites in the relatively soft Idaho Springs formation.

The schists of the Idaho Springs formation rarely crop out at all unless protected in the manner described above, but remain concealed beneath a regolith of sandy and micaceous character. The resistance of biotite gneiss varies from that of the schist to that of the granitic rocks or aplites, depending on the amount of introduced material.

The granitic rocks weather generally to gentle knobs of rounded boulders, or in some places to cliffs showing many rounded segments resulting from weathering along jointing planes. Some of the coarser grained granitic rocks weather to a coarse gruss. Fine-grained diabase dikes crop out as cobbly zones, or if coarse-grained, as rounded boulders showing spheroidal weathering.

The sedimentary rocks generally weather rapidly and deeply, although some of the large pre-Cambrian boulders in the conglomeratic facies are highly resistant. These remain on the surface in boulder-strewn areas after the fine-

grained matrix material has been removed.

There is great variation in the response of the extrusive rocks to weathering and erosion as a result of their wide variation in texture, mineralogy and chemistry. With the exception of some of the dense varieties which may form cap rocks on the peneplained surfaces of older rocks, however, they weather generally to very gentle rolling surfaces.

GEOLOGY

General

The area is underlain chiefly by pre-Cambrian rocks which are covered to the east, north and west by Tertiary extrusives. A down-faulted block of Paleozoic (?) sediments forms a conspicuous unit in the west-central part of the area. The contacts between the pre-Cambrian rocks and the extrusives in general appear to be erosional rather than faulted.

The pre-Cambrian rocks may be grouped into the metamorphic rocks, schists, hornblende gneiss and biotite gneiss and the granitic intrusives and associated units. Probably all of the metamorphic rocks may be correlated with the Idaho Springs formation which includes the oldest rocks exposed through the Front Range, but some may possibly belong to the Swandyke hornblende gneiss and quartz monzonite gneiss formations. Widespread and intimate lit-par-lit injection of the Idaho Springs formation by the granitic intrusives formed the migmatite portion of the biotite gneiss. The granitic intrusives apparently are affiliated almost exclusively with the Boulder Creek granite which is closely related to the Pikes Peak batholith, although a few small outcrops resembling Silver Plume granite were observed. Associated with these intrusions are pegmatite, aplitic granite, aplite and possibly diabase dikes. The reported sequences of selected pre-Cambrian rock-types in

different sections of Colorado are correlated in Table No. 1.

The Paleozoic (?) sediments are exposed only in a relatively limited area in the west-central section. They bear a remarkable resemblance to the Lower Pennsylvanian Fountain formation, and are tentatively correlated with it.

The extrusive rocks are assigned to a post-Eocene extrusive period, and evidently are related to the Thirty-nine Mile andesite series. Apparently they covered most of the entire area for an indeterminate period following their extrusion, but have subsequently been removed by erosion in large parts of the Currant Creek drainage, and to a minor extent in the West Four Mile Creek drainage. A monzonitic stock and two volcanic breccia necks that probably served as feeders for the source of flow material have been identified in the area.

A very small area of post-extrusive sandstone crops out near the Rowe ranch west of Currant Creek, and two small recent travertine deposits occur on the Guffey road.

Structure

Pre-Cambrian folding is extremely complex in the Idaho Springs formation and the associated biotite gneisses. The folds range in size from those of microscopic scale to large structures persistent along strike for several miles. The dominant structural trend is approximately N. 30° W., and the dips are generally high, approaching vertical. Isoclinal folding is very prominent, but because of the thick-

ness of the metamorphic section involved, distances from crest to crest of these folds may be as much as several miles.

Because of their close relationship it is necessary to consider the structure of all of the Idaho Springs members and that of the closely associated biotite gneiss together. These form a complexly folded series.

A major syncline, with the keel in the vicinity of Micanite Ridge and roughly parallel with it along the east side of Mac Gulch strikes between N. and N. 20° W. An anticline trends nearly north in the vicinity of Mound Soda Spring, disappearing under the lavas near White Elephant. Near Black Mountain road and Spring Gulch the axis of a major syncline plunges northeast to north, whereas to the south and west of this an associated anticline trends northwest from near the Copper King mine to near the Thirty-one Creek ranch. In the northwest section of the area, the exposures all appear to be part of the northeast limb of a northwesterly trending anticline, locally overturned.

There are countless minor folds and faults and evidence of extensive isoclinal folding in the steep dips and close spacing of anticlines and synclines in the thick section. The general trend of the structure is approximately N. 30° W. The average dip of the foliation is high; commonly it is near 70° NW. or 70° SE. and in many places it is at or near vertical.

Foliation in the granitic rocks is essentially parallel

with that of the metamorphic rocks enclosing them where extensive injection has taken place. Elsewhere it is parallel with the margins of the intrusive body, and with the contacts of the intrusive masses with the metamorphic rocks.

Near their western margin the sedimentary Paleozoic rocks dip gently northeast, and near the eastern margin they dip steeply southwest. A short distance to the east of the easternmost sedimentary outcrops is a high angle northeast-southwest fault plane of at least three miles extent with the down-thrown block to the northwest. The dip and displacement could not be determined. In addition to the regional structure and nature of the Paleozoic-pre-Cambrian relationship, there is evidence of this fault in a resultant irregularly distributed fault breccia along the inferred contact. This is not considered sufficiently silicified to be called a breccia reef, although some silicification has indeed taken place. The fault may continue along the west flank of Thirty-one Mile Mountain, but no conclusive evidence for this could be found. The fault is probably associated with the Laramide orogeny.

The Tertiary extrusive rocks show little or no evidence of having been disturbed, but what appear to be initial dips are generally within a few degrees of horizontal and uniformly away from the center of the Guffey area in all directions. This is well illustrated by Cover Mountain with dips to the east, Thirty-nine Mile Mountain with dips to the north, Black Mountain with dips to the west and Thirty-one

Mile Mountain with dips to the south. In the Stag Mountain augite-biotite-monzonite stock, vertical lineations are reported, supporting the theory of its intrusive character.

Previous Work in Guffey Area

The Hayden report (1869), which includes a reconnaissance map of all of Colorado and parts of adjoining states, recorded the first significant work in the Guffey area. Stevenson (1875) did somewhat more detailed work in 1873 in the area bounded by the 105th and 107th meridians, and north latitude 39° 45' and the southern boundary of Colorado. The Pikes Peak Folio (1894) reports detailed mapping by Cross. The field work included the eastern margin of the Guffey district, but all of the pre-Cambrian rocks were mapped as one undifferentiated Archean unit.

The Micanite district pegmatites were examined by Sterrett (1923, pp. 51-55) in 1908 and 1913. Heinrich and Hanley in 1942, and Hanley and Trites in 1944 (Hanley, Heinrich and Page, 1950, pp. 42-55) re-examined the economically valuable pegmatites, and mapped a number of them by means of plane table and stadia.

Eckel (unpublished report of the U. S. Geol. Surv.) examined the Lone Chimney mine which is now known as the Betty mine, and the Carbonate King and Susannah mines in 1932, and also obtained some information on the Copper King and Mill Gulch mines which he did not visit. Some of his information is reported in Lovering and Goddard (1950,

pp. 69-70, 289).

A brief report on the petrography of two of the sillimanite concentrations in the area was written by Richards (1947) working with hand specimens collected by E. Wm. Heinrich and with thin sections prepared from these. In 1946 and 1949 Heinrich (1950, pp. 173-177) re-examined the Climax pegmatite giving particular attention to the cordierite-pinite concentrations in it.

In 1944 Lovering and Goddard (1950, p. 289) examined the monzonite stock at Stag Mountain, and did some reconnaissance in other parts of the area. Their results are shown on the geological map of the Front Range which they compiled.

South Park, which is adjacent to the Guffey area to the north, has been studied by Stark et al. (1949), and the Pikes Peak Folio compiled by Cross (1894) covers a large area adjacent to the east. Areas of similar geology within the Front Range have been described by many authors, with those most closely related to the problems in the Guffey area being studies in the Georgetown area by Spurr, Garrey and Ball (1908), the Montezuma area by Lovering (1935), the Jamestown area by Goddard (1936), the Eight Mile Park area, with special emphasis on pegmatites, by Heinrich (1947), the Vasquez Mountains by Tweto (1947), the area near Bergen Park, with special emphasis on migmitization, by Snively (1948), and the Never Summer Mountains by Buckwalter (1950).

PRE-CAMBRIAN ROCKS

General

In spite of many papers on the occurrence, nomenclature, and relationships of the pre-Cambrian rock types within the Front Range of Colorado, considerable question still exists as to the identity, identification and designation of the various units. The picture is particularly confused as a result of the gradational nature of the contacts between the older metamorphics and the intrusive igneous rocks, the presence of marginal, satellitic, and regional variations within the intrusive units, and the possibility that rocks which are extremely similar texturally and mineralogically have been derived from either sedimentary rocks, igneous rocks, or a combination of both.

The pre-Cambrian rocks of Colorado consist primarily of schists, gneisses, and granitic rocks intruded into them. The schists are extremely variable in mineral content, texture and structure, and all were highly metamorphosed before the first period of intrusion. Subsequent intrusion, injection and deformation have further modified these rocks to their present state.

The earliest detailed study of the pre-Cambrian rocks of the central Front Range was carried out by Ball (1908, pp. 37-96) in his work with Spurr and Garrey in the Georgetown Quadrangle. He described the following nine major rock types (from youngest to oldest):

Pegmatite, granite-pegmatite and associated granites, and granite porphyry (youngest)

Silver Plume granite (porphyritic biotite granite)

Rosalie granite (biotite granite)

Quartz-bearing diorite and associated hornblendite

Quartz monzonite (adamellite)

Gneissoid granite (mashed biotite granite)

Quartz monzonite gneiss (adamellite gneiss)

Hornblende gneiss

Idaho Springs formation, including biotite-sillimanite schist, biotite schist, quartz gneiss, ellipsoidal masses and lime-silicate rocks (oldest).

The name Idaho Springs formation, originated by Ball (1908, p. 37) is generally accepted for the oldest metamorphic rocks, presumably of metasedimentary origin, which had previously been referred to as Archean schists in most reports. Lovering (1929, pp. 73-74), by comparison with the rocks in the Lake Superior district, suggests that these rocks are early Algonkian, as was earlier suggested by Cross (1894, p. 3) from his studies in the Pikes Peak quadrangle.

Hornblende gneiss was described by Ball (1908, pp. 45-46) as being intrusive into the Idaho Springs formation, generally in concordant manner but in some places showing cross-cutting relationships. Patton (1909, pp. 123-124) recognized similar hornblende gneiss in the Montezuma quadrangle, and Lovering (1935, pp. 10-11) re-examined this unit and gave it a formational name, the Swandyke hornblende

gneiss. He decided that it represented metamorphosed interbedded flows at the top of the Idaho Springs formation and metamorphosed doleritic sill-like masses intrusive into it. The cross-cutting facies reported by Ball are ascribed by Lovering to an entirely different, later period of dioritic intrusion associated with the Pikes Peak granite. Tweto (1947, pp. 11-12, 59-60) believes that all or a large part of the hornblende gneiss is of sedimentary origin, and so has substituted the name "hornblende gneiss" for Swandyke hornblende gneiss to avoid the implication of igneous gneiss associated with the latter name.

Quartz monzonite gneiss was described by Ball (1906, p. 47) as being intrusive into the Idaho Springs formation and the hornblende gneiss. He found the contacts to be sharp in most outcrops, although locally some were notably gradational. He also describes a later period of quartz monzonite intrusion. Lovering (1935, p. 11) thought that the early quartz monzonite magma was the source of the added material in the lit-par-lit injection of the Idaho Springs formation and probably the Swandyke hornblende gneiss, thus forming the large masses of injected biotite gneiss. Lovering and Goddard (1950, pp. 23-25) suggested that it is quite probable that this material was genetically related to the Swandyke hornblende gneiss, whereas the small stocks of quartz monzonite gneiss found near outcrops of Pikes Peak or Boulder Creek granite were an early facies of the Boulder Creek granite. However, Tweto (1947, pp. 11-

12) believes these rock types to be of sedimentary origin and suggests that the name "quartz monzonite gneiss" is misleading unless an unquestionable igneous origin can be established. If a dominantly sedimentary origin is indicated he suggests the use of the names quartz-biotite-feldspar paragneiss or migmatite. Snively (1948, pp. 70-71) and Buckwalter (1950, p. 67) used the non-genetic name, biotite gneiss, to describe these rocks.

The gneissoid granite of Ball (1908, pp. 49-51) or granite gneiss and gneissic aplite of Lovering (1935, pp. 11-12) and quartz diorite of Ball and Lovering are thought by Lovering and Goddard (1950, p. 25) to represent complementary dike rocks related at least in part to the Boulder Creek intrusives.

It was suggested by Ball (1908, p. 57) that the Rosalie granite was related to the Pikes Peak granite described by Mathews (1895 and 1900, pp. 217-225) and Lovering (1935, p. 13) was able to trace the Rosalie granite to the south until it actually merged with the Pikes Peak granite. As a result of this the name Rosalie granite has been discarded in favor of Pikes Peak granite. Lovering and Goddard (1950, p. 28) also suggest that the Sherman granite, described by Blackwelder (1908), cropping out in northern Colorado and in Wyoming may be correlated with the Pikes Peak granite.

The Archean quartz monzonite described by Ball has been found by Lovering (1929, p. 70) to grade into Pikes

Peak granite. Goddard (1936, pp. 45-49) found the same relationship to exist in the Overland Mountain granite which he believes is equivalent to the Pikes Peak granite. He described gradation from a dark gray gneissic border facies, equivalent to the Boulder Creek granite (described by Boos and Boos, 1934) into more typical Pikes Peak granite centrally. This dark gray gneissic quartz monzonitic rock, which is found marginal to Pikes Peak granite units, and as small satellitic bodies around them, is now generally referred to as Boulder Creek granite (Lovering and Goddard, 1950, pp. 25-27).

Ball (1908, pp. 58-60) suggested that the Silver Plume granite described by him might be related to the Cripple Creek granite described by Mathews (1895 and 1900, pp. 229-232). Lovering and Goddard (1950, p. 28) in later examinations have agreed with this and list the Silver Plume granite, Cripple Creek granite, Longs Peak granite (Fuller, 1924) and the Mount Olympus granite (Fuller, 1924) all as being equivalent.

Pegmatites and aplites occur associated with both of the major periods of intrusion, but ordinarily these units associated with different granites are not sufficiently distinct in field relations or mineralogy to permit dependable distinction between them.

Diabase dikes were observed by Heinrich (1948, pp. 428-431) as the latest pre-Cambrian intrusives in the Eight Mile Park area where he associated them with the Pikes Peak

intrusives. These are also present in the Guffey area, and both Heinrich (oral communication) and the writer think that these may represent a very late pre-Cambrian intrusive period, although the possibility of a Tertiary origin cannot be completely eliminated.

From the above correlations plus the conclusions of the writer, the following generalized section of the Front Range pre-Cambrian is suggested (youngest to oldest):

Diabase (youngest)

Pegmatites and aplites

Silver Plume group of granites (including Cripple Creek granite, Longs Peak granite and Mount Olympus granite)

Olivine syenite (Cripple Creek area only, hence omitted from chart)

Pegmatites and aplites

Pikes Peak group of granites (including Boulder Creek granite, Overland Mountain granite, granite gneiss, gneissic aplite, the diorite-hornblendite rocks, and Sherman granite (?))

Biotite gneiss (igneous or sedimentary)

Hornblende gneiss (igneous or sedimentary, including the Swandyke hornblende gneiss)

Idaho Springs formation (oldest)

On this basis Chart I is designed to show cross-correlation of the pre-Cambrian units as reported by different authors. Most of these reported occurrences are within the Front Range but some are from adjacent Colorado and Wyoming areas.

x = present
-- = no record
? = uncertain correlation

Figure 2.
Selected regional pre-Cambrian relationships

Area and Author	Idaho Springs	Hornblende gneiss	Quartz monzonite gneiss	Granite gneiss	Pikes Peak	Silver Plume
Colo. recon. Hayden (1869)	--	--	--	--	granite	--
Colo. recon. Stevenson (1875)	schist and hornblende rocks		--	--	feldspathic granite	
Pikes Peak Cross (1894)	schists etc.	--	--	Pikes Peak and assoc. gneiss		fine-grained granite
Pikes Peak Mathews (1900)	--	--	--	--	x	Cripple Creek
Georgetown Spurr (1908)	x	intrusive	x	x	Rosalie	x
No. Colo. and Wyo. Blackwelder (1908)	--	--	--	--	Sherman	--
Gunnison Canyon Hunter (1925)	Black Canyon, River Portal schists	Dubois greenstone	--	Powder Horn and assoc. inject.?		Curecanti?
Longs Peak-St. Vrain Boos and Boos (1934)	x	--	Boulder Creek granite gneiss?			Longs Peak

	Idaho Springs	Hornblende gneiss	Quartz monzonite gneiss	Granite gneiss	Pikes Peak	Silver Plume
Montezuma Lovering (1935)	x	Swandyke	All present, related and approx. contemporaneous			x
San Juan Region Cross and Larsen (1935)	schists gneiss[illegible] amphibolites	Irving greenstone	--	--	--	--
Cripple Creek Loughlin and Koschman (1935)	x	--	olivine syenite?		x	Cripple Creek
Sawatch Range Stark and Barnes (1935)	Holy Cross, Sawatch schists, migmatite	--	--	--	x	--
Jamestown Goddard (1936)	x	Swandyke	x	--	Boulder Cr. Overland Mtn.	x
Front Range Lovering and Goddard (1938)	x	Swandyke	x	aplitic Boulder Creek	x	x
Gold Hill Goddard (1940)	x	--	injection gneiss	gneissic granite aplite	Boulder Creek	x

Figure 2 (cont.)

	Idaho Springs	Hornblende gneiss	Quartz monzonite gneiss	Granite gneiss	Pikes Peak	Silver Plume
Eight Mile Park Heinrich (1947)	x	hornblende gabbro	injection gneiss		x	--
Vasquez Mtns. Tweto (1947)	Idaho Springs		migmatite and paragneiss		Boulder Creek	--
Bergen Park Snively (1948)	x	Swandyke	biotite gneiss	gneissic aplite	Boulder Creek	--
South Park Stark (1949)	Idaho Springs		--	--	x	x
Front Range Lovering and Goddard (1950)	x	Swandyke	x	granite gneiss, gneissic aplite	x	x
Northwestern Park County Singewald (1950)	x	--	--	--	x	x
Never Summer Mtns. Buckwalter (1950)	x	x	biotite gneiss	--	?	
Guffey Bever (1954)	Idaho Springs		biotite gneiss	gneissic aplite	Boulder Creek	--

Figure 2 (cont.)

IDAHO SPRINGS FORMATION

History and Distribution

Ball (1908, pp. 37-44) first described the Idaho Springs formation from outcrops in the vicinity of Idaho Springs, Clear Creek County, Colorado, in the Georgetown quadrangle, which he, Spurr and Garrey mapped. He described it as including biotite-sillimanite schists, biotite schist, and quartz gneiss, with lenses of lime-silicate rocks. The schists and quartz gneiss he found to be interbedded with and transitional into one another, while the lime silicate rocks, although interbedded with the others, appeared only to grade into the quartz gneiss. Ball assigned probable sedimentary origin, and described the Idaho Springs formation as the oldest member of the pre-Cambrian series in Georgetown quadrangle, forming the country-rock into which the other formations were injected.

Many outcrops identified as Idaho Springs formation, and many others which although not so originally identified also appear to be Idaho Springs formation, have been reported by investigators throughout the Front Range mineral belt as defined by Lovering and Goddard (1938). Other important Front Range occurrences have been described outside the mineral belt. Cross (1894, 1894a) described similar rocks in the Pikes Peak and Crested Butte quadrangles, and Lindgren, Ransome and Graton (1906), Finlay (1916) and Loughlin and Koschman (1935) described rocks of this type in the

Cripple Creek area. These probably can be correlated with the Idaho Springs formation. Exposures have also been reported by Tweto (1947) in the Vasquez Mountains, Gorton (1941) and Buckwalter (1950) in the Never Summer Mountains, Snively (1948) in Bergen Park, Stark et al. (1949) in South Park and Heinrich (1948) in Eight Mile Park. Exposures in the Big Thompson Canyon region, named the Big Thompson schist by Fuller (1924), later (Boos and Boos, 1934) were correlated with the Idaho Springs formation.

A number of exposures of metamorphic rocks outside the Front Range also have been correlated tentatively with the Idaho Springs formation. Hills (1900) described briefly metamorphic rocks in the Wet Mountains which bear at least some similarity to the Idaho Springs formation, and Cross (1896) described a group of variable gneisses in the Silver Cliff and Rosita Hills district, including many types similar to typical Idaho Springs members, but correlation of these occurrences with the Idaho Springs formation is at best doubtful. Metasediments in the Dillon, southern Gore and northern Ten-mile areas were mapped by Buckwalter in 1940 (1950) and were considered by him sufficiently similar to the Idaho Springs formation to justify correlation. Outcrops described by Emmons in the Mosquito Range (1886) and Tenmile district (1898), by Butler and Vanderwilt (1930) in the Climax district, Patton et al. (1912) and Singewald and Butler (1933) in the Alma district and by Behre (1939) near Leadville are sufficiently similar to the Idaho Springs to

allow correlation. Pre-Cambrian metamorphic rocks in the Sawatch Range can probably be correlated with the Idaho Springs formation as indicated in the reports of investigations by Stark and Barnes (1934) who mapped the entire range in reconnaissance, Howell (1919) in the Twin Lakes area, Goddard (1936b) in the Tin Cup district and Crawford (1910, 1913, 1916 and 1924) in the Monarch, Tomichi, Gold Brick and Redcliff districts.

There is wide geographical separation between the known outcrops of Idaho Springs formation and the outcrops of pre-Cambrian metamorphics in the Gunnison Canyon and the Sangre de Cristo Range. Because of the general textural and mineralogical dissimilarity of the latter to typical Idaho Springs specimens, in spite of local similarity, it is felt that there would be no justification for correlating these with the Idaho Springs formation.

On the geologic map of Colorado published in 1935, the Idaho Springs formation was assigned to the Gunnison River series, which includes all of the oldest exposed rocks in Colorado. Lovering (1929), in comparing the Idaho Springs formation to early Algonkian formations of the Lake Superior district, finds a marked lithologic similarity and suggests that the ages are very likely the same.

Occurrence

The largest exposure of the Idaho Springs formation in the Guffey area is approximately six square miles in the

southeast section. The erosion surface extending from one-half mile north of the Skyline ranch to the southern boundary of the area shows, particularly along the margins of the more resistant pegmatites, outcrops of biotite-sillimanite schist which are uniform over large areas. To the east and north of the erosion surface the schist disappears beneath the Tertiary extrusive rocks, whereas to the west it grades imperceptibly into biotite gneiss near Mac Gulch. Along the eastern margin of the area there is evidence of a contact with Boulder Creek granite, but this relationship is generally obscured by the overlying extrusives.

There are similar outcrops at Guffey extending for about one and one-half miles to the north and one and one-half miles to the southeast. From the distribution and structure and similarity of rock types, it seems likely that this group of rocks represents a continuation of the larger one to the southeast, now superficially divided from it by the intervening andesite flow.

Another large exposure in the northwest part of the area crops out in the vicinity of Dicks Creek and continues north as far as Sheep Gulch, varying between one-half and two and one-half miles west of Currant Creek. One small outcrop appears to the north of Sheep Gulch about two miles west of Currant Creek. The individual outcrops are generally irregular or isolated, however, as the exposed units are separated by areas underlain by biotite gneiss or by overlying extrusive rocks.

Other small exposures crop out along Thirty-one Mile Creek near the Copper King mine, on Currant Creek one-half mile south of the Black Mountain road, along and north of the Black Mountain road from one-quarter to one mile and one-quarter west of Currant Creek, at the intersection of Lues Gulch and Currant Creek, and near the intersection of Dicks Gulch and Currant Creek.

Schist

Petrology

The schist typically includes many dark biotitic rocks, but gray to whitish rocks with a larger content of sillimanite, quartz and muscovite are common, with all gradations between. Many of the outcrops appear reddish-brown to brownish-black from the alteration of biotite and magnetite. These rocks show a very well developed schistosity (pl. 9, fig. A), but with increased segregation of constituents into bands gradation imperceptibly into gneissic, or even locally into massive structures takes place. This change is principally due to injection by granitic material.

Almost all of the schist is injected to some degree, but the amount of added material may range from a very low to a very high percentage. Lovering (1935, p. 7) states that it is difficult to find any mass of schist more than 25 feet thick in the Montezuma quadrangle that has not been injected by one or more of the granitic intrusives, and this applies also in the Guffey area. Lit-par-lit injection is common, and aplitic and pegmatitic seams vary in thickness

from microscopic dimensions to 3 or 4 centimeters; locally they are considerably thicker. As the amount of injected material increases, the schist grades into biotite gneiss, and it is necessary to make a somewhat arbitrary separation of the two types (pl. 9, fig. B).

Generally the reaction of the schist with the intruded material has been minor, as shown by the fine banding, the very sharp, clearly defined contacts and the limited occurrence of xenolithic material, but locally prominent xenoliths exhibit very ragged boundaries, indicating that small-scale solution and recrystallization have taken place.

The schist does not commonly crop out except where it is adjacent to more resistant rocks, where it has been injected to such an extent that it is more resistant or where erosion has removed the regolith in valley walls and floors. Generally the schist and the biotite gneiss are roughly concordant, with the amount of injected material nearly constant along the strike for considerable distances. Locally, however, there is marked lateral variation in the amount of injected material. In some places this has necessitated placing a schist-injection gneiss contact at an angle with the foliation.

The typical schists within this region are quartz-biotite-sillimanite rich varieties that range in color from brownish-black, which is most common, to silvery gray, and form irregular outcrops. The high sillimanite content of these rocks is in contrast with other localities throughout

Plate 9

Figure A: Biotite-sillimanite schist cropping out on flat south of Cover Mountain.

Figure B: Injected biotite schist, intermediate in character between true biotite schist and biotite gneiss. Outcrop near Meyers Ranch.





the Front Range in which the reported proportion of sillimanite is lower than in the Guffey area. Some outcrops of quartz-biotite schist without prominent sillimanite occur, but these are uncommon. In several areas there are outcrops of quartz-sillimanite schist and quartz-muscovite-sillimanite schist which are typically very poor in dark constituents. Some of the schist contains microscopic anhedral to subhedral garnet crystals, but these are not abundant enough even locally to justify the identification of the rock as the quartz-biotite-garnet schist commonly found in other areas. The low garnet content may be, as suggested by Tweto (1947, p. 16) a result of the general high concentration of sillimanite. Quartz-biotite-feldspar schists are common, particularly as the amount of injected material increases as margins of the granitic bodies are approached and schists grade into injected biotite gneiss. Both potash feldspar and plagioclase are present in variable proportion.

The schistosity of the rocks is primarily formed by abundant, well-oriented biotite flakes. Wherever these flakes are large (2 centimeters or more) they are dominant and obscure the light constituents. Where the biotite is in small flakes, the rock generally has a "salt and pepper" appearance, but even in this rock with approximately equal distribution of light and dark constituents, faint dark bands with higher biotite concentrations are present. The light-colored minerals, particularly quartz, are commonly concentrated in bands, especially in the injected material,

and some of this quartz appears smoky or bluish. Sillimanite also contributes notably to the foliation, either as discrete needles, grayish to whitish layers of needles, or as fibrolitic bundles or sheaves. Locally muscovite helps to accentuate the schistosity. In at least one locality near Micanite Ridge magnetite is unusually abundant and markedly flattened in the plane of schistosity.

Megascopically much of the schist shows a strong development of "knots" or ellipsoidal masses consisting predominantly of sillimanite and quartz. Some of these are as much as two to three inches in length, and are sufficiently abundant to impart to the rock a pseudo-conglomeratic appearance. The pods are commonly enclosed in a thin envelope of muscovite and biotite flakes. This rock type has been reported from many other localities in the Front Range, and has been described as "ellipsoidal masses" by Ball (1908, p. 41) as "pebble bearing gneiss" by Spurr (1908, p. 177) and as "knotted schist" by Lovering (1935, pp. 7-8).

Although much of the schist that is essentially uninjected shows megascopic banding, this textural feature becomes increasingly dominant as injection becomes more prominent. The injected material varies in texture from very fine-grained aplitic to coarse-grained pegmatitic. It is generally felsic in composition, but locally recrystallized biotite, particularly along the margins of the injected layers, may cause the material to look mafic. On microscopic examination all of the sections of schist examined

show compositional banding, even where this is not visible in the hand specimen. Quartz is the one mineral invariably present. Other essential minerals, in order of decreasing importance, are biotite, sillimanite, microcline and plagioclase (chiefly oligoclase and andesine). Muscovite and magnetite are locally sufficiently abundant to be classed as essential. Accessory minerals include zircon, apatite, magnetite, garnet, spinel, ilmenite and possibly graphite (see fig. 3). Sericite, hematite, limonite, chlorite, calcite, epidote and leucoxene have been formed as the result of various alteration processes.

Quartz.--This occurs commonly with any feldspars present as clusters of irregular grains in layers alternating with biotitic bands. There is much evidence of extensive and intensive shearing stresses. Quartz shows granulation, shattering of even the larger grains, the development of through-going fracture planes, development of undulatory extinction and interlocking and mosaic textures. In some areas cleavage occurs as numerous closely spaced sub-parallel shear planes.

In many specimens quartz grains are large (as much as 3 millimeters in diameter) and nearly equi-dimensional in the quartz-biotite parts of the rock distant from fibrolitic sillimanite concentrations, whereas near sillimanite concentrations the quartz grains are much smaller, and in some places are abnormally elongate parallel with the schistosity. These elongate quartz grains generally show an

imbricate texture, and strong concentrations of dominantly fibrolitic sillimanite (pl. 10, fig. A), locally replaced by muscovite commonly occur between these quartz layers. Movement along these planes of schistosity has caused extensive brecciation resulting in cataclastic zones in which the stress minerals, biotite and subsequently sillimanite, have developed. In the best examples fracture planes in quartz grains contain sillimanite which gives the rocks a very pronounced foliation. In some sections the quartz grains are optically oriented with the c-axes lying nearly parallel within the plane of schistosity (pl. 10, fig. B).

Small replacement grains of sillimanite and biotite are scattered through some quartz grains, and some of the small individual biotite grains show incipient coalescence to form large single plates. Some of the quartz is transected by many hair-like randomly oriented veins of chlorite and sericite. Another feature of the quartz is bubble or inclusion trails that are continuous across grain boundaries.

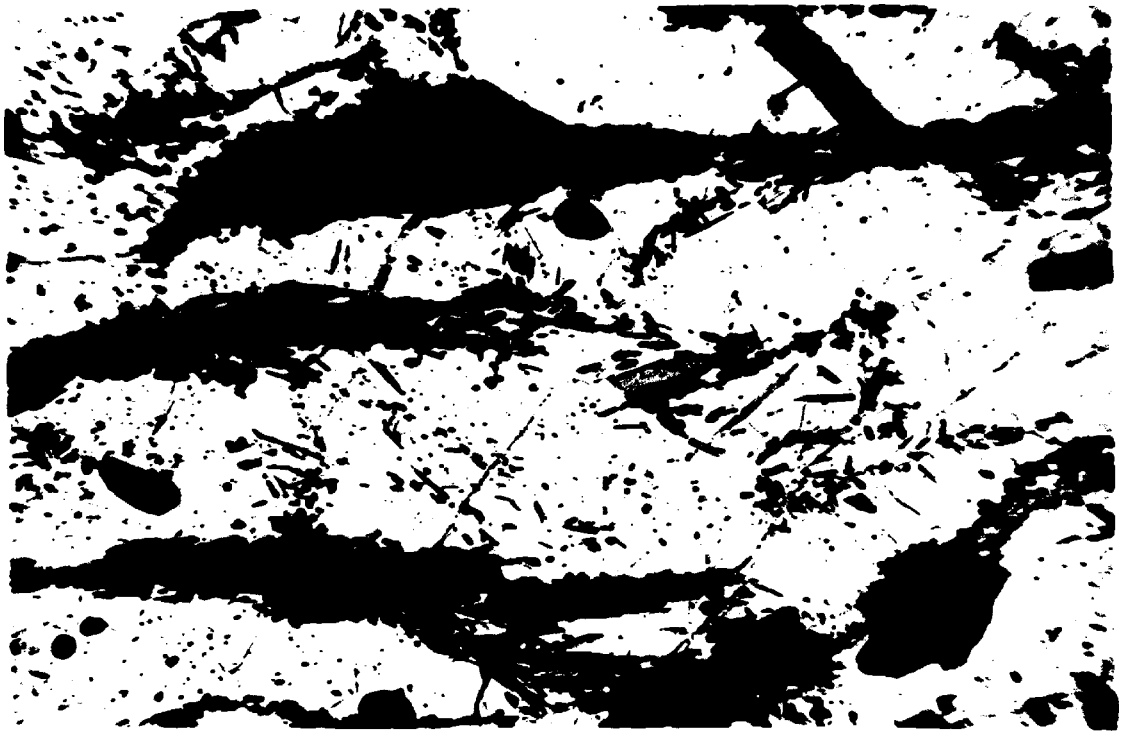
As mentioned above the quartz is in some places replaced by biotite, but elsewhere, particularly where recrystallized or in lit-par-lit veins, quartz replaces biotite.

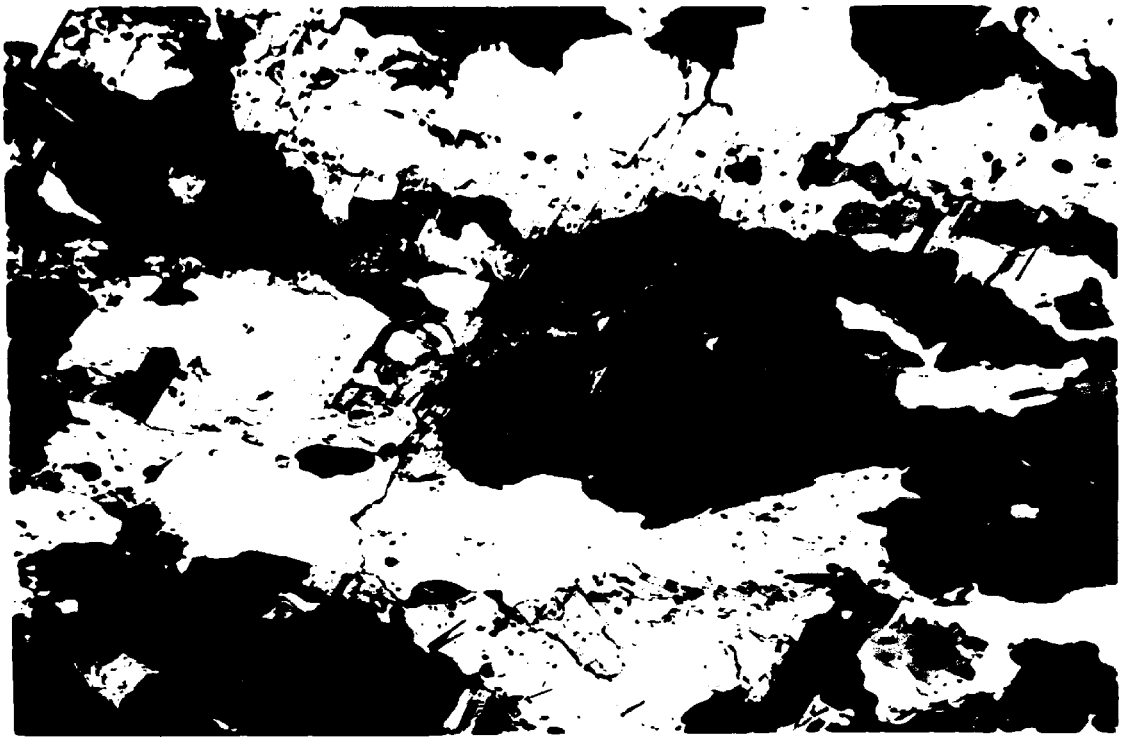
Biotite.--This normally forms between 20 and 30 per cent of the rock by volume. Locally concentrations contain much more biotite, particularly in some almost pure pods. In some types the biotite is nearly absent particularly where it has been replaced by muscovite. Although much

Plate 10.

Figure A: Fibrolitic sillimanite along boundaries of flattened quartz grains. Gold Hill area.
(-) nicols, x 85.

Figure B: Flattened quartz and feldspar grains in injected biotite schist. The c-axes of the quartz grains show orientation close to parallel. Muscovite porphyroblasts have commenced development along grain boundaries. North of Betty Mine.
(+) nicols, x 43.





with crystallographic unity. There is evidence of some replacement of biotite by late quartz. Some of the quartz-biotite intergrowths show symplectitic relationships.

In areas of extensive retrogressive metamorphism, biotite has been partially or entirely replaced by muscovite. Commonly this has taken place with the muscovite retaining the crystallographic orientation of the biotite (pl. 11, fig. A). Elsewhere abundant, minute, randomly oriented sericite flakes form aggregate pseudomorphs (pl. 11, fig. B). Byproduct magnetite from this replacement is present in some occurrences, but in others it is absent.

Sillimanite has replaced biotite extensively in some rocks and has crystallized parallel with the cleavage traces of the mica. Minor biotite has altered to chlorite and dusty magnetite. In some of the muscovite which has replaced biotite, excess iron has been retained as hematite along grain boundaries and cleavages.

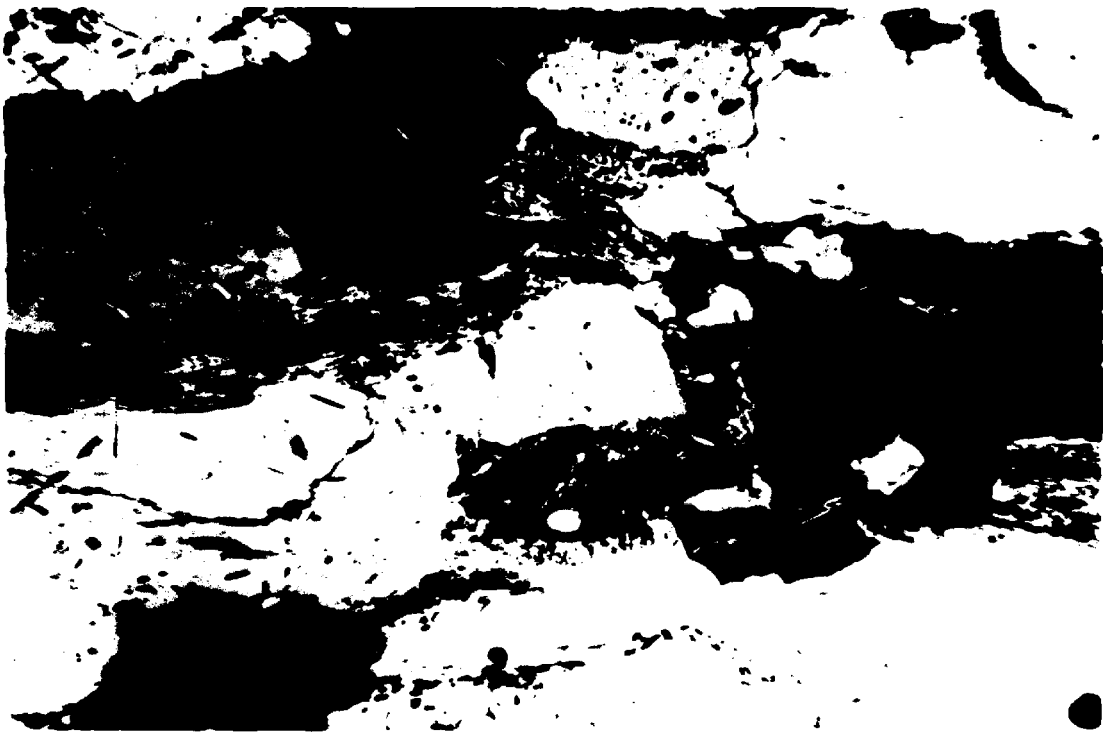
Sillimanite.--With few exceptions sillimanite is an essential constituent in the schists throughout the area. It occurs in the fibrolitic form as parallel to sub-parallel sheaf-like aggregates of many very thin elongate needles and also as coarser euhedral individual grains. These usually exhibit the typical diamond-shaped cross-sections with prominent (010) cleavage parallel with the long diagonal. The refractive indices are generally in the low part of the sillimanite range with n_α=1.657-1.658 and n_γ=1.677-1.679, and the 2V is generally between 20 and 25

Plate 11.

Figure A: Oriented replacement of biotite by muscovite in a biotite-sillimanite schist from the headwaters of Lues Gulch. (-) nicols, x 85.

Figure B: Biotite to sericite to muscovite transition in biotite-sillimanite schist from Gold Hill. (+) nicols, x 85.





degrees.

Aggregates of fine needles of fibrolitic (fibrous) sillimanite occur most commonly along the planes of foliation, but with only poor linear orientation. Subsequent to fibrolitic sillimanite formation extensive shearing has taken place along the foliation planes. Sillimanite concentrations are associated with elongate, optically sub-oriented quartz grains which are commonly brecciated, and small strongly oriented biotite plates (pl. 10, fig. A). The sillimanite generally has formed along the quartz grain boundaries, but less commonly fibrolite zones cut directly across quartz grains, particularly where fractures have developed. In these cataclastic zones the quartz, biotite and sillimanite all show a much more marked preferential orientation, and all are much finer grained. In these zones also, magnetite and zircon are conspicuously closely associated with the sillimanite. Constituental banding is particularly well developed in these zones of shearing. In the vicinity of marked sillimanite concentrations feldspar is uncommon or absent.

Between planes of strong development of the stress minerals, quartz, biotite and sillimanite grains are larger and show a more nearly random orientation. In these zones quartz is dominant. Biotite decreases less than sillimanite.

Sillimanite abundantly replaces both quartz and biotite, and is replaced by muscovite (pl. 12, fig. A). In some areas the biotite is replaced almost entirely and the

sillimanite may retain the approximate orientation of the biotite. Elsewhere sillimanite replaces quartz preferentially, and in at least one place this replacement is of a subgraphic nature (pl. 12, fig. B). In general the sillimanite appears to be of later origin than all other primary rock constituents except muscovite. In a few places it is even observed replacing muscovite.

Replacement of sillimanite by fine-grained sericite and muscovite is common and in places is preferential. Zones in quartz and biotite which have been previously replaced by sillimanite may alter more easily to large muscovite metacrysts. In the Thirty-one Mile Creek sillimanite deposit some of the sillimanite laths have been cross-fractured and replaced along these fractures by an unidentified clay mineral with very low birefringence, index greater than Canada balsam and some accordionlike aggregates and cross fiber veinlets. Here also there has been some veining and replacement by late quartz.

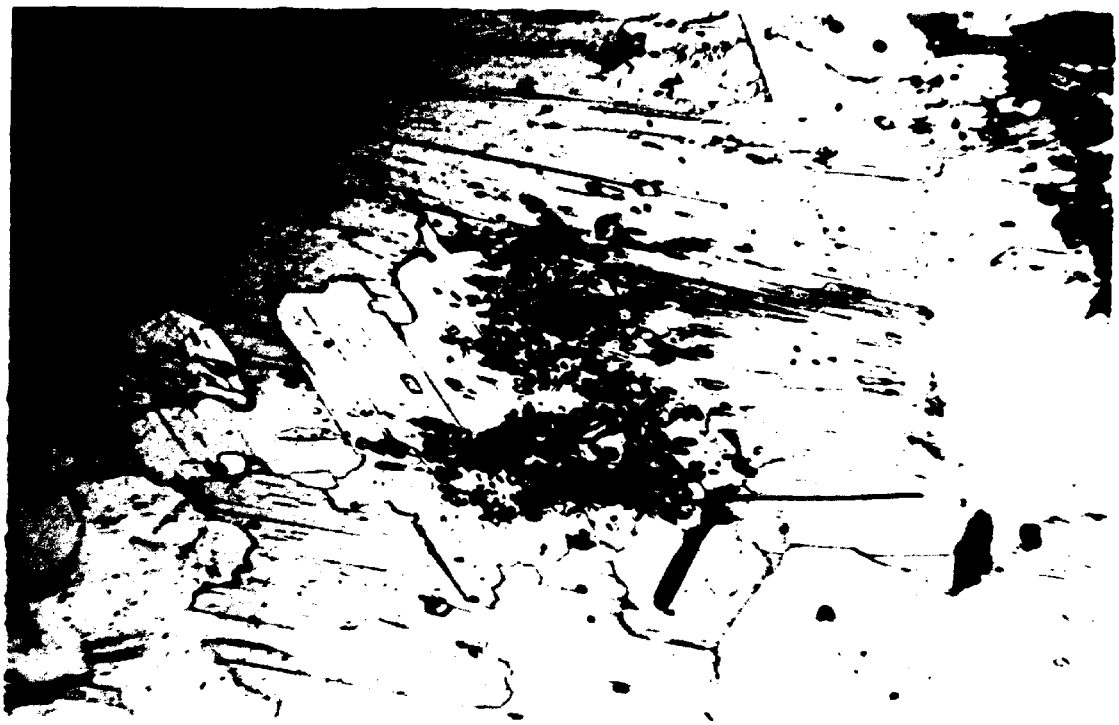
In general sillimanite concentrations are greater toward margins of intrusive bodies. This is particularly true toward the more mafic phases of the Boulder Creek granite.

Feldspars.--In these rocks feldspars are usually minor, rarely exceeding 10 per cent; in many specimens they are essentially absent. Microcline, the most abundant, is typically extensively sericitized, particularly along the albite twin lamellae and less commonly along pericline lamellae. Some of the fine sericite shreds have begun to

Plate 12.

Figure A: Sillimanite aggregates being replaced by porphyroblastic muscovite. Individual sillimanite laths show corrosion. Sillimanite schist on west side of Micanite Ridge. (-) nicols, x 85.

Figure B: Quartz-sillimanite symplectite in a sillimanite schist from 31 Mile Creek near the Copper Queen mine. Sillimanite has replaced quartz. (+) nicols, x 85.





coalesce into large muscovite plates.

In some thin sections exsolution microcline-microperthite may be observed. Micropegmatitic textures have developed locally through the replacement of microcline by quartz. Some of these quartz blebs and vermiform grains seem to have developed preferentially along pericline twins; perhaps as these are typically broader than the albite twins. Elsewhere microcline may be observed apparently replacing large quartz grains along boundaries and fractures.

Orthoclase also is strongly sericitized in places, and commonly exhibits perthitic and micropegmatitic textures. One thin section shows the development of blocky orthoclase metacrysts. These show a pronounced poikiloblastic texture with rounded relicts of biotite, quartz and subhedral to euhedral magnetite crystals as inclusions. Subsequent to their development these orthoclase metacrysts have been extensively replaced by dominantly fibrolitic sillimanite.

Plagioclase is normally the least abundant of the feldspars, and is most extensively sericitized. The composition ranges from Ab 79 to Ab 51 with the median approximately Ab 67. Locally well-developed myrmekitic textures are present (pl. 13, fig. A). Very commonly alteration of the plagioclase is controlled by the albite twinning lamellae, with fine sericite aggregates and larger muscovite needles and plates developing along only one set of twins. Here, also, coalescence of the fine-grained muscovite to larger crystals is encountered. In at least one occurrence

Plate 13.

Figure A: Myrmekite in sillimanite schist from Gold Hill. Also (lower left) replacement of quartz by muscovite. (+) nicols, x 85.

Figure B: Porphyroblastic growth of large muscovite crystals replacing quartz, feldspars and biotite. From north bank of Thirty-one Mile Creek. (+) nicols, x 43.





sillimanite has replaced andesine along albite twinning lamellae.

Feldspars are much less common in the rocks that have been strongly metamorphosed, particularly where there is evidence of hydrothermal development of late sillimanite and muscovite. Prominent shear zones shown by the elongation of quartz, biotite and development of extensive sillimanite occur. Shear zones evidenced by fracture and the development of muscovite have developed, usually superimposed on the stress zones. Feldspar is essentially absent in these zones. If present, it is more common in the lower metamorphic intensity zones of more nearly equidimensional quartz and biotite, grains which exist between the zones of higher metamorphic intensity.

Muscovite.--In some schists of the area, muscovite is absent, but generally some is present. It varies from a minor to the major constituent, and increases in rocks in which metasomatism and retrogressive metamorphism operated strongly. In some localities metasomatic muscovite is sufficiently abundant to form a hydrothermal muscovite rock.

Some of the muscovite is apparently contemporaneous with the biotite. This muscovite is fine-grained and oriented in the plane of schistosity. Most of the muscovite, however, has originated as the latest metamorphic mineral, replacing all earlier minerals except the magnetite, zircon, and apatite (pl. 13, fig. B). Replacement proceeds along grain boundaries and fractures, and in biotite and feldspar

may be controlled structurally by cleavages and twinning. In other cases it may show essentially random replacement. The replacement may begin as minute shreds of sericite which later coalesce to form large crystals or it may form directly as muscovite in very large poikiloblastic crystals. In the latter formation, muscovite seems to indicate a greater hydrothermal influence, and may appear as symplectitic intergrowths with quartz and the feldspars (pl. 14, figs. A and B). In addition to its occurrence in oriented and non-oriented replacement of biotite, muscovite occurs rarely as an oriented overgrowth on biotite.

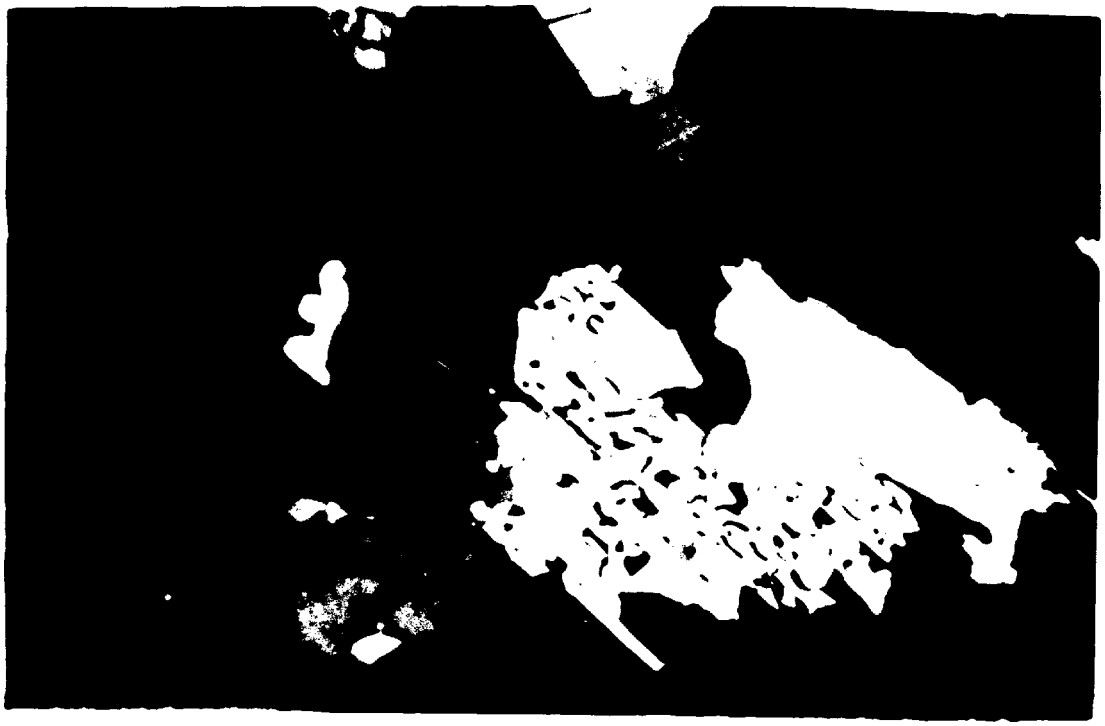
Generally muscovite replaces biotite preferentially, but where hydrothermal activity has been great, it replaces quartz and the feldspars to essentially the same extent as it does biotite. The replacement of sillimanite is variable. In some rocks it seems almost to be preferential, particularly by sericitic muscovite. In others sillimanite seems to resist replacement to a marked degree and will retain its identity within muscovite which has replaced enclosing biotite, quartz and feldspars. This suggests two generations of sillimanite.

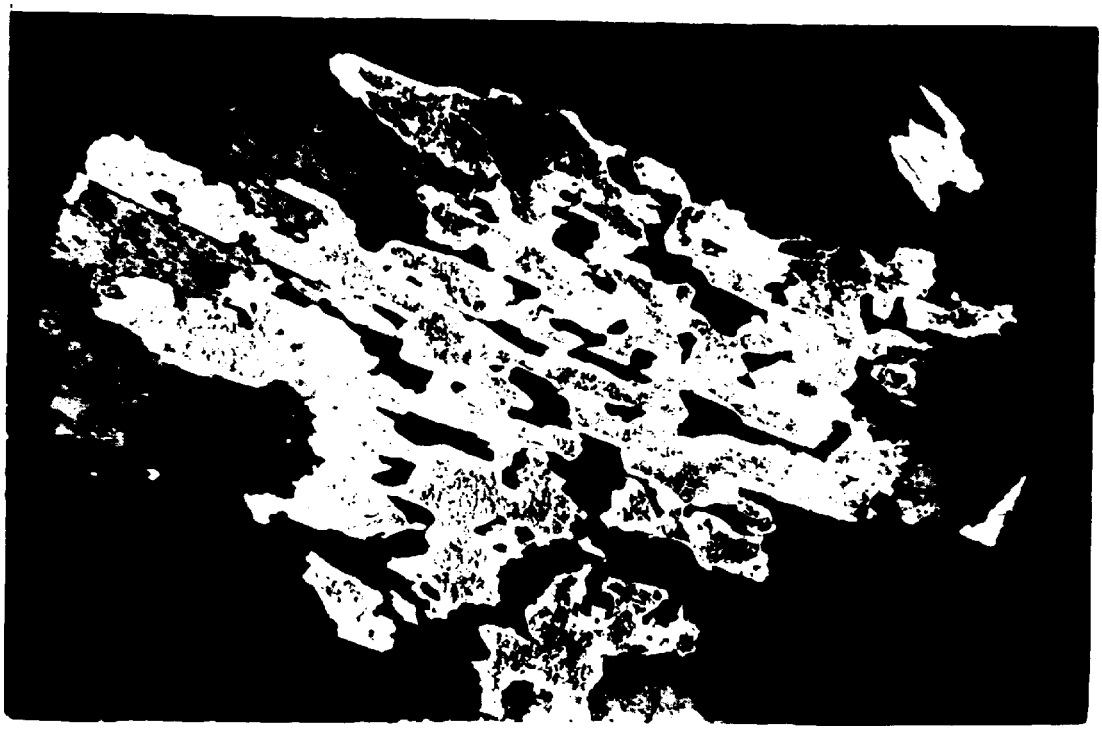
Cordierite.--This was observed in one occurrence: a gneissic rock associated with the quartz-biotite-sillimanite schists near the top of Micanite Ridge. It occurs as large poikiloblasts with abundant inclusions of quartz, biotite, muscovite, zircon, magnetite and some sillimanite. These inclusions generally are notably rounded or embayed.

Plate 14.

Figure A: Quartz-muscovite symplectite from schist on west slope of Micanite Ridge. (+) nicols, x 85.

Figure B: Quartz-muscovite symplectite similar to above, but with higher magnification. Micanite Ridge. (+) nicols, x 170.





This cordierite is the uncommon (+) variety with an approximate 2V of 75 degrees. Well developed halos pleochroic from colorless to orange-yellow surround zircon inclusions. Bladed narrow twin lamellae, locally multiple, are common.

Some of the sillimanite is later than the cordierite and replaces it. Some of the cordierite grains are rimmed by sillimanite needles oriented nearly parallel with the grain boundaries. Some of the sillimanite of this rock is the coarsest encountered within the area.

Magnetite.--The content ranges from none to sufficient abundance to be considered one of the major constituents of the rock. It occurs as a dusty byproduct of the alteration of biotite, or as larger subhedral to euhedral grains which may have resulted at least in part from recrystallization of the dusty material. The large grains are most commonly associated with sillimanite but also though not quite so characteristically with biotite. In the vicinity of planes of schistosity magnetite, too, exhibits locally a pronounced elongation parallel with these planes, either as single large grains or as aggregates of smaller grains. As metasomatism becomes more evident, the amount of magnetite typically decreases, and in the hydrothermal muscovite rocks it is generally absent. One rock contains ilmenite altering to leucoxene as abundant grains in or associated with biotite. Leucoxene occurs in one other rock as an alteration product, but the alteration has gone to completion

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and it is not possible to ascertain what the original titanium mineral was.

Others.--Zircon is present in most of the rocks, either as small inclusions surrounded by pleochroic haloes in biotite, or as larger single grains closely associated with magnetite and to a somewhat lesser degree with biotite and sillimanite. The grains are euhedral to sub-rounded, colorless, and in general are fresh.

Apatite is somewhat less abundant than zircon and has a somewhat larger average size with grain diameters as much as 2 millimeters. One thin-section contains it as myriad inclusions exhibiting a typical "insect egg" texture. It occurs commonly as inclusions within or near biotite, and although these are usually rounded, rarely they may be somewhat larger and show euhedral outlines.

Pleonaste is present in a few sections as microscopic to macroscopic grains. Its color in thin section is a faint blue green, its mean index about 1.77. Some of the crystals are poikiloblastic and contain inclusions of quartz, muscovite and biotite.

Epidote, calcite and sphene are present in a few rocks of more calcic composition as secondary minerals. The major occurrence of epidote is in cavities lined by limonite in a very sillimanite-rich rock. Hematite is fairly general as an alteration product of iron-bearing minerals. Chlorite, in addition to the biotite replacement described above, is present as fine-grained alteration material along grain

Quartz-biotite-sillimanite schist - Modes

	1.	2.	3.	4.
Quartz	53.	76.	56.	11.
Biotite	27.	13.	3.	36.
Muscovite	1.	1.		
Sillimanite		9.	39.	36.
Microcline		0.4		5.
Orthoclase				2.
Plagioclase	18.			2.
Magnetite		0.6	2.	8.
Apatite	0.7		0.6	
Zircon		0.2		
	99.7	100.2	100.6	100.

1. Biotite schist from ridge 1/4 mile south of West West pegmatite.
2. Biotite-sillimanite schist from upper Lues Gulch.
3. Sillimanite schist from Creek bottom, west flank of Cover Mountain.
4. Biotite-sillimanite schist from 1/2 mile east of Gold Hill.

Figure 3

boundaries, and even along fractures in quartz and other minerals. Kaolinite occurs to a limited extent as an alteration of the feldspars. Rutile is present in one sillimanite rock that has been extensively altered hydrothermally, but this rock apparently is of magmatic descent.

Almandite is present in only a few rocks. This is unusual if one considers its relative abundance in rocks of this type in other areas.

Origin

It has been generally accepted by investigators in the Colorado pre-Cambrian that the Idaho Springs schists were formed through the metamorphism of argillaceous (pelitic) sediments (Ball, 1908, p. 44, and others). Individual studies are still necessary within new areas to evaluate the relative importance of original composition, regional metamorphism, thermal metamorphism and metasomatism.

A comparison of numerous chemical and recalculated (on an oxide basis) modal analyses of these schists with the composite analysis of 51 Paleozoic shales reported by Clarke (1924, p. 552) shows marked similarities, particularly with regard to the high alumina to alkali ratio (fig. 4). Bastin (1909, p. 472) stated that a value of this ratio greater than one (unity) indicated a sedimentary rather than an igneous origin. Also the excess of MgO over CaO and K_2O over Na_2O satisfies his sedimentary criteria.

Analyses of shales and Colorado schists

	1. Clarke	2. Sniv-ely	3. Wells	4. Bast-in	5. Wells	6. Buck-walter	7. Hunter
SiO_2	60.15	70.09	42.20	64.23	62.04	66.49	71.06
Al_2O_3	16.45	18.51	35.45	16.45	17.43	16.86	13.23
Fe_2O_3	4.04	0.94	1.70	2.40	0.95	2.50	1.17
FeO	2.90	3.36	8.18	4.31	7.12	3.66	3.57
MgO	2.32	1.80	2.80	1.68	2.07	2.93	0.95
CaO	1.41	0.97	0.18	3.11	0.52	0.47	1.48
Na_2O	1.01	0.80	0.62	3.75	0.68	1.59	3.98
K_2O	3.60	2.25	4.32	2.14	4.10	3.82	2.74
H_2O-	0.89	0.82	0.19	0.02	0.12	0.97	0.32
H_2O+	3.82		3.29	0.89	2.97		1.16
TiO_2	0.76	0.46	1.25	0.80	1.16	0.14	0.60
ZrO_2						0.09	0.02
CO_2	1.46		tr.		0.88		
P_2O_5	0.15		0.06	0.10	0.05	tr.	0.16
MnO	tr.		0.09	0.08	0.06		0.13
F					0.17		
BaO	0.04			0.02	0.09		
S				0.03			0.02
SO_3	0.58						
C	0.88						
	100.46	100.00	100.33	100.01	100.41	99.49	100.59

Figure 4

Sources for Analyses of Figure 4

1. Composite analysis of 51 Paleozoic shales. From: Clarke, F. W. The data of geochemistry: U. S. Geol. Survey Bull. 77, p. 552, 1924.
2. Average of oxide analyses of eight Idaho Springs schists calculated from Rosiwal micrometric analyses. From: Snively, N., Genesis of the migmatites and associated pre-Cambrian formations near Bergen Park, Colorado Front Range. Univ. of Mich. Doctoral Dissertation, 1948. Table 1.
3. Biotite-sillimanite schist, 2 1/2 miles southeast of Jamestown. From: Wells, R. C., Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1914-1936; U. S. Geol. Survey Bull. 878, p. 18, 1937. R. E. Stevens, analyst.
4. Quartz-biotite schist, near Penn Mill, just below Blackhawk. From: Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colorado; U. S. Geol. Survey Prof. Paper 94, p. 27, 1917. George Steiger, analyst.
5. Biotite schist, old millsite 0.5 mile southeast of Springdale, Boulder County. From: Wells, R. C., Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1914-1936; U. S. Geol. Survey Bull. 878, p. 23, 1937. Charles Milton, analyst.

6. Average of Oxide analyses of three Idaho Springs schists calculated from Rosiwal micrometric analyses. From: Buckwalter, T. V., Jr., Geology of the Southern Part of the Never Summer Mountains, Colorado. Univ. of Mich. Doctoral Dissertation, 1950, p. 23.
7. River Portal mica schist. 3/4 mile south of Nyswonger Spring Vernal Mesa, Montrose County, Coloredo. Analyst: George Steiger. From: Hunter, J. F., Pre-Cambrian rocks of Gunnison River, Colorado. U. S. Geol. Survey Bull. 777, 1925.

Close approach to parallelism of the schistosity and lithologic variations is general and schistosity characteristically parallels unit contacts. This suggests that the schistosity essentially follows the original bedding. No transecting relationships between the various members of the formation have been reported in the literature or observed by the writer. In the variation of mineralogy, both laterally and vertically, there is a strong suggestion of the original presence of sandy, limy, chloritic and even phosphatic zones within the original pelitic sediments. The usual lenticular character of these bodies and the character of the transitional zones surrounding them renders the evidence of a varied sedimentary source even stronger. Elsewhere in the Front Range relatively pure marbles (Lovering and Goddard, 1950, p. 20)

and quartzites (Lovering and Goddard, 1950, p. 20) have been reported within the formation, interbedded with the schists. Their purity is such that they have been considered as assignable only to sedimentary origin.

The schists of the Guffey region, on the basis of their mineral assemblages, fall within the special high grade sillimanite-almandine sub-facies of the amphibolite facies as defined by Eskola (1939, pp. 351-355). This corresponds to an environment approximately intermediate between Grubenmann's (1904) meso-zone and kata-zone. Since metamorphic mineral assemblages commonly do not reach a state of complete equilibrium, some super-position of facies assemblages would be expected, and actually occurs. The amphibolite facies as described by Eskola includes a wide intensity range, and is interpreted by Turner (1948, p. 76) as being equivalent to the sillimanite, kyanite, staurolite and part of the almandine regional metamorphic zones of the modified Barrow classification plus a corresponding range in contact metamorphism. Thus it may be considered as being an environment of moderately high to high temperature and variable stress embracing the complete range from absent (contact metamorphic environment) to extremely high (regional metamorphic environment) stress.

The general abundance of sillimanite in the schists of this area would be interpreted as indicative of a high temperature formational environment, perhaps associated with the presence of granitic intrusions. This interpretation is

born out by examination of field evidences. Small granitic bodies crop out throughout the area, and commonly the proportion of sillimanite in the rocks becomes greater as the margins of these are approached. These scattered granitic outcrops, the abundant pegmatites and the intensively injected character of much of the country rock suggest that the entire area is very near the margins of a large intrusive body, either laterally or vertically, and that a high temperature environment was general. Some of the sillimanite, particularly that replacing the micas, shows strong orientation parallel with the schistosity, but, in addition, the presence within quartz of larger non-oriented, matted sillimanite needles suggests that with increasing thermal metamorphism directional pressures were dissipated.

The unusually high concentrations of sillimanite in some schists marginal to the intrusives may result as suggested by Goddard (1936, pp. 32-33) from assimilation of schist by the magma and late stage re-injection of alumina-rich liquids. This may be supported by the evidences of low to non-existent directional stress during part of the formational period, and also by evidences of addition and subtraction of other ions during metasomatism.

Almandite garnet is characteristic of this type of occurrence in other areas described. Its almost complete absence here is unusual, and in similar areas has been considered difficult to explain. Turner (1948, p. 85) implies that such absence may exist where ferrous iron is not

sufficiently abundant: "There is also a tendency for almandine and orthoclase to develop at the expense of biotite and muscovite, but the extent to which this occurs is limited by the high ratio FeO/MgO in almandine." In these rocks, however, there is abundant iron in the biotite and as dusty magnetite and euhedral magnetite crystals. Tweto (1947, pp. 26-28) suggests that garnet formed in three ways:

1) From chloritic and sericitic material remaining after the formation of biotite.
2) Rarely from the conversion of biotite to garnet plus orthoclase.
3) From the conversion with increasing intensity of staurolite plus quartz to garnet plus sillimanite, also rarely.

The writer feels that the abundance of biotite in many of the rocks is evidence that there was sufficiently abundant chlorite for garnet formation as well, and as stated above there is also evidence of sufficiently abundant iron.

The greatly diminished quantity of magnesium and iron in the very high grade metamorphics is a striking feature. In some of these rocks only muscovite, quartz and sillimanite remain and no iron or magnesium minerals are evident. Tweto (1947, p. 27) suggested that perhaps the magnesium was removed by the magmatic solutions that permeated the rocks. The writer believes that the iron was quite possibly removed contemporaneously in like fashion, as might well be expected from the similarity of behavior of the magnesium and ferrous

ions.

Progressive metamorphism may have proceeded in normal sequence through the formation of biotite and some recrystallization of the magnetite. However, with the superimposed thermal metamorphism and metasomatism which resulted in the formation of the sillimanite, the active role of solutions prevented the formation of significant quantities of either staurolite or garnet as not so much as a relict of these was observed in any rocks of this type. Another factor might have been the release of directional pressures through shearing associated with the emplacement of the batholith, and the relaxation of stresses occurring nearly concurrently.

The abundant biotite apparently formed in the normal metamorphic sequences as stated above. The olive-green to less common olive-brown color of this indicates dominant ferrous iron and magnesium. The red-brown color indicative of titanium and brownish-black to black tints indicative of abundant ferric iron and titanium (Hall, 1941, p. 32) are not present to any important degree.

No direct evidence of the development of kyanite or staurolite was discovered, but one rock containing large kyanite metacrysts which had been altered extensively to sillimanite was found near Dicks Gulch. This may be an indication that kyanite was at one time more abundant in the area, but that the inversion to sillimanite and destruction of the original form under thermal metamorphism has

essentially removed it.

Some of the muscovite in the rocks was undoubtedly formed early in the metamorphic process, perhaps in the biotite stage. This occurs as small, well-oriented plates, which, though not abundant, are fairly evenly distributed through the rocks. The bulk of the muscovite, however, was formed as one of the latest metamorphic minerals. It oocurs in large plates of random orientation which are commonly skeletal or strongly poikiloblastic. These show a strong tendency to replace all of the pre-existing silicates.

This spectacular muscovite replacement becomes quantitatively more important toward the margins of intrusive bodies (granite, pegmatites), and in some cases has also taken place within these intrusive bodies. This mode of occurrence suggests that solutions with high concentrations of the alkali metals and hydroxyl ions have played an important part in a metasomatic muscovite formation. These solutions may have been derived entirely from the magma, or perhaps in part from removal and re-injection of the alkali metals in the schist. As suggested by Billings (1937, pp. 298-300) the absence of staurolite in metasediments with muscovite replacement of sillimanite suggests that the potash was introduced (magmatically) rather than redistributed from the original sediment. Similar conclusions were reached by Goldschmidt (1921, p. 133) in the Stavanger region, Norway, and Barth (1936, p. 832) in Dutchess County, New York.

A decrease in the proportion of the alkalis and hydroxyl is apparent in the schists with increasing metamorphism, until the retrograde muscovite becomes important. This decrease is reflected in the diminution of both biotite and the feldspars.

The presence of cordierite gneiss on Micanite Ridge associated with the quartz-biotite-sillimanite schists is another indication of the relaxation of directional pressures and high temperatures. Its poikiloblastic character, with inclusions of quartz, biotite, muscovite, sillimanite and magnetite, supports the postulate of late origin. The cordierite is replaced to some extent by the late non-oriented sillimanite, which here includes sillimanite needles that are the coarsest within the area. The pronounced rounding of magnetite grains and biotite grains associated with this cordierite suggests that at least some of the iron and magnesium necessary for its formation was acquired from them.

The general abundance of quartz throughout these rocks suggests that the original rocks were arenaceous, and local abundance of the feldspars may indicate the original presence of arkosic lenses within the shales. The metamorphic quartz and somewhat less prominent feldspars may have developed chiefly through the recrystallization of materials in the original shales, but it is difficult or impossible to estimate the relative importance of this origin as contrasted to origin through addition of material associated with the

general lit-par-lit injection of magmatic fluids.

In summary, the genetic history of the Idaho Springs schists of the Guffey area may be stated as follows:

1) Deposition of pelitic sediments of the basin type. These deposits were locally somewhat calcareous, as well as perhaps arenaceous and arkosic in places.
2) Burial of the sediments to a considerable depth.
3) Regional metamorphism of the sediments.
    a) Formation of chlorite and recrystallization of sericite may have taken place, but no evidence of chlorite formation remains, and this stage may have been largely non-existent.
    b) Development of biotite. The biotite developed during this metamorphic stage is still prominent in most of the rocks.
    c) There is no evidence of formation of staurolite or of significant quantities of garnet with increased metamorphism. Only token evidence of the development of kyanite has been discovered.
4) Initial stages of intrusion of Pikes Peak granite and its affiliates. This may have been in part contemporaneous with and partly responsible for the strong regional deformation. Within this period striking lit-par-lit injection of the metamorphic rocks took place.
5) The formation of sillimanite. This mineral formed

with an increase in temperature and through a period of decreasing directed pressure. Associated with its development was a minor formation of cordierite.

6) Final consolidation of the Pikes Peak batholith. Increase of temperature was associated, and decrease of directed pressure through increased plasticity of the rocks through heating, and to some extent, perhaps, release of stresses through shearing. The intrusion and heating of the rocks developed the prevalent liquids which soaked the adjacent country rocks and were related to the above mentioned formation of sillimanite and cordierite, and the formation of muscovite described below. Fe^{++}, Mg^{++} and the alkali metal ions apparently were being selectively removed at this time and Al^{+++} and Si^{++++} added. Injection of material related to the magma was extensive, and probably operative over a fairly long period. This is evidenced by the quantitative importance and diversified type of injected material: microscopic injections along planes of schistosity of aplitic and pegmatitic material, larger concentrations of injected material, some of which show transecting relationships, and the late large pegmatitic injections. Under the influence of these injections recrystallization of the minerals in the schists may have taken place

as well as metasomatic modifications.

7) Shearing, generally in the planes of schistosity, resulting in moderate cataclasis, granulation of the quartz and feldspars and shredding and deformation of the biotite and early muscovite. Some of the evidences of shearing observed are undoubtedly the result of Laramide orogenic movements when the metamorphics were in a shallower environment.

8) Continued reaction with magmatic liquids resulting in the pronounced development of large, poikiloblastic muscovite crystals and some continued sillimanite formation. Evidence of continued addition of Al^{+++} and new addition of K^{+} and $(OH)^{-}$.

Lime-silicate Rocks

General

Occurrences of lime-silicate rocks intimately associated with schists, hornblende gneisses and biotite gneisses have been described from areas throughout the Front Range. Commonly these grade through transitional zones into closely associated marbles and quartzites, as well as into the other rock types listed above. Although outcrops of these rocks are typically lense-like, in some reported occurrences they maintain lateral continuity for several miles.

Occurrence

These rocks are not so prominent in the Guffey area as in many other areas in the Front Range and, as the units are

almost all too small to be mapped individually, they have been mapped with enclosing units, chiefly hornblende gneiss, but also injection gneiss and schist. The marbles and quartzites associated with them elsewhere are absent in this area.

Small outcrops of lime-silicate rocks are found in large numbers throughout the Guffey area. The thickness of individual bodies rarely exceeds a few tens of feet, and commonly is less than one foot. The rocks are characterized by their content of prominent calcium silicates which contain significant amounts of both magnesium and iron. Metamorphic quartz and calcite are generally present, and many of the rocks effervesce in dilute hydrochloric acid.

The group includes a number of genetically related but mineralogically rather dissimilar rock types, including the quartz-feldspar-diopside gneisses, the giant-grained rocks containing quartz, garnet, amphibole, epidote, scapolite, calcite and scheelite, the cordierite-anthophyllite rocks, and some actinolite-zoisite rocks. All of these are believed to have been derived through thermal metamorphism and metasomatism of limy sediments of variable composition, and in many respects they could well be considered as variant types within the hornblende gneiss unit.

Some of the larger and more interesting bodies are in the following areas:

1) Throughout biotite gneiss and hornblende gneiss in the vicinity of the Betty mine and nearby Copper

King and Copper Queen prospects.

2) Associated with hornblende gneiss along the north bank of Warner Gulch.

3) At the West Tungsten prospect, in hornblende gneiss and biotite gneiss.

4) Many small lenses associated with hornblende gneiss in the vicinity of the West West pegmatite.

In all occurrences lime-silicate rocks exhibit conformable relationships with the enclosing rocks, although commonly their poorly foliated character may render this relationship obscure.

Petrology

The grain-size of these rocks is extremely variable. Some are quite fine-grained, particularly the varieties transitional to schists and gneisses, such as the quartz-feldspar-diopside gneisses. Others are notably coarse-grained with large metacrysts of epidote, garnet, actinolite, hornblende and tremolite, less commonly anthophyllite, cordierite, pleonaste and rarely scheelite. Within vuggy pockets, individual epidote crystals as much as 8 centimeters long are found.

Banding of the rocks is common, but it is much less prominent than in the associated schists and gneisses. In some coarse-grained bodies only the slightest suggestion of banding remains. In many places thin ribbons of coarsely crystalline material are parallel with the foliation within

dominantly fine-grained lime-silicate rocks. The coarsest rocks are the quartz-garnet-epidote rocks, the cordierite-anthophyllite rocks and the zoisite (thulite)-actinolite rocks. Unusual textures have developed: large rosettes of anthophyllite in a matrix of large poikiloblastic cordierite crystals and small grains of quartz, sillimanite and biotite (pl. 15, fig. B); coarse thulite-actinolite rocks, with long fibers of actinolite in a matrix of thulite, sphene, apatite, cordierite and other minerals.

The fine-grained rocks are mostly greenish-gray or gray. The coarse rocks exhibit the colors of the dominant minerals in patchy fashion, browns, grays, greens, reds and yellows.

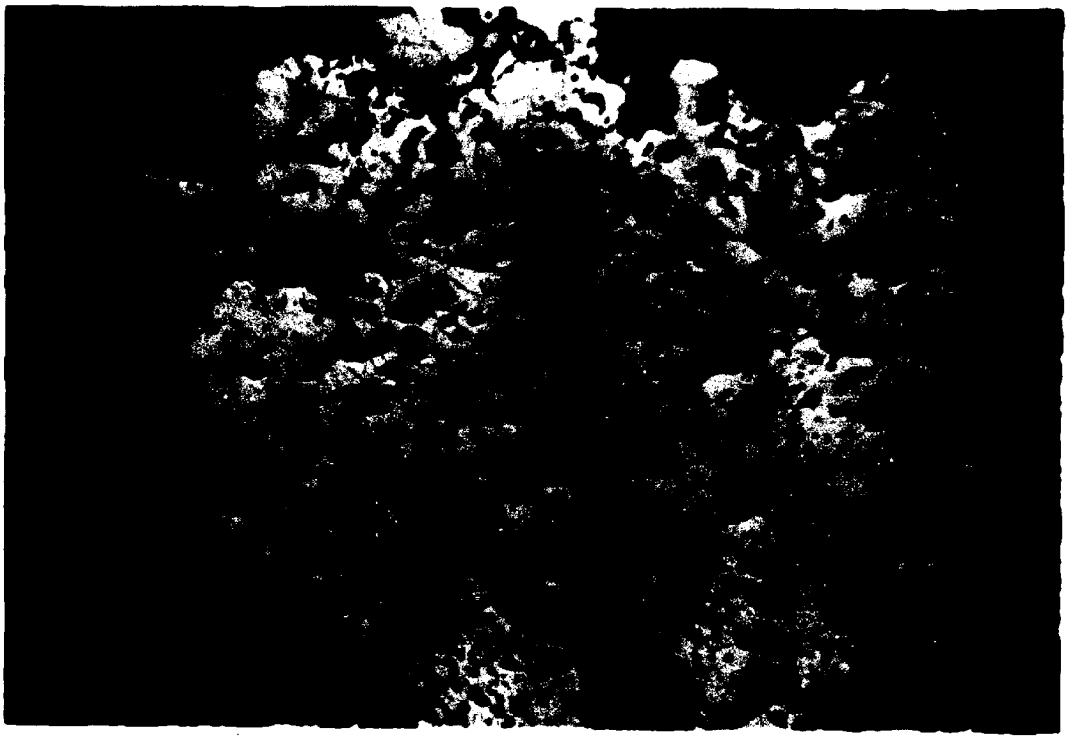
In the vuggy quartz-garnet-epidote rocks, the grain size generally is too large to permit the effective use of thin sections. In these, large crystals of epidote, clinozoisite, garnet, diopside, hornblende, scheelite and the accessories appear as metacrysts, whereas quartz, plagioclase (albite or albite-oligoclase), microcline and orthoclase, biotite, scapolite and calcite or magnesite occur as interstitial minerals. Alteration is general, with the formation of more clinozoisite, talc, sericite, chlorite, hematite, calcite, magnesite and uralitic amphibole. These rocks grade into the quartz-plagioclase-diopside gneisses.

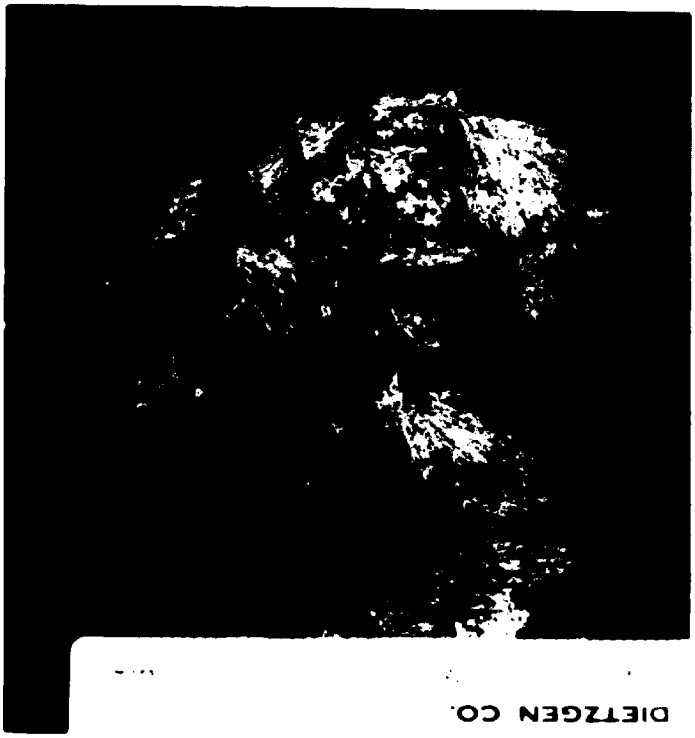
Epidote.--This occurs in many of the rock types as large poikiloblastic crystals containing rounded inclusions of quartz, feldspars, pyroxenes and amphiboles and also as

Plate 15.

Figure A: Poikiloblastic cordierite crystal with quartz, feldspar, biotite, anthophyllite and magnetite as rounded inclusions. From cordierite-anthophyllite rock on east flank of Thirty-one Mile Mountain. (+) nicols, x 32.

Figure B: Cordierite-anthophyllite rock showing anthophyllite rosettes in cordierite-quartz-biotite matrix. Near Copper Queen Mine.




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scattered aggregates of small grains or as alteration veins replacing pyroxene and the feldspars. It exhibits typical anomalous interference colors in suitably oriented sections, is generally darker than and shows a higher relief than clinozoisite, and it may be slightly pleochroic from colorless to yellowish green.

Clinozoisite.--This is very abundant, and occurs with epidote or alone. It is colorless and has a lower relief than epidote, but also typically shows anomalous interference colors. It is typically poikiloblastic, containing rounded inclusions of quartz, pyroxenes, amphiboles, feldspars, and sericite aggregates that represent altered feldspars. Some clinozoisite grains or aggregates are rimmed by small rounded grains of epidote. In a few occurrences large metacrysts of clinozoisite form the bulk of the rock. These large grains typically show extensive (100) polysynthetic twinning. Fine veinlets of zoisite and epidote cut these grains, and replacement by sericite is extensive. Some of the epidote and clinozoisite is manganiferous as evidenced by the strong pink color in hand specimen and by a colorless to pale pink pleochroism in thin section.

Cordierite.--A prominent mineral in some rocks, cordierite is locally the dominant matrix mineral. Both optically positive and optically negative cordierite were identified. The negative varieties exhibit a 2V from 75° to 90°, whereas the positive varieties have 2V = 83°-90°. Large

grains having an extremely poikiloblastic character are typical of the cordierite, with quartz, biotite, magnetite, apatite and anthophyllite being common as rounded inclusions (pl. 15, fig. A). In one specimen host cordierite exhibits a graphic texture with guest anthophyllite. The anthophyllite appears to be replacing the cordierite in sub-oriented fashion. A number of cordierite grains show well developed and typical (110) polysynthetic twinning of the peculiar bladed variety (pl. 16, fig. A). In some grains pleochroic haloes from colorless to faint lemon-yellow occur around zircon inclusions (pl 16, fig. B).

Although some of the cordierite is relatively fresh, most of it is partly altered to pinite, and in some cases the alteration has gone nearly to completion. This alteration has proceeded both along grain margins and along the basal (001) parting, with extensive formation of chlorite and sericite. In one specimen biotite has replaced cordierite along the (001) parting, and in several places anthophyllite apparently is replacing cordierite.

Amphiboles.--Anthophyllite, like cordierite, is restricted in its occurrence, being found only in one locality outside of the small area that includes the Copper King and Copper Queen prospects and the Betty mine. All of the anthophyllite examined is optically positive and 2V = 80-85°. It is pleochroic from colorless to light brown or grayish-brown. Typically it occurs as large bladed to fibrous crystals (pl. 17, fig. B) which have been formed in a matrix

Plate 16.

Figure A: Bladed polysynthetic cordierite twinning. Cordierite-anthophyllite rock from near Copper Queen Mine. (+) nicols, x 85.

Figure B: Pleochroic haloes surrounding zircon inclusions in cordierite. Cordierite gneiss from near crest of Micanite Ridge. (-) nicols, x 85.





Plate 17.

Figure A: Pleonaste with talc reaction rim in cordierite-anthophyllite rock from Copper King Mine. (+) nicols, x 85.

Figure B: Bladed anthophyllite in cordierite-anthophyllite rock from east flank of Thirty-one Mile Mountain. Associated biotite and magnetite. (-) nicols, x 32.





of cordierite, quartz, plagioclase and alteration minerals. Replacement veinlets of chlorite and biotite may transect anthophyllite crystals, and hematite may appear along cleavages.

In addition to anthophyllite, tremolite-actinolite and hornblende are present in some of the rocks; however, only one amphibole variety was observed in any single rock specimen. At the Copper King prospect an actinolite-clinozoisite-sphene-magnetite rock is prominent. This apparently is a thoroughly hydrothermally altered rock and shows some copper mineralization. The actinolite occurs as large unoriented fibers. Elsewhere actinolite or actinolitic-hornblende occurs as a retrograde replacement of diopside. The hornblende is similar to that occurring in the hornblende gneisses and is found in rocks transitional to these.

The only pyroxene encountered is diopside, which may contain important amounts of Fe and Al. This occurs in transitional zones between lime-silicate lenses and hornblende gneisses and biotite gneisses and to a minor extent in the giant-grained lime-silicate rocks. The typical moderately large metacrysts are extensively altered to fibrous amphibole and to clinozoisite and sericite.

Feldspars.--These are very subordinate in all of these rocks. The plagioclase ranges in composition from calcic andesine to albite (Ab_{52}-Ab_{92}). The cordierite-anthophyllite rocks contain the most calcic varieties and there is a decrease in quantity of feldspar with more metasomatism.

much of it is strongly sericitized and saussuritized. Some of it forms myrmekitic intergrowths with quartz. Very minor microcline and orthoclase may be present, both of which are commonly perthitic. In some places these are apparently considerably altered clastic relicts, but in others are fresh and probably magmatically introduced.

Quartz.--This is abundant in many of these rocks, although some quartz-free varieties are present. In the banded rocks it may show elongation and interlocking boundaries, but in the poorly foliated rocks these characteristics are absent. Undulatory extinction is general. Rounded inclusions of feldspars, sericite aggregates, and replacement clinozoisite are common. Rounded quartz inclusions occur in most of the associated minerals; thus, some of the quartz is apparently original clastic material, and some introduced later.

Micas.--These are common in the lime-silicate rocks. Biotite generally occurs with garnet, cordierite and anthophyllite. Locally it forms sub-oriented rims around garnet metacrysts and also has replaced these along small veinlets. It also has replaced anthophyllite. If the rocks are well foliated, the biotite is well oriented along the foliation planes. Generally it is in small flakes. Dark green, olive green, and reddish brown varieties are present. Much of it has altered to chlorite and dusty magnetite, and locally hematite is present along cleavages. Pleochroic haloes are

common. Muscovite is much less common, but a few large hydrothermal muscovite porphyroblasts were observed. Sericite is prominent as a replacement mineral.

Spinel.--Pleonaste is abundant in the actinolite, anthophyllite, and clinozoisite rocks of the Betty mine area. It is faint green in thin section and commonly poikiloblastic. Replacement is general with strong embayment by fine-grained talc and clinozoisite aggregates (pl. 17, fig. A). In a few localities the spinel is so abundant that it imparts a greenish color to the entire enclosing rock. A few octahedra as large as 2 centimeters on edge were observed.

Garnet.--Grossularite is particularly prominent in the giant-grained lime-silicate rocks associated with very coarse epidote, quartz, scapolite and calcite, but also some occurs in limy lenses within hornblende gneiss and biotite gneiss. In the banded rocks it shows a marked poikiloblastic character, and biotite and quartz grains are concentrated around the garnet crystals. Some of the biotite shows orientation of the long grain dimensions near parallel with garnet grain boundaries. Replacement by biotite, chlorite and epidote is general.

The garnet index is n = 1.792-1.819 $\pm$ 0.002, and 1.80 is used as an average. Five specific gravity determinations averaged 3.71. As microscopic examination showed moderately abundant inclusions of quartz, the specific gravity was arbitrarily corrected to 3.75. Using these values and the

triangular diagram designed by Kennedy (1947, p. 570) for members of the garnet series to be expected in this rock type, the garnet was computed to be of the composition 54% grossularite, 33% andradite and 13% almandite. Therefore it seems appropriate to call the garnet grossularite.

There is some doubt cast on this composition estimation by an inspection of the records of Ford (1915) and Fleischer (1937). Neither reports any high-calcium garnets (grossularite, andradite) in the index range given above, although they do not state that such an occurrence is not to be found in nature. All of the analyses they list show garnets in the 1.79-1.82 index range to be dominantly almandite or spessartite. For these, however, the calculated specific gravity would be much higher than the observed specific gravity reported above.

Others.--Scapolite is present only in the vuggy, giant-grained lime-silicate rocks. It occurs as large anhedral grains and granular aggregates. As $W = 1.586 \pm 0.002$, it is in the calcic portion of the Na - Ca series according to the diagram of Winchell (1924, p. 108), and following the usage of Berman (1937, pp. 370-371) would be referred to as Me 65.

Non-fibrolitic sillimanite occurs in some of the cordierite-anthophyllite rocks. It has replaced quartz, feldspar and cordierite.

The most abundant accessory is magnetite which occurs as euhedral to subhedral grains and also as laths and inclusions with hornblende. Sphene is extremely abundant in

some of the actinolitic rocks, perhaps in part as a product of the alteration of the actinolite, occurring with dusty magnetite. Generally, however, sphene is uncommon. Apatite is common, both as small scattered grains and as large euhedral to subhedral grains that are characteristically associated with clinozoisite. Pyrite, chalcopyrite and secondary malachite and chrysocolla are present in the actinolite and anthophyllite rocks of the Betty mine and of the Copper King and Copper Queen deposits.

Chlorite, mainly pennine, is prominent as a retrograde metamorphic mineral replacing biotite, cordierite, garnet and anthophyllite. Concentrations have formed as accordion-shaped groups and as irregular and cross-fiber veinlets. Some of the chlorite is faintly pleochroic in shades of light green. Talc, sericite, kaolinite, magnesite, calcite and hematite are also abundant alteration minerals.

Origin

For most of these rocks an origin through the metamorphism of impure dolomites or magnesian limestones is widely accepted. The impurities may have consisted of various admixtures of siliceous, argillaceous and chloritic material. The original carbonate-bearing sediments were probably present as thin beds and lenses transitional into adjacent rock types. During the folding of the entire section, their relative incompetence undoubtedly intensified the lens-like character. The carbonate rocks would tend to develop

plasticity and migrate toward zones of minimum pressure, such as fold hinges.

In the giant-grained varieties there is extensive evidence of thermal metamorphism and metasomatism. The coarse-grained character undoubtedly resulted from recrystallization (with some chemical additions) through thermal metamorphism. As stated by Harker (1939) the presence of scapolite cannot be considered, as some believe, an exclusive evidence of action by basic magma. This is particularly true in this case as the scapolite is relatively carbonate-rich, not the chlorine-rich variety. The presence of scheelite (zoned within single crystals with powellite) suggests the hydrothermal addition of tungsten and molybdenum. The general enrichment of magnesium and iron indicates either magmatic addition, or selective removal and reprecipitation of these ions by circulating solutions within the country rock.

The mixed rocks containing tremolite-actinolite, epidote-group minerals, spinel, sphene, plagioclase, and some quartz, cordierite, diopside, anthophyllite and calcite are typical of metamorphosed limy sediments. No forsterite was observed in these rocks, perhaps since the composition was unfavorable as a result of excess iron, silicon and aluminum. Some of the assemblages observed can only have developed in a non-equilibrium environment, for example quartz-spinel associations and quartz-calcite-tremolite-diopside associations.

The strong general development of epidote-group minerals may be in part assignable to retrograde metamorphism, but this has not been clearly established. The sphene abundantly associated with tremolite-actinolite (alteration of the actinolite to form sphene and clinozoisite) is more clearly of a retrograde metamorphic origin. Also the alteration of spinel to talc is undoubtedly a retrogressive change.

The diopside-hornblende gneiss shows much less evidence of metasomatic additions, although perhaps minor general additions such as Mg and Fe took place through the action of volatile constituents. The intimate intergradation of these rocks with the hornblende gneisses in a number of localities is an indication that the source rocks for these two types were remarkably similar. The parallel intergradation of the epidote-rich lime silicate rocks with both of the above named types again suggests a similarity of types of source material although in this case metasomatism may have been more important. Retrograde metamorphism is indicated in these rocks by uralitization of the pyroxene, saussuritization of plagioclases and perhaps additional development of the prominent epidote-group minerals.

Tweto (1947, p. 74) summarizes the origin of these rocks in this fashion: "The more impure dolomite formed hornblende gneiss; and with decreasing content of silica and clays in the dolomitic rocks, diopsidic hornblende gneiss, lime-silicate rock, and impure marble formed." In the

Guffey region, as stated above, no marbles are found, and the more calcic types of lime-silicate rocks are also absent. Igneous additions (hydrothermal, contact) are perhaps more important than elsewhere as a result of the proximity throughout the area of the batholith margins, so generally contact metamorphism is prominent. In some rocks strongly weathered, apparently original, clastic grains of feldspar and quartz are present in the same specimen with fresh magmatically introduced grains of the same minerals.

The inclusion of the cordierite-anthophyllite rocks within this classification is open to considerable question. Although these rocks are rare throughout the world, a number of occurrences have been described in detail; however, no general agreement has been reached on the mode of formation, or even on the types of source materials involved. Most investigators agree that Mg-Fe metasomatism was involved. Since in the Guffey region the cordierite-anthophyllite rocks are characteristically closely associated with a lime-silicate environment, the writer feels that inclusion here is justified.

Eskola (1914, 1915, 1920, 1932b and 1950) concluded (1914, p. 252) that these rocks at Orijärvi, Finland were the product of Fe-Mg metasomatism of supercrustal leptites (meta-acid volcanics) by pneumatolytic introductions from granitic magma. He described parallel conversions of closely associated limestones to skarns, and amphibolites to cummingtonite amphibolites. Geijer (1916) reached essentially

the same conclusion from a study of similar rocks in central Sweden. Tilley and Flett (1930, p. 37), Brögger (1934) and Harker (1939, pp. 132-135) all have expressed doubt that residual granitic liquids could be an adequate source. Early removal of magnesium in magma crystallization is axiomatic, and the residual magma is thought to be Mg poor. However, Eskola (1932b, p. 74) countered this by stating that although perhaps only small quantities of magnesium were present in the solutions, extremely long soaking by these was involved, and the magnesium was selectively removed through the formation of the poorly soluble magnesium metasilicate. Eskola (1932a, pp. 455-481) thought it also possible that the rocks might have been formed in connection with granitization, representing a solid residue after differential refusion (partial anatexis, Eskola, 1933, pp. 12-25) and a squeezing out of the portion of the lowest melting point from different kinds of rocks.

Tilley and Flett (1930, pp. 24-41) thought that similar rocks at Cornwall were derived from weathered doleritic rocks. On closer examination Tilley (1935, p. 197), however, concluded that the composition of the above source rock was not suitable, and stated that no known weathering products of any rock type are of proper composition to serve as a direct source. He suggested instead "a widespread removal of lime, accession of silica, alkalis, particularly potash, and an internal magnesia metasomatism as contrasted with an accession of magnesia characterizing the Orijärvi

and Falun regions."

Magnusson (1930) postulates for similar rocks in Sweden, internal migration and interchange of magnesia and other ions between skarn, leptite, and associated rock types, and concurrent withdrawal of alkalis. Brögger (1934) emphasizes that in the Kongsberg-Bamle formation of Norway cordierite-anthophyllite bearing rocks of the "Orijärvi type" occur in connection with amphibolites and supposes that they are a special facies of amphibolites or have been formed from amphibolites through the metasomatic removal of calcium and the alkalis. Bugge (1943, pp. 82-103), also from work in the Kongsberg-Bamle formation, concluded that these rocks had originated during migmatization through Mg metasomatism of a variety of rock types by material leached from gabbros and amphibolites.

Simonen (1948, pp. 38-44) encountered cordierite-anthophyllite rocks in the Aulanko area of Finland associated with amphibolitic rocks. He concluded that these were formed through Mg metasomatism, as the rocks are characterized by low CaO, Na_2O and K_2O and high FeO and MgO (and SiO_2). He was unable to decide, however, whether the Mg was derived from original primary material in a nearby granodiorite, or whether it was leached from the associated amphibolites.

Wegmann and Kranck (1931, pp. 63-104), Magnusson (1936) and Gavelin (1939) all have concluded that during migmatization Mg is very mobile, causing Mg metasomatism in adjacent

rocks. Wegmann (op. cit.) suggested that at Orijärvi the Mg metasomatism was associated with migmatization in the area. Reynolds (1947, pp. 34-35) elaborated on this, postulating origin of cordierite-anthophyllite rocks at Cornwall through widespread basification and solid diffusion. She stated "Fe and Mg are now known to become displaced from rocks, both igneous and sedimentary, undergoing granitization, and to become fixed in a frontal zone in advance of the main theatre of granitization; granite magma is not their source."

Tuominen and Mikkola (1950, pp. 87-91) arrived at an entirely different conclusion. These authors examined the Orijärvi region and suggested that metasomatism was <u>not</u> the generating process for cordierite-anthophyllite rocks. They believe that the gliding of thick competent beds over thin clayey beds (as contrasted to Eskola's leptites) during folding resulted in the flowage of the clayey material to fold hinges where it formed "phacolithic" bodies. They conclude that under penetrative movements the rock recrystallized into minerals with platy structures (chlorite and others), and simultaneously excess constituents emigrated resulting in a Fe-Mg enrichment of the residue. During this process they postulate hydrothermal conditions caused by progressive regional metamorphism. The present actual mineral composition they assign to later recrystallization. Eskola (1950, pp. 93-95) in rebuttal concedes that much of the leptite material is sedimentary in origin, but feels it

is best classified as an agglomerate. He also admits the structural localization of the rocks but rejects the "kinematic origin", suggesting instead that the metasomatism was structurally controlled. The close association of tremolite skarn shows, he believes, that metasomatism was the dominant genetic process, with Mg, Fe and Si introduced and CO_2 and part of the Ca removed.

The association of ores of Cu and other metals with these rocks is common. Tuominen and Mikkola (1950, p. 90) believe, at least with regard to Orijärvi that these represent concentration from the surrounding sedimentary rocks. Eskola (1950, pp. 101-102) believes that these ores also are valid evidence of magmatic affiliations.

The writer believes, as stated by Harker (1939, pp. 132-135) that redistribution of Fe and Mg through the agency of heated waters from magma with concurrent abstraction of Ca was effective in the formation of these rocks. He also believes, as stated by Tilley (1937, pp. 300-309) and Bugge (1943, p. 92), that there is evidence that cordierite-anthophyllite rocks are the final products of the magnesium (and iron) metasomatism of vastly different rock types.

In the Guffey area the writer has cited evidence of the removal of Mg and Fe from both schists and hornblende gneisses during intensive thermal metamorphism and perhaps to some extent during lit-par-lit injection, both of which are associated with migmatization. This would furnish more than an adequate supply of these ions to fill the require-

ments of the very minor bodies of cordierite-anthophyllite rocks. In addition some Mg may have been supplied by dolomite and magnesian limestones. The writer also feels that there is a close affiliation between the source rocks for the cordierite-anthophyllite rocks and original limy sediments. This is certainly true in the Guffey region where typical lime-silicate rocks and amphibolites are closely adjacent, but also, as revealed by a survey of the literature seems to be the case in similar occurrences elsewhere.

The writer believes that the dominant portion of the actual source rocks contained moderately abundant carbonate minerals. The reactivity of such rocks is well known and they should provide an excellent environment for interaction with metasomatizing solutions with deposition of Mg-Fe silicates and simultaneous removal of Ca and CO_2. The removal of Ca is reported by Simonen (1948, pp. 40-43) as shown by the progressive removal of plagioclase parallel with the stronger development of cordierite and anthophyllite. This identical progression can be observed in the Guffey area. Eskola (1950, p. 101) and Harker (1939, pp. 133-135) also suggest Ca removal. As reported above, Tilley and Bugge believe that various source rocks serve for formation of cordierite-anthophyllite rocks, and the writer believes that the source rocks were impure limy sediments in the Guffey area.

Retrograde metamorphism in these rocks is evidenced by the partial conversion of cordierite to pinite and by some

replacement of anthophyllite by chlorite. Also there is some replacement of both minerals as well as associated minerals by minerals of the epidote group.

Turner (1948, p. 77), following the classification of Eskola, assigns these rocks to the excess silica-potash deficient type of the "cordierite-anthophyllite subfacies" of the amphibolite facies. These, he states, "may be regarded as essentially 'contact' assemblages which not uncommonly include antistress minerals such as cordierite or andalusite, . . . the development which is conditioned by shearing stress of low magnitude."

In summary, the genetic history of the lime-silicate rocks, closely similar in most respects to that of other meta-sedimentary rocks in the area, is:

1) Deposition of argillaceous, chloritic and siliceous carbonate-rich sediments.
2) Burial.
3) Regional metamorphism. A number of lines of development were possible and may have occurred here, depending on the variable chemistry of the source rocks.
    a) Formation of biotite-zoisite, tremolite-actinolite, calc-chlorite-sericite or calc-albite-chlorite schists (plus or minus epidote). Some relicts of these mineral assemblages have persisted into the final metamorphic products.

b) Development of grossularite, green aluminous hornblende, calc-epidote (zoisite)-mica-schist, or hornblende-schist or hornblende-biotite-schist. Here again a number of the minerals have persisted into the present higher metamorphic intensity assemblages.

c) Formation of pyroxene-plagioclase (plus or minus hornblende), diopside-spinel, calc-green hornblende-schist or garnetiferous hornblende-schist. No evidence of presence of forsterite is present, and it is believed that it did not form as the sediments did not contain sufficient carbonate or Mg.

4) Initial stages of intrusion of the Pikes Peak granite, which was perhaps in part contemporaneous with the developments described under 3). Associated with this was lit-par-lit injection, but this was even less prominent here than it was in the hornblende gneisses. Perhaps it is better to say that there is less evidence of it here, since the reactive nature of the injected rocks was such that the fine injection structures seen in the schists and gneisses could not be preserved.

5) Increase in temperature and decrease in directed pressure resulting in little mineralogical change in the regionally metamorphosed rocks. Perhaps additional pyroxene formed at the expense of pre-

existing amphibole, and lime-feldspar at the expense of epidote-group minerals.

6) Crystallization of the Pikes Peak batholith. Maximum temperatures attained and diminution of directed stresses. Extensive metasomatism resulting in formation of scapolite, scheelite and andradite in tactites, additional pyroxene, and cordierite and anthophyllite in sources of lower lime content. Some metallic mineralization also took place at this time.

7) Minor shearing, some granulation.

8) Continued reaction with fluids through periods of declining temperatures. Retrograde metamorphism with uralitization of the pyroxene, pinitization of the cordierite, replacement of the anthophyllite and garnet by chlorite, saussuritization of plagioclase, replacement of spinel by talc and replacement of a number of the minerals by epidote-group minerals.

Hornblende Gneiss

General

Throughout the Front Range mafic rocks with an essential or dominant content of hornblende are common. These are generally of only local occurrence and are characteristically found associated with the Idaho Springs formation and its injected equivalent (injection gneiss or migmatite). Lovering (1935, p. 11) and others have ascribed the bulk of

these to meta-igneous origin and assigned the formational name Swandyke hornblende gneiss to these occurrences, from the type locality at Swandyke, 10 miles east of Breckenridge in Summit County. Tweto (1947, pp. 58-64) has examined similar occurrences and considered them meta-sedimentary, whereas Snively (1948, pp. 51-56) thought them both meta-igneous and meta-sedimentary.

Occurrence

Hornblende gneiss is not as abundant in the Guffey region as in many of the other similar areas of the Front Range. Most of the occurrences are scattered and too small to be mapped at the scale used, for the units have a thickness at most of only a few feet. The largest outcrop found is about one-quarter mile wide by three-quarters of a mile long and is about one mile west of the Meyers Ranch pegmatite. The West West pegmatite has been intruded into this block. Other large outcrop areas occur just north of the Black Mountain road about one-half mile west of Currant Creek, and just to the north of Warner Gulch also about one-half mile west of Currant Creek. All of the major occurrences of hornblende gneiss within the Guffey area are closely associated with large masses of either Boulder Creek granite or biotite gneiss, and commonly are near the gradational contacts of these two types.

The hornblende-rich rocks generally are only poorly resistant to weathering, and good outcrops are not common.

Good exposures are generally only marginal to more resistant rocks, or where significant injection has taken place (pl. 18, fig. A). The hornblende-rich rocks grade both laterally and vertically into surrounding biotite gneiss (pl. 18, fig. B), granitic rocks, schists and lime-silicate rocks. In numerous localities layers or pods of lime-silicate rocks were found within hornblende gneiss with complete transition between the two.

Layers and lenses of the hornblende gneiss are conformable with adjacent schists and gneisses. No evidences of cross-cutting were observed. Injection of granitic material is common in the fine-grained megascopically banded hornblende gneiss varieties, but in the dense, coarse-grained varieties, injection is much less common than in the surrounding rocks. Where injection has taken place it is extremely irregular and generally in the form of cross-cutting pegmatitic veins or glassy quartz veinlets, which, although injected along foliation planes, are localized in small lenses interconnected by thin ribbons (similar to boudinage structure).

Petrology

Typically the hornblende gneiss is considerably darker than the associated schists, being gray or greenish-gray to black in color. The proportion of dark minerals present is extremely variable (fig. 5). In some occurrences the rock consists almost entirely of hornblende. Some of the rocks

Plate 18.

Figure A: Contorted hornblende gneiss injected by many small stringers of pegmatitic material. North bank of Spring Gulch.

Figure B: Outcrop of hornblende gneiss on White Elephant. Some injection by pegmatitic material, and gradational into adjacent biotite gneiss.





Modes of typical hornblende gneisses.

	1.	2.	3.	4.
Hornblende	71	53	59	55
Plagioclase	23(Ab58)	40(Ab51)	21(Ab32)	20(Ab68)
Quartz			11	
Diopside				18
Magnetite	3	1	4	2
Epidote		1	1	1
Sphene	2	3		2
Clinozoisite	1	1		1
Apatite		1	2	1
Calcite			2	

1. Fine-grained, mafic hornblende gneiss lens within biotite gneiss near West West pegmatite.
2. Felsic "salt-and-pepper" hornblende gneiss from northeast flank of Thirty-one Mile Mountain.
3. Medium-grained hornblende gneiss from Colorado State Highway 9, adjacent to Meyers sillimanite prospect.
4. Fine-grained diopsidic hornblende gneiss from near West West pegmatite.

Figure 5.

are strongly foliated, and possess a general parallelism of the amphibole needles. Generally, however, particularly in the coarser-grained varieties, foliation is poor at best, and random orientation of the needles within the plane of foliation gives the texture of a feather amphibolite.

In some types amphibole is present, only as scattered grains. All gradations between these two extremes are present. With variation from absent to extremely abundant amphibole gradation from typical biotite schist (including the biotite-sillimanite schists and others), biotite gneiss or lime-silicate rock to a typical hornblende gneiss takes place.

The grain size of these rocks ranges from very fine (less than 1 mm.) to very coarse (30 mm. or more). Those varieties which contain very high percentages of amphibole are commonly much coarser-grained than those of a more diversified mineralogy, and rarely show any well developed compositional banding. The plagioclase that is present is also coarse-grained and has a distinctly glassy appearance.

Finer-grained varieties are typically more feldspathic and exhibit a greater mineralogical variety. In these, foliation is much more pronounced, and compositional banding is general. The plagioclase in these is usually chalky white in appearance. In some of these which are not strongly banded and which contain approximately half plagioclase, a characteristic "salt-and-pepper" texture has been developed (pl. 19, fig. A). In a number of these fine-grained

varieties diopside as well as hornblende is an essential constituent (pl. 19, fig. B), and there may be an alternation of diopside-rich and hornblende-rich layers. Others of the rocks contain important amounts of biotite, although this is not common.

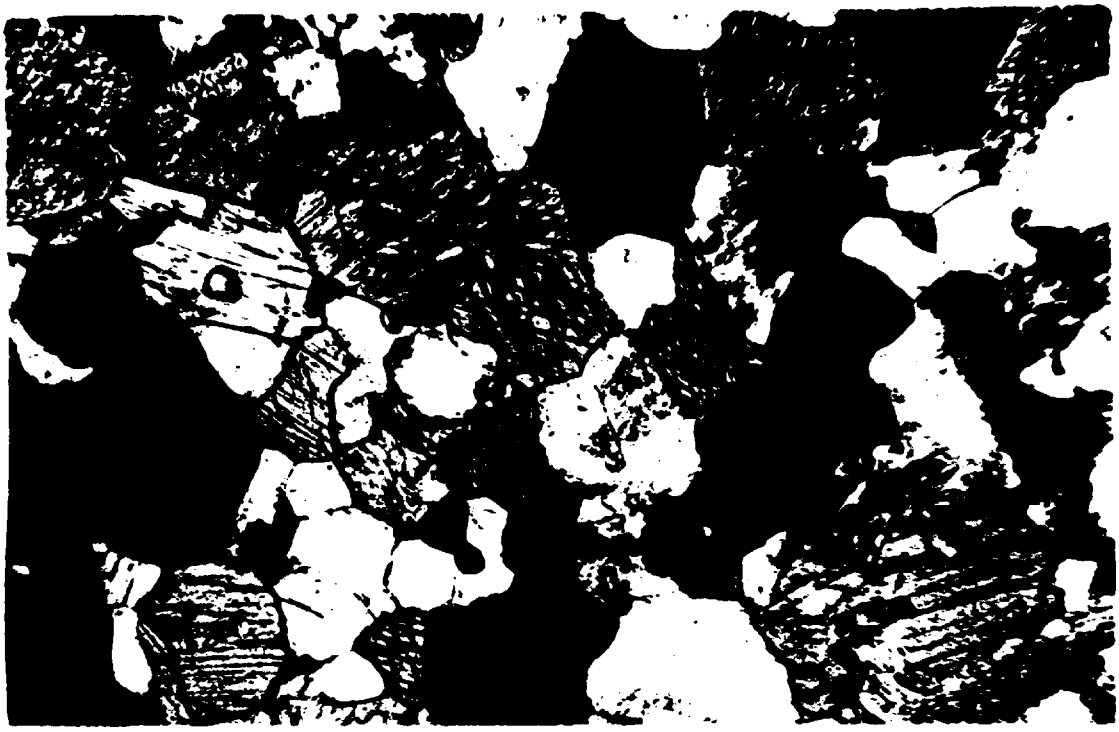
The gneissic texture of these rocks is caused by orientation of the long axes of the individual hornblende crystals in the plane of foliation, segregation into bands of the mineral constituents, and to a minor degree by differentiation of layers by coarseness or fineness of grain and by degree of injection. Although the hornblende laths lie within the plane of foliation, parallel orientation of the long axes within this plane is not general. Other minerals also show flattening in the plane of foliation, particularly the plagioclase. Pyroxene and biotite, where present, and to some extent quartz and the accessories, exhibit a variable degree of orientation, but locally this is marked.

All of the rocks show microscopic banding, but this is generally only slightly apparent in those specimens that contain a very high percentage of amphibole, particularly where this mineral is coarse-grained. These bands are generally layers of hornblende and layers of intermediate to calcic plagioclase, although diopside-rich bands are also common. In the hornblende bands small grains of feldspar are commonly present, while conversely in the plagioclase bands small hornblende crystals also occur. The accessory minerals, sphene, apatite, magnetite, zircon, and minerals

Plate 19.

Figure A: Typical hornblende gneiss in a thin section cut normal to the foliation. Quartz and feldspars are associated with it. North flank of Thirty-one Mile Mountain. (-) nicols, x 43.

Figure B: Uralitic hornblende (dark) replacing diopside (light) in specimen transitional between lime-silicate rock and hornblende gneiss. Near West West pegmatite. (-) nicols, x 85.





of the zoisite group typically occur much more closely associated with the hornblende-rich layers. The hornblende-plagioclase ratio shows a considerable variation, but rocks with less than 25 per cent hornblende are generally referred to a different classification (biotite gneiss, biotite schist, sillimanite schist, etc.).

Microscopically as well as megascopically the transitional character of these rocks to biotite schists and biotite gneisses and to lime-silicate gneisses is apparent. Quartz and biotite become abundant whereas hornblende and plagioclase become less important. Also epidote and in some cases diopside and even andradite commonly become more abundant as the rock approaches a typical lime-silicate gneiss character.

Hornblende.--The hornblende is typically strongly pleochroic according to the following formula:

α = light yellow green, yellow green, light olive green

β = yellow green, dark green, olive green

γ = blue green, dark blue green

Adsorption generally is $\gamma > \beta > \alpha$, but in at least one specimen it is $\beta > \gamma > \alpha$. γ = 1.65 - 1.67.

Except for the coarsest hornblende, poikiloblastic texture is general. It is evident in even large hornblende crystals where replacement of inclusions has not gone to completion. Rounded inclusions of quartz and plagioclase and somewhat less abundant sphene and potash feldspar are

very common, in some cases even giving rise to a sieve structure. In some sections, fine swarms of magnetite and hematite needles and grains lie along cleavage directions, but are very unevenly distributed throughout single crystals.

Development of small hornblende needles along grain boundaries between earlier minerals, and the rounded inclusions described above suggest the late origin of amphibole. In addition, in some cases, hornblende can be observed in oriented replacement of plagioclase along twinning lamellae as well as embaying it along grain margins. Pyroxene in one occurrence is veined and replaced marginally by an aggregate of hornblende needles, although generally the pyroxene is later.

In a number of thin sections replacement of hornblende by pyroxene is apparent. Generally this is of a marginal nature, but locally has progressed so far that only a pseudo-breccia of small hornblende relicts within large pyroxene grains remains. The hornblende is also replaced by chlorite, although this, too, is far from general. This change is accompanied by a gradual loss of color, pleochroism and birefringence, although some color and traces of the cleavage remain until the replacement has gone essentially to completion. There is suggestion of replacement of hornblende by clinozoisite, but this relationship cannot be verified.

Feldspar.--The abundant plagioclase is variable in composition, but in all but two of the thin sections it is

within the andesine range. Ab 32 and Ab 68 are the extremes, with the average Ab 58. Much of it is extensively sericitized and kaolinized, some so completely that it is only identifiable as having been plagioclase by form and associations. Saussuritization is also prominent, with extensive development of zoisite and lesser development of epidote, albite and sericite. Microcline is present in some of the rocks, becoming more abundant with quartz.

Diopside.--Pyroxene is not so common nor abundant in these rocks as it is reported to be in similar rocks from other areas throughout the Front Range. It becomes more abundant in rocks transitional to lime-silicate gneisses. The only pyroxene identified is diopside containing significant amounts of the hedenbergite molecule as shown by indices, γ = ca. 1.73, and suggested by the faint green color (which may, however, be caused by Cr). This pyroxene is markedly poikiloblastic, with many small rounded or ragged inclusions of plagioclase, sphene and hornblende, or many very large polymineralic aggregate inclusions. Some of the pyroxene contains oriented rod-like inclusions in a schiller structure, and some of it has developed (001) parting. The diopside commonly replaces hornblende, but in many cases the reverse is true. Some of the diopside which has replaced hornblende has, itself, very thin marginal replacement by actinolite fibers which are oriented with their long axes normal to the grain boundaries. Uralitization of the pyroxene has occurred in a number of rocks, and in several

has proceeded essentially to completion. Commonly there has been extensive development of clinozoisite and epidote in addition to uralitic fibrous amphibole.

Biotite.--This is found only in rocks that are transitional to biotite schists and gneisses. Generally it is in medium sized grains showing only fair orientation, but in one occurrence it is forming in moderately large areas as an alteration of pyroxene. Very minor muscovite occurs in one section.

Sphene.--Moderately abundant sphene occurs in these rocks. Typically it is associated with the dark minerals as aggregates of small rounded grains, and also as much larger diamond-shaped subhedra. Many occurrences are unusual in that large magnetite inclusions are present in the cores of sphene grains. Apatite, epidote and to a lesser degree zircon are also common, closely associated with the more mafic layers. Generally these are moderately coarse-grained and subhedral to euhedral, although they, too, may occur as aggregates of small rounded grains.

Magnetite.--This is very abundant. It occurs as medium sized subhedral to euhedral grains, as dusty alteration material, and as oriented rods in the amphiboles and pyroxenes. It is one of the commonest inclusions in the other minerals and is also typically associated with the mafic layers.

Quartz.--Some quartz is present in most of the rocks, but it becomes more abundant as the rocks become lighter colored. Some of it is very coarse-grained, occurring in feldspathic layers, and some occurs disseminated as rounded inclusions in hornblende. In many places these quartz-rich layers represent injections, but others apparently have developed as a result of segregation. Quartz generally shows undulatory extinction. It is typically metamorphic exhibiting elongate shapes and mortar textures. Some minor calcite occurs, typically as late transecting veins which may have resulted entirely or in part from weathering.

Origin

These rocks have been interpreted as representing metamorphic derivatives of igneous rocks, of sedimentary rocks, and of a combination of the two. Difficulties in deducing origin of rocks of this type are not peculiar to the Front Range, but have been encountered in similar areas throughout the world (Snively, 1948, pp. 52-55).

In the Georgetown quadrangle Ball (1908, pp. 45-46) noted crosscutting relationships between the hornblende gneiss and the enclosing Idaho Springs schists, and concluded that the gneiss therefore represented metamorphosed basic sills, flows, or both. Bastin (1917, pp. 32-33) however, found no evidences of igneous origin and assigned the gneiss to the Idaho Springs formation, interpreting it as a metamorphosed arkose. Lovering (1935, pp. 10-11) concluded

that the gneiss in the Montezuma quadrangle was chiefly meta-igneous, but at the same time reported that the cross-cutting members reported by Ball were not actually hornblende gneiss, but were much later basic associates of the Pikes Peak granite. Tweto (1947, p. 59) decided that the hornblende gneiss in the Vasquez Mountains was entirely metasedimentary on the basis of strong field and petrographic criteria, but Snively (1948, p. 56) concluded that in Bergen Park it gave evidence of both igneous and sedimentary relationships. He reported some cross-cutting types and an occurrence suggesting the metamorphosed equivalent of a pillow structure.

Hornblende gneiss is much less prominent in the Guffey area than in the type locality at Swandyke (6,000 feet thick), and less prominent than in most of the described Front Range occurrences. No evidence was observed here which in any way suggests an origin other than meta-sedimentary.

The features that support a meta-sedimentary origin in this area are:

1) The contacts between the hornblende gneiss and other closely associated Idaho Springs units are parallel with the foliation, and hence the original bedding of the schists.
2) Individual hornblende gneiss units have lens-like shapes suggestive of lateral as well as vertical changes in an original environment of sedimentation. They do not have the lateral continuity or

constant thickness that is to be expected of sills and flows.

3) Hornblende gneiss lenses lie conformably within the schists and lime silicate rocks, and conversely lenses of schists and lime silicate rocks occur conformably within the hornblende gneiss.

4) Gradational contact zones are general and commonly wide, containing rocks transitional in mineralogy between hornblende gneiss and biotite schist, biotite gneiss and lime silicate rocks.

5) The constituental banding in many of the hornblende gneiss members is extremely suggestive of a relict layering of the original sedimentary rocks.

6) No textural or structural evidences of an original igneous source were observed.

7) The wide compositional variability within the unit suggests diversity of sedimentary types. Igneous derivatives would be expected to present a more homogeneous character.

8) The variability in composition and properties of the plagioclase and hornblende, even within the same hand specimen is typical of a sedimentary rather than an igneous origin.

As Tweto (1947, p. 63) has pointed out, it is not difficult to postulate sedimentary sources of reasonably abundant types which would account for the composition of these rocks. These include dolomitic shales and chlorite calcar-

eous or dolomitic shales. Perhaps much of the aluminum was present in clay minerals of the beidellite-nontronite-montmorillonite group and the calcium and magnesium in the dolomite. The iron may have come in part from clay minerals and in part from isomorphously combined iron within the dolomite. Possibly some of the source sediments were glauconitic. Also, of course, there may have been metasomatic modification of the original chemistry of the sediments.

The role of metasomatism here was probably not so important as in the schists, biotite gneisses and lime-silicate rocks. First, the hornblende gneisses are injected to a much lesser degree than the other metamorphic rocks, even where these lie adjacent. Second, the extreme quantitative mineralogical variation of the hornblende gneisses is opposite from the uniformity which extensive metasomatism would tend to produce.

These rocks belong within the amphibolite facies described by Eskola (1915, 1920, 1939, pp. 351-355), which includes the fairly wide range of temperature and pressure conditions for which the assemblage hornblende-plagioclase is stable. Its upper (high temperature) limit is marked by the appearance of diopside or hypersthene in place of hornblende and its lower limit by instability of calcic plagioclase and its breakdown to albite-epidote (or zoisite or clinozoisite).

The mineral assemblages in these rocks correspond to those of similar chemistry found in Eskola's staurolite-

kyanite and sillimanite-almandine sub-facies of the amphibolite facies, where excess potash is present. In these the excess potash prevents the appearance of andalusite, cordierite, almandine and anthophyllite. The plagioclase is rarely more calcic than sodic labradorite. According to Turner (1948), the restrictions imposed upon the lime content of the plagioclase by the prevailing physical conditions allows Na_2O, CaO and Al_2O_3 to act as essentially independent components, thus the maximum number of minerals that can co-exist in equilibrium in the presence of excess water is raised from five to six. Rocks from the Guffey area include the range between the following typical assemblages for these subfacies:

a) Plagioclase-hornblende-biotite-epidote (clinozoisite)-microcline-quartz

b) Plagioclase-hornblende-diopside-epidote (clinozoisite)-microcline-quartz.

The appearance of pyroxene replacing hornblende in the Guffey district indicates an environment of increasing intensity after the hornblende formation. The uralitization of the diopside and saussuritization of the plagioclase show development of subsequent retrograde metamorphism. It is not clear whether the epidote and clinozoisite represent a stable part of the sub-facies assemblages described above, or whether they formed retrogressively in a period of decreasing intensity. The abundance and modes of occurrences of these, however, suggest perhaps both types of formation

were involved.

The absence of garnet and rutile and the abundance of sphene and pyroxene in these rocks indicates that the condition of Eskola's very high intensity almandine-diopside-hornblende sub-facies were not attained.

In summary, the history of the development of the hornblende gneisses, which is remarkably similar to the history of the schists is:

1) Deposition of dolomitic chloritic shales in the same basin as the shales from which the schists were derived.
2) Burial.
3) Regional metamorphism.
    a) Development of hornblende schist, or hornblende-biotite schist (low intensity part of amphibolite facies).
    b) Development of the coarse-textured hornblende schist (high intensity part of amphibolite facies).
4) Initial stages of intrusion of the Pikes Peak granite, which was perhaps in part contemporaneous with the developments described under 3). Associated with this was the lit-par-lit injection, which, however, was not so prominent in the hornblende gneisses as in the schists, probably owing to the better foliation of the latter.
5) Increase in temperature and decrease in directed

pressure resulting in formation of pyroxene at expense of amphibole through thermal metamorphism.

6) Final emplacement of the Pikes Peak batholith. Maximum intensity reached; continued formation of pyroxene, and perhaps some formation of epidote and clinozoisite.

7) Minor shearing resulting in some granulation of constituents.

8) Continued reaction with fluids through a period of declining temperatures, resulting in retrograde metamorphism with formation of saussurite and sericite at the expense of plagioclase, uralitization and replacement by clinozoisite of the pyroxene, and replacement of amphibole by chlorite.

BIOTITE GNEISS (QUARTZ MONZONITE GNEISS)

History and Distribution

Large exposures of gneiss in the Guffey region are lithologically similar to gneisses described in many other areas throughout the Front Range. Investigators have assigned these a variety of names and origins.

Ball (1908, p. 46) named these rocks quartz monzonite gneiss (adamellite) and considered them as igneous rocks, whereas Lovering (1935, p. 11) uses the term, quartz monzonite gneiss, to refer to a hybrid Idaho Springs formation injected by a quartz monzonitic magma. Tweto (1947, p. 32) calls these rocks "paragneiss and migmatite", stating

"(these gneisses) . . include rocks of two different origins, neither of which is entirely igneous. These are (1) quartz-biotite-feldspar paragneiss which was derived from arkose and related sedimentary rocks, and (2) migmatitic gneiss formed by reaction between schist and materials of magmatic origin." Snively (1948, pp. 18-21, 58-72) and Buckwalter (1950, pp. 67-80) use the name, "biotite gneiss". As described by Buckwalter (op. cit. p. 67) it "includes a fairly wide variety of migmatite, paragneiss, and orthogneiss, characterized by conspicuous banding and by biotite as the major mafic mineral." The writer will also use the designation, biotite gneiss, for he believes it desirable to avoid detailed genetic connotations.

Biotite gneiss crops out over a larger part of the Guffey area than any other of the pre-Cambrian formations. The largest single exposure, which is approximately eight square miles, is in the south-central section, and smaller outcrops, some of which are partially assimilated xenoliths in granite (pl. 20, fig. A and B), occur in many other places.

Petrology

The biotite gneiss is notably variable in its character. Most of it is strongly banded (pl. 21, fig. A), particularly where intensive injection has taken place. In the strongly banded rocks quartz and the feldspars are more prominent than in weakly banded varieties (pl. 21, fig. B),

or those in which banding is essentially absent. The banded gneisses grade into the non-banded gneisses, and into schists, lime silicate rocks, hornblende gneisses and intrusive rocks (pl. 22, fig. A). Grain size is also quite variable, ranging from grains distinguishable only with the microscope to some a centimeter or more in diameter (pl. 22, fig. B).

The banded character of these gneisses is chiefly a result of layering of quartz-feldspar bands, generally of coarser grain size and as much as one inch thick, with biotite-rich bands that also contain quartz and feldspars but in smaller proportion and smaller grain size. In the biotite-rich bands muscovite, hornblende, accessories, and rarely pyroxene are also present. Generally these rocks are pinkish to pinkish gray on fresh outcrops.

The non-banded gneisses are of several types. First, those which have been essentially uninjected. These contain dominant quartz, feldspar, particularly plagioclase, and biotite, but the minerals are evenly distributed, and the rocks commonly have a salt-and-pepper appearance. Garnet is prominent in some of these.

The gneisses that have been intensely injected commonly show almost no banding as metasomatism has redistributed the constituents of the mafic minerals. These gneiss resemble the gneissic aplites rather closely. They also are very difficult to distinguish from some types of the Boulder Creek quartz monzonite locally (pl. 22, fig. A). Cordierite

Plate 20.

Figure A: Partially assimilated xenolith of biotite gneiss in Boulder Creek granite. North bank of Thirty-one Mile Creek.

Figure B: Injection, assimilation and crumpling of biotite gneiss. Dicks Gulch.





Plate 21.

Figure A: Intensively injected biotite gneiss showing strong banding. Road cut near Lues Gulch.

Figure B: Weakly banded biotite gneiss on hillside north of Dicks Gulch.



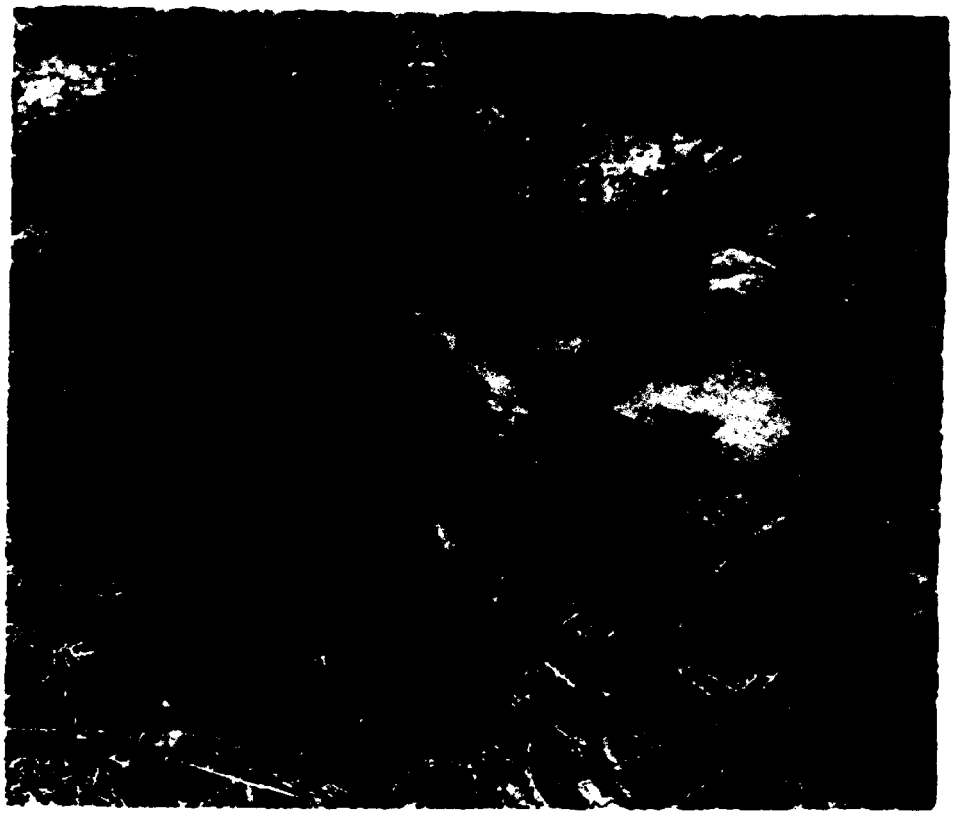


Plate 22.

Figure A: Transitional zone between biotite gneiss and Boulder Creek granite cropping out on east flank of Thirty-one Mile Mountain. Foliation of the gneiss is partially retained.

Figure B: Coarse-grained segregation of biotite in transitional zone between biotite gneiss and Boulder Creek granite. One mile east of Guffey.





gneisses, which are very limited in occurrence, are also non-banded, and show only very poor foliation.

Some of the gneisses display very unusual textures. One shows very leucocratic zones in a fine-grained pink and gray gneiss. At the center of each of these is a magnetite-biotite segregation of crystals much larger than those found elsewhere in the rock (pl. 23, fig. A). These have also probably resulted from the action of late solutions, as shown by the relatively large non-oriented mafic crystals in the center of areas in which normally foliated mafic constituents have been removed. Another shows elongate "pencils" of hornblende needles which lie in parallel orientation within the plane of foliation (pl. 23, fig. B). These are surrounded by bleached zones and apparently were developed late in the period of injection. Solutions may have supplied some of the necessary ions but more probably concentrated them from the adjacent zones in the rock.

In mapping these gneisses the various units have not been distinguished, as they are intimately related in both occurrence and apparently in genesis.

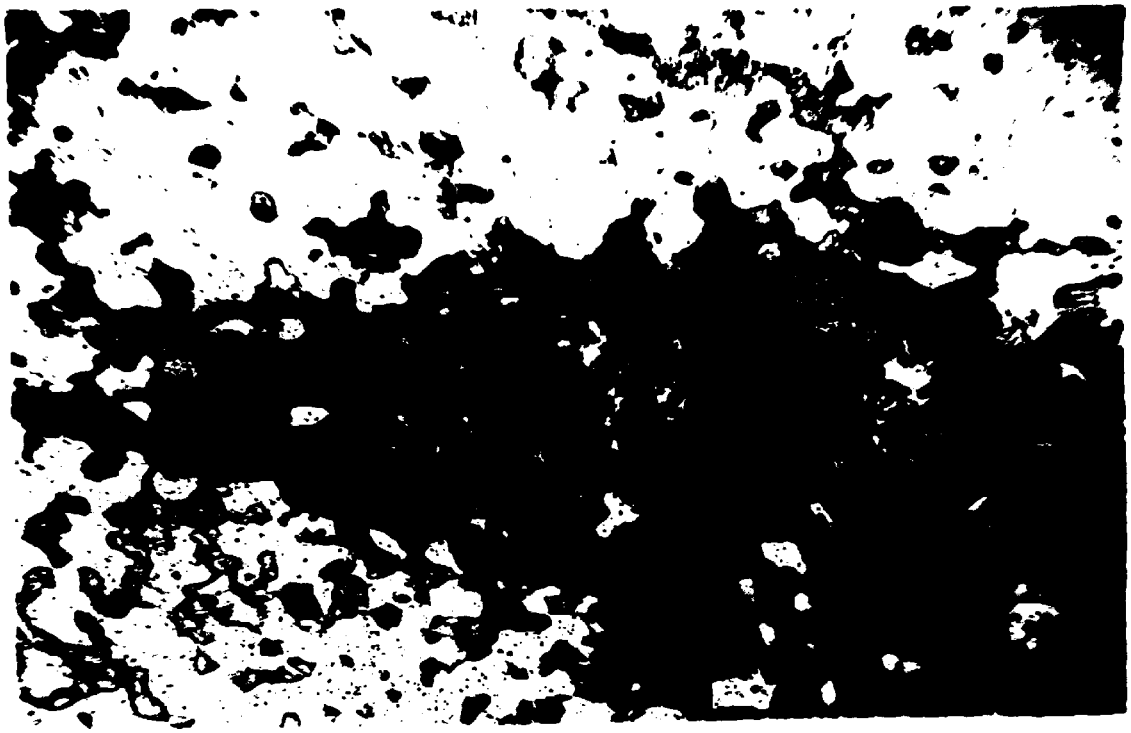
The foliation in the gneisses is primarily a result of the orientation and segregation of biotite grains, although this is not generally so prominent as in the schists. It is also to a lesser degree a product of the flattening of the quartz and feldspars. Where present sillimanite and hornblende needles also generally lie with their long dimensions within foliation planes.

Plate 23.

Figure A: Magnetite porphyroblasts bordered by biotite flakes in bleached halo. Biotite gneiss on south bank of Dicks Gulch. (-) nicols, x 9.

Figure B: Hornblende "pencil" in bleached halo. Biotite gneiss on south bank of Dicks Gulch.
(-) nicols, x 32.





Modes of biotite gneisses

	1.	2.	3.	4.
Quartz	39	46	39	53
Biotite	9	15	28	10
Potash feldspars	44	14	21	8
Plagioclase	7(Ab74)	24(Ab74)	9(Ab65)	16(Ab71)
Garnet				11
Magnetite	1	1	2	1
Zircon			1	
Apatite				1

1. Migmatic biotite gneiss from near Lues Gulch.
2. Paragneiss, apparently from metamorphism of arkose. North end of Chumway Park.
3. Mafic paragneiss from Lues Gulch.
4. Garnetiferous paragneiss from north bank of Dicks Gulch.

Figure 6.

Quartz.--With few exceptions, quartz is the most abundant mineral in the biotite gneisses (see fig. 6). Part of it has come from the original sedimentary rocks, arkoses and shales, and, in some of the rocks, part has been subsequently introduced by injection and metasomatism.

The quartz is typically metamorphic. Characteristically it exhibits undulatory and patchy extinction. Its grain boundaries show mosaic, sutured, interlocking, mortar and granular textures in different specimens and commonly show mutual relationships with hornblende and plagioclase. Much of it is flattened in the plane of foliation, particularly where it is in or adjacent to the more mafic bands (pl. 24, fig. A and B). Some of the quartz is biaxial with 2V as much as 6°.

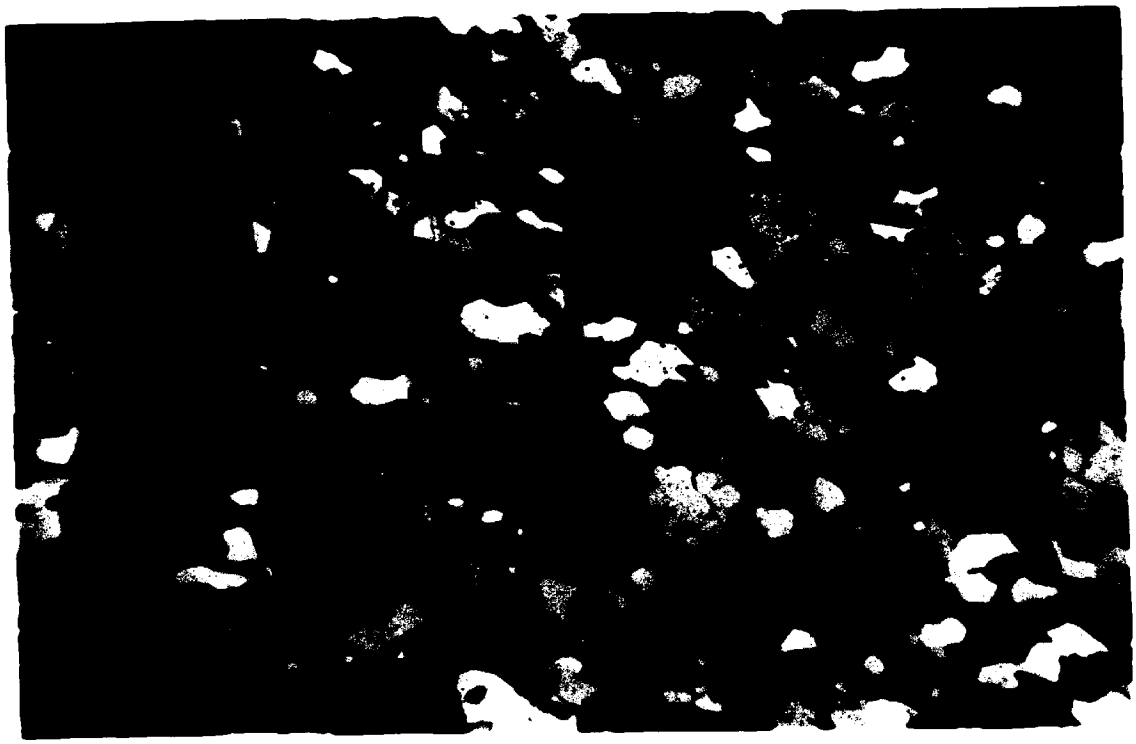
In many specimens the form of the quartz suggests that it originated in small rounded grains or pebbles from an original arkose. Some grains show rounded cores with abundant fine inclusions surrounded by clear borders oriented parallel with the cores which must have been formed either by peripheral freshening by solutions or by oriented overgrowth. Some other grains show non-oriented overgrowth on rounded grains which may indicate a clastic origin. Some of the grains or pebble-like aggregates are rimmed by biotite.

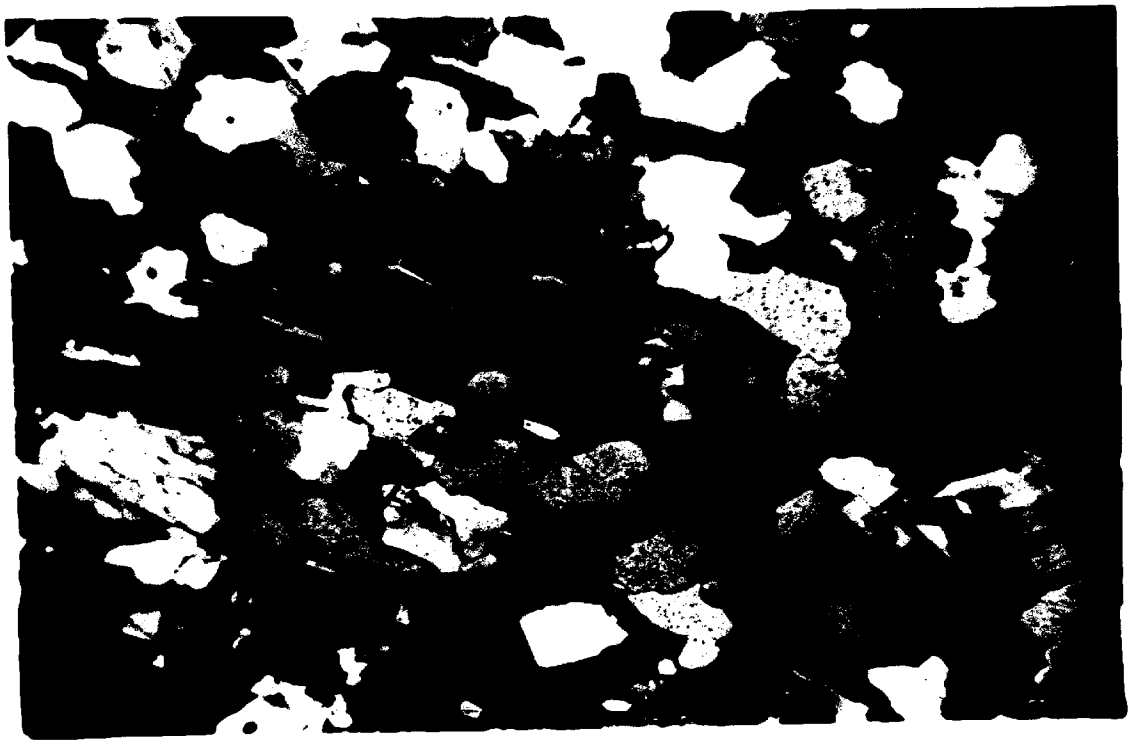
Early quartz appears as inclusions in feldspar, biotite, hornblende and garnet. Although most of these included quartz grains are rounded, some few show subhedral outlines, particularly in garnet.

Plate 24.

Figure A: Biotite gneiss showing flattening of quartz and feldspar in the plane of foliation, and also scattered oriented biotite flakes. South of Dicks Gulch. (+) nicols, x 32.

Figure B: Biotite gneiss similar to that above, but coarser-grained, and showing some interlocking textures. White Elephant. (+) nicols, x 32.





The grain size of the quartz is variable even within a single rock specimen. Typically larger nearly equidimensional grains are concentrated between zones containing flattened quartz and feldspar grains and mafic minerals. Very large quartz grains occur in the cordierite-bearing rocks, and also in rocks in which there has been extensive replacement by late quartz. Commonly large quartz grains are surrounded by fine-grained quartz-microcline-plagioclase aggregates.

Some sericite has replaced quartz, particularly as fine veinlets. Also metasomatic sillimanite and particularly muscovite have replaced quartz, commonly in spectacular symplectitic textures.

Late quartz, associated with injection, has veined and replaced hornblende and biotite, wrapped around and replaced garnet, and replaced the feldspars. These minerals (except garnet) commonly occur as inclusions, many strongly altered to chlorite, sericite and saussurite within quartz.

Feldspars.--Whereas generally quartz is dominant in these rocks, in a few types feldspar is more abundant. This is more likely to be the case where there has been extensive igneous addition, that is, in the more strongly injected rocks. Here too, potash feldspars locally exceed plagioclase in abundance, although generally the reverse is true.

The feldspars also are commonly flattened in the plane of foliation. Perthite is very common, and locally antiperthite, micropegmatite and myrmekite occur. Grain size is

variable, and fine-grained quartz and feldspar are almost universally present, interstitial to larger grains.

Microcline is more common than orthoclase, although both are present in some places. Both show evidence of more than one formational period. Highly altered orthoclase and microcline relicts occur locally selectively replaced or overgrown by fresh non-sericitized orthoclase or microcline (pl. 25, fig. B). This late feldspar, although typically formed optically parallel with the early associated feldspar grains, may also have formed without structural control and be non-oriented. Similar relationships can be observed between potash feldspars and plagioclases, and between plagioclases of different composition. Fresh potash feldspars commonly occur marginal to plagioclase grains, exhibiting both parallel and non-parallel crystallographic relationships with these. Plagioclase occurring as overgrowth on or replacement of earlier plagioclase is invariably more sodic.

The plagioclase is in the oligoclase-andesine range, from Ab 54 to Ab 74, with an average (eight determinations) of Ab 65. Normal zoning is common, with grains becoming more sodic toward grain boundaries. Although most of the plagioclase shows albite twinning, in some rocks this twinning is essentially absent. Some orthoclase shows Carlsbad twinning, and the microcline shows typical gridiron twinning.

Sericitization and clay mineral replacement of both potash and plagioclase feldspars is widespread, although

Plate 25.

Figure A: Corroded garnet metacryst rimmed and replaced by biotite. Biotite gneiss near Betty mine. (-) nicols, x 43.

Figure B: Fresh microcline containing strongly sericitized potash feldspar and plagioclase relicts. Near Dicks Gulch. (+) nicols, x 43.





feldspars introduced late are characteristically fresh. Some of the plagioclase is saussuritized, particularly that in the amphibole- and pyroxene-bearing rocks. In some specimens, poikiloblastic muscovite, formed through coalescence of small sericite replacement flakes, has begun development. This is a characteristic reaction in pre-Cambrian rocks throughout the entire region.

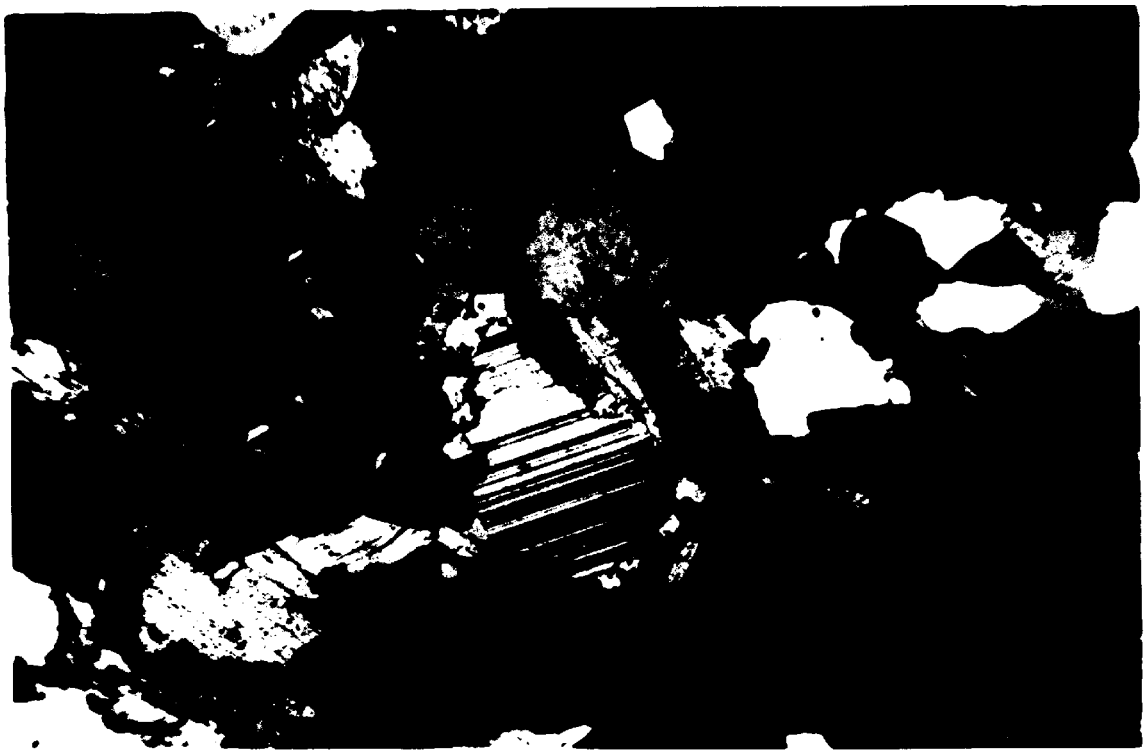
Biotite.--This makes up about 15% of these rocks on the average. The typical pleochroism is in shades of olive green and clove brown, but some specimens show more dominant greenish or reddish-brown tints. In most places the flakes are well oriented in the plane of foliation, with an angular divergence from this of only a few degrees at most. Exceptions are where the biotite occurs rimming or replacing garnet or in spheroidal segregations with magnetite (pl. 25, fig. A). In the strongly banded gneisses the biotite is segregated into layers of abundant, relatively coarse flakes which alternate with layers of the light minerals, containing smaller, less abundant dispersed biotite flakes, whereas in the gneisses showing a salt-and-pepper texture the smaller biotite flakes are more uniformly dispersed. Shredding and crenulation of biotite are widespread.

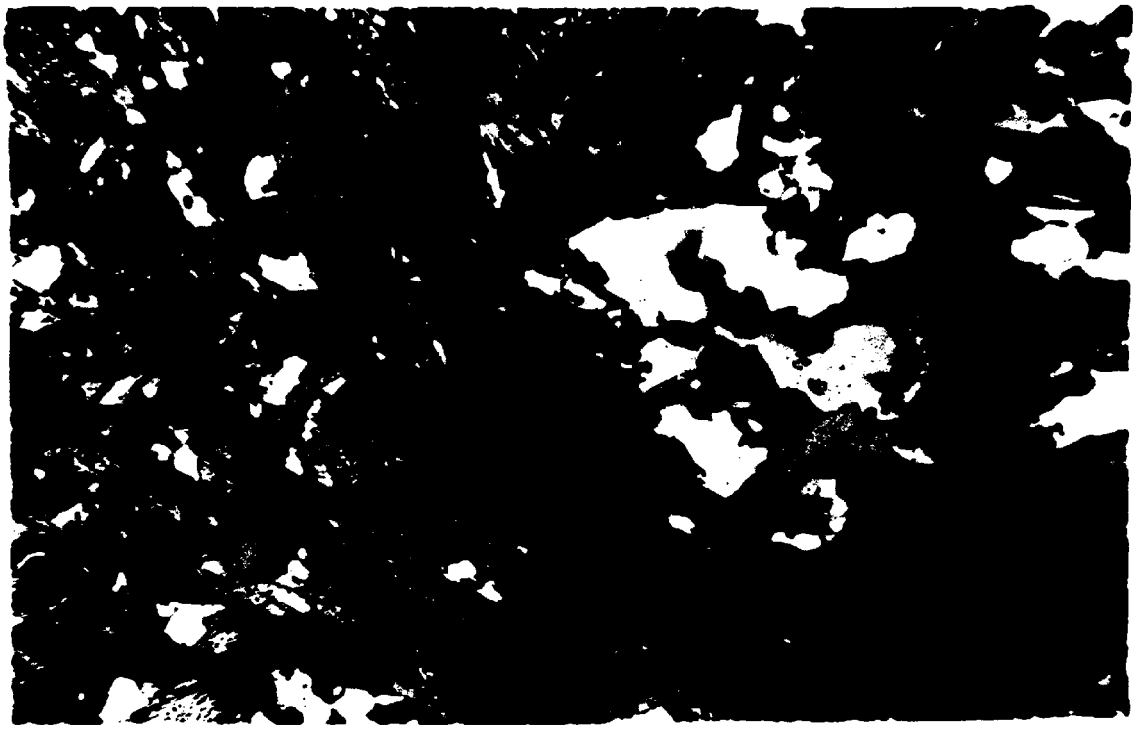
Inclusions of zircon are common and are typically surrounded by pleochroic haloes. These grains are subhedral to rounded, and occur outside biotite only rarely; perhaps where biotite has been replaced. Apatite, quartz and magnetite inclusions are somewhat less abundant.

Plate 26.

Figure A: Biotite development along fractures and grain boundaries, not so well oriented as disseminated flakes. Biotite gneiss east of Current Creek one mile southeast of Meyers Ranch pegmatite.
(+) nicols, x 32.

Figure B: Abundant biotite in mafic biotite gneiss. Also interlocking quartz grain boundaries. One-half mile north of Guffey. (+) nicols, x 32.





In many specimens biotite has replaced quartz, feldspars and garnet along fractures and grain boundaries (pl. 26, fig. A). In one thin section there is a suggestion of poikiloblastic biotite development similar to that of muscovite in its typical engulfment of all associated minerals. Some mafic varieties contain very abundant biotite (pl. 26, fig. B).

Much of the biotite has been partially or completely altered to chlorite and dusty magnetite. Much also has been replaced pseudomorphously by muscovite flakes, or in non-oriented fashion by large muscovite porphyroblasts. These porphyroblasts, however, are far less abundant here than in the schists. Hematite is present locally in muscovite cleavages as a byproduct of the replacement of biotite.

Hornblende.--This generally occurs in these rocks only where they are transitional to hornblende gneisses. The strongly poikiloblastic "pencils" in the rocks found near Dicks Gulch may, however, represent a different formational environment; perhaps a late segregation in which the requisite chemicals were concentrated from the altered groundmass (pl. 23, fig. B). These "pencils" lie within the plane of foliation with their long axes parallel, and are surrounded by conformable bleached "envelopes" with their mafic constituents removed.

Others.--In a hornblende-bearing rock from White Elephant, relicts of light bluish-green pyroxene remain within

uralitic hornblende. The pyroxene is optically positive, with an extinction angle from the vibration direction of the fast ray of -22° and is identified as aegirine-augite. Epidote and clinozoisite occur in these rocks as replacements of pyroxene and amphibole and are typically closely associated with magnetite. Also subhedral to euhedral sphene grains with diamond-shaped cross-sections are abundant. These occur along hornblende cleavages or with chlorite as a replacement of diopside. Oriented lath-like magnetite inclusions occur in some of the hornblende.

Garnet is rare in the schists and gneisses of the Guffey area, but there are a few gneisses which contain abundant almandite. It is markedly poikiloblastic with inclusions of quartz and magnetite. Replacement by biotite, chlorite and hematite has taken place marginally and along fractures as transecting veinlets (pl. 25, fig. A). Sillimanite is present, particularly in rocks transitional to the schists, but is not abundant.

Cordierite (pl. 16, fig. A) is abundant in one type of gneiss from Micanite Ridge, but as it occurs typically in the lime-silicate rocks to which this gneiss is probably transitional, it is discussed under this latter category. Several other types of highly altered rocks are thought to represent cordierite-rocks that have been strongly altered to pinite, but this could not be verified. In the more mafic varieties calcite veinlets are present.

Origin

As has been concluded by prior investigators, cited above, it is apparently necessary to consider a variety of genetic factors in studying the formation of the biotite gneiss. Igneous solutions have played a major role in biotite gneiss formation in the Guffey area as evidenced by the close spatial relationships of the truly intrusive bodies and biotite gneiss bodies. Almost without exception as margins of igneous bodies are approached, adjacent biotite gneisses are more strongly injected, and in most cases formational boundaries here are discretionary, as they are between schist and gneiss bodies.

The freshening of feldspars, decrease in mica content and increase in quartz all suggest modification of the original chemistry and mineral content of the metamorphic rocks by igneous solutions. There appears to have been addition of K, Na and Si and an associated decrease in Ca, Mg, Fe and perhaps Al. The latter (decrease) may be illustrated by the bleached haloes surrounding mafic mineral segregations, indicating incomplete removal. Development of these mafic segregations with conformable bleached haloes suggests the effects of percolating igneous solutions. Pegmatitic stringers are common in the gneisses, and, although generally they are conformable, locally they transect the foliation at large angles.

A source of the solutions which reacted with the sediments is readily available in the adjacent bodies of Boulder

Creek granite. Extensive deuteric mineral formation within these intrusives indicates that the magma was rich in water and suitable as a source for extensive hydrothermal solutions. As suggested by Lovering and Goddard (1950, pp. 23-24) these solutions probably developed as a fore-runner of the intrusion of the Boulder Creek granite (although they ascribe a magmatic rather than hydrothermal character to the resultant gneisses).

The sedimentary heritage of the gneisses is also apparent. The close parallelism of structure in the gneisses and associated schists is much closer than could be expected if the gneiss were of igneous derivation alone. The dominant isoclinal folding is more typical of meta-sediments than of intrusive igneous rocks. Mineralogically the gneisses and schists are very similar, although some important quantitative differences may be observed, as described above. As concluded by Tweto (1947, pp. 42-44), part of the gneisses may have developed from a sedimentary source-rock different from that of the typical schists. The textures suggesting large recrystallized and metamorphosed quartz grains may indicate sandy lenses existed. Possibly the high feldspar content of some varieties of these rocks is the result of an arkosic source rock rather than of additions by hydrothermal solutions. The relatively even-grained (salt-and-pepper) biotite gneiss is particularly suggestive of an absence of hydrothermal additions. Marked segregations are unusual in these even-grained rocks, although a moderately banded

character is general.

The writer believes that throughout the Guffey area the biotite gneiss originated dominantly through extensive metasomatism and injection of the Idaho Springs formation by pegmatitic and hydrothermal solutions associated with the Boulder Creek granite. Field evidence suggests that intrusive bodies are near the surface throughout the area, even where they do not crop out. Lit-par-lit injection is widespread and locally even the poorly reactive hornblende gneiss has been extensively injected. In almost all exposures of biotite gneiss it is not a question of whether injection has played a part but rather a question of how great a part it has played.

GNEISSIC APLITE

History and Distribution

Gneissoid granite in the Georgetown quadrangle as described by Ball (1908, pp. 49-51) is very similar to the rock here designated as gneissic aplite. Bastin and Hill (1917, pp. 30-33) described somewhat similar rocks in Gilpin County and called them granite gneiss, as did Lovering and Goddard (1938, pp. 13-14) in their description of equivalent rocks throughout the Front Range Mineral Belt. Snively (1948, pp. 17-18, 56-58) referred to similar rocks in Bergen Park as gneissic aplite. Lovering and Goddard (1950, p. 25) stated "....rocks mapped as gneissic aplite and granite gneiss are a lithologic unit but not an age group; they are believed to be indistinguishable minor members, similar in relationship,

genetically associated with different major members of the batholithic complex." The writer uses the designation gneissic aplite as it is most descriptive of the rock occurring in the area which he has mapped.

The only major outcrops of this rock type in the Guffey area are a number of generally concordant bodies approximately one mile west of Currant Creek, chiefly between Dicks Creek and Sheep Gulch. These have a uniformly northwesterly strike and on the basis of structural evidences are apparently sills intruded into schists and gneisses. These sills have a maximum width of about 900 feet and a maximum length of slightly less than two miles. Cross-cutting relationships with the earlier metamorphic rocks are found locally, with the gneissic aplite cutting across the foliation at small angles. Such relationships are described elsewhere by each of the investigators cited above. Although typically more felsic than and not so well foliated as the biotite gneiss, some of the gneissic aplite resembles it sufficiently closely to suggest that some gneissic aplite may have been overlooked when associated with biotite gneiss.

Petrography

The gneissic aplite is uniformly fine-grained and very poor in mafic constituents. It is generally very light pink or light gray in color, although near its contacts with adjoining units it may be darker. Commonly it is only poorly foliated at best, with this foliation resulting chiefly from

flattening of quartz and feldspar grains. Near the margins of the bodies where the mafics become somewhat more abundant they also contribute to the foliation.

Quartz is invariably the dominant mineral. Commonly it is flattened, shows undulatory extinction, has strongly interlocking textures and may be somewhat mylonitic. In most specimens the quartz is sagenitic, containing abundant minute needles of rutile. In some grains these exhibit orientation with three sets of parallel needles; in others orientation is not apparent. Bubble and inclusion trains may be present and some cross grain boundaries. Quartz may occur locally as pod-shaped aggregates of grains, and some of these are imperfectly rimmed by biotite. Rounded orthoclase, microcline, sericite (plagioclase) and less commonly biotite inclusions are general in the quartz.

Microcline is the dominant feldspar in all of these rocks that were examined microscopically and is second only to quartz in abundance. Much of it is perthitic. Sericite (forming muscovite) and quartz typically replace it. Orthoclase and plagioclase are both minor. The plagioclase is of remarkably constant composition, averaging Ab 70, and is uniformly strongly sericitized.

Biotite generally is not abundant, but even in the more biotite-rich varieties it occurs as small disseminated grains which are not well oriented. It exhibits pleochroism chiefly in shades of brown, although some is greenish. Pleochroic haloes are not common. Alteration to muscovite

is wide-spread, both oriented and non-oriented, with some by-product hematite and magnetite formation; however, in one specimen chlorite and dusty magnetite have been developed instead. There has been some poikiloblastic muscovite development at the expense of biotite and feldspar, but this is minor.

All specimens contain small euhedral zircon grains. Some of these are colorless and not altered, but most have been partially converted to malacon. There has been very minor sillimanite development in a few specimens.

Origin

Several lines of evidence indicate an unquestionable igneous rather than a sedimentary or dominantly mixed origin for the gneissic aplites. These include:

1) Uniform proportions of the mineral constituents.
2) Limited mineral suite.
3) General sagenitic character of the quartz.
4) Relatively constant plagioclase composition.
5) Abundant euhedral zircon of uniform characteristics.
6) Foliation minor.

Age is a more difficult question. Although criterion 6) above and evidence of intrusive relations indicate it is younger than the metamorphic rocks, the relationship to the granites is not clear. The more shattered character and

slightly better developed foliation indicate the aplite to be older. Gneissic aplite is certainly younger than the zoned pegmatites which intrude it west of Meyers Ranch.

Apparently the gneissic aplite originated in the intrusion of an aplitic magma at some time after the subsidence of the major metamorphism which developed the Idaho Springs formation and the biotite gneiss. In all probability this aplitic magma was genetically related to the Boulder Creek granite intrusive.

BOULDER CREEK GRANITE

History and Distribution

Rocks considered equivalent to the Boulder Creek granite (Boos and Boos, 1934) have been described throughout the Front Range. Primarily through the work of Lovering and Goddard (1950, p. 27) this granite is generally recognized as "forming stocks and small batholiths whose regional distribution is satellitic to the larger batholiths of Pikes Peak granite".

In the Guffey area the Boulder Creek granite outcrops are limited to generally narrow elongate exposures which are roughly concordant with the regional metamorphic structure (pl. 27, fig. A and B). These may be several miles long and as much as a mile wide, although many are small ovoid bodies with long diameters of only a few tens or hundreds of feet. Contacts with the biotite gneiss are commonly discretionary. A slightly more mafic phase of the granite has been desig-

mited granodiorite (symbol pcgd, pl. 1 and 2), as it is sufficiently distinctive in several localities to warrant separate consideration. One of these bodies follows the crest of Micanite Ridge and its extension all the way to Guffey, approximately five miles. It is, however, generally transitional into typical Boulder Creek granite.

Petrology

The typical Boulder Creek granite is pink, but locally it may be light to dark gray or mottled red to pink and gray to black. An apparently chiefly primary foliation is general, and, although ordinarily it is much too poorly developed for its attitude to be deduced, it appears to parallel roughly that of the enclosing metamorphic rocks. This foliation is a result of the segregation of mafic minerals and to a minor extent of the flattening of felsic minerals.

Evidences of assimilation of intruded rocks are common (pl. 28, fig. A), and undoubtedly some of the marginal granitic rock originated in metasomatism of bordering metamorphic rocks. The biotite-rich phase particularly is probably of this origin. This conclusion is supported by the presence locally in this rock of microcline metacrysts as large as three by six centimeters (pl. 28, fig. B).

The more acidic granitic rocks average about 30% quartz, 32% oligoclase (Ab 73), 24% microcline and subordinate orthoclase, 10% biotite, 3% muscovite and 1% accessories. Thus the rock would be designated a quartz monzonite

Plate 27.

Figure A: Outcrop of Boulder Creek granite on ridge north of Warner Gulch.

Figure B: Boulder Creek granite cropping out to north of Spring Gulch. Chumway Park is in the background.





Plate 23.

Figure A: Biotite-enriched xenoliths in Boulder Creek granite on flat to north of Betty mine.

Figure B: Mafic (granodiorite) phase of Boulder Creek granite showing large microcline porphyroblasts. Upper Lues Gulch.





following Lindgren's classification. In the more mafic varieties the averages would be 30% quartz, 35% andesine (Ab 60), 16% potash feldspars (almost exclusively microcline), 16% biotite and 2% accessories. This rock falls within Lindgren's granodiorite range. These averages are based on typical specimens. Actually in many places the two types intergrade.

Generally these granitic rocks are even-grained with a moderate grain size. In the mafic phases particularly, however, they are commonly strongly porphyroblastic and have a knotted appearance megascopically (pl. 28, fig. B). Jointing is widespread with locally as many as four different sets of planes developed.

Quartz.--This is present in all varieties of these granitic rocks and dominant in some. It shows undulatory extinction and strain shadows, and is commonly moderately mylonitized. This has resulted in development of mortar textures. There is evidence for a second generation of late quartz which replaces the feldspars extensively and micas and other minerals to a lesser degree. Quartz replacement of the micas has resulted in the segregation of rejected iron as hematite along grain boundaries.

Feldspars.--Medium-grained plagioclase that is generally abundant to dominant (see above) is commonly strongly altered selectively. This may be shown by grains with sericitized and kaolinized cores with clear margins and by

grains with preferential sericite (and muscovite) development along certain crystallographic directions (pl. 29, fig. A). The major preferred directions in the latter are parallel with (010) and (001). Although most of the plagioclase shows albite twinning and some shows pericline twinning, a considerable amount of oligoclase is untwinned. Some cyclic crystallization occurred as shown by repeated overgrowth of plagioclase on plagioclase or microcline with ragged corrosional boundaries between the different growth periods (pl. 29, fig. B). Although parallel orientation was maintained in these overgrowths, the interruption shows up in very moderate changes in extinction angles and twinning patterns. As many as three growth periods are shown by individual grains.

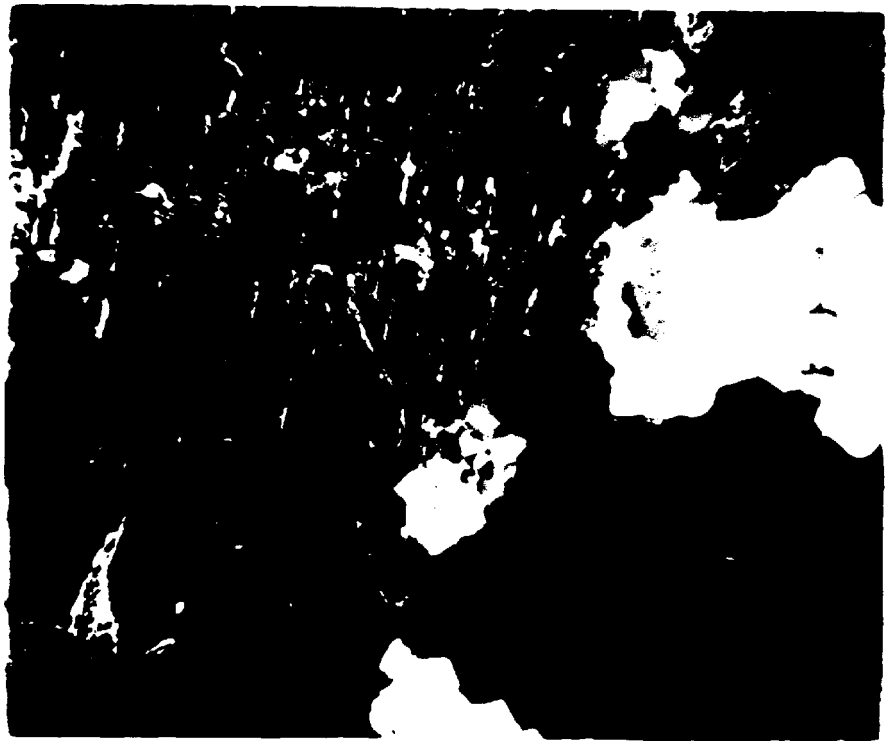
Orthoclase is generally minor. Microcline is the common potash feldspar and forms locally the largest crystal grains in these rocks. As stated above, these appear to be metacrystic. Many of these microcline crystals contain relicts of partially replaced plagioclase, and some contain rounded quartz inclusions. Most of the potash feldspar is perthitic. Although some is sericitized, most is fresh.

The dominant mafic mineral is biotite. It is generally light to dark olive green in pleochroism, and thus similar in appearance to the biotite of the schists. Most of it includes zircon with surrounding pleochroic haloes, as well as apatite and magnetite inclusions. Much of the biotite has been altered to chlorite and dusty magnetite and a little to

Plate 29

Figure A: Preferential sericitization of plagioclase along albite twin lamellae. Granite one mile southeast of Meyers Ranch pegmatite. (+) nicols, x 85.

Figure B: Oriented overgrowth of oligoclase (Ab 74) on microcline. Ragged corrosional boundaries separate the two. Mafic granite (granodiorite) near Meyers Ranch pegmatite. (+) nicols, x 43.





muscovite and hematite. Locally cleavages show crumpling, or grains may be shredded. Some granitic rocks show evidence of late biotite introduction along grain boundaries, but generally, if this has taken place, it cannot be recognized.

Magnetite, zircon, and apatite are the dominant accessories. All are abundant and are euhedral to rounded. The magnetite occurs in ragged grains as well, and may be altered in part to hematite. Some of the zircon shows zoning. Hornblende was noted in two thin sections, pleochroic from yellow green to blue green, and some contains small diopsidic augite relicts. Part of the hornblende is replaced by epidote, and epidote was observed as an abundant constituent in two other rocks, probably having resulted from replacement of mafic minerals. Abundant subhedral sphene was observed in two rocks and large garnet crystals partially replaced by biotite in another. This garnet may be indicative of the local ingestion of a xenolith.

Origin

These granitic rocks show the characteristics of the Boulder Creek granite as it crops out in other parts of the Front Range. They are small, irregular bodies near the margin of a large intrusive body. A very few miles to the east of the Guffey area typical Pikes Peak granite is the country rock and these bodies appear to be gradational into the Guffey outcrops. Typically the Boulder Creek quartz

monzonite is in bodies marginal to the Pikes Peak granite batholith and is of a slightly more mafic composition. This suggests that perhaps at least some of the differences are caused by reactions between invading magma and country rock.

If this is the case the granodioritic bodies become significant. Their outcrop shapes (see pl. 1, for "sill" following Micanite Ridge and running through to Guffey) and porphyroblastic textures suggest a syntectic origin. Where probably less magmatic matter was introduced the rocks are similar but still more mafic. In addition local marked segregations of biotite in both types of the Boulder Creek granite suggest an origin in digested country rock.

SILVER PLUME GRANITE

Contrary to what would be expected from examination of existing reconnaissance maps of this and surrounding areas, no outcrops that could be conclusively identified as Silver Plume granite (Ball, 1908, p. 58) were observed. E. N. Goddard (personal communication) identified three hand-specimens as possibly Silver Plume granite. One of these from Thirty-one Mile Creek came from a sill intruded into hornblende gneiss that could be traced for only a few feet on strike and was too narrow to be represented on the areal map. Another occurs as a small exposure, roughly 50 feet in diameter, projecting upward through overlying trachyte porphyry about 100 yards north of Dicks Creek. This is mapped as Silver Plume granite. The third was found as one of the

boulders in the conglomeratic facies of the Paleozoic Fountain formation west of Thirty-one Mile Mountain. None of these, however, can be correlated with any degree of certainty with the Silver Plume granite.

PEGMATITES

Pegmatites are very abundant throughout the pre-Cambrian of the Guffey area. Nearly all of these are unzoned bodies, including a wide range of shapes and sizes (pl. 30, figs. A and B). The largest are as much as a quarter of a mile long and one hundred yards wide; the smallest mere ribbons of modest length which could not be given map representation. These ribbons are wide-spread throughout the strongly injected biotite gneiss, some of them concordant and fewer cross-cutting. As noted by Snively (1948, pp. 76-77), there are no evidences of distortion of the intruded rocks.

The constituents in these unzoned pegmatites are quartz, microcline, albite, muscovite, orthoclase, biotite and magnetite. These rocks are generally even-grained, although the mafic constituents are much less prominent and occur typically in smaller grains. The maximum grain-size is approximately eight centimeters. They crop out most abundantly on the plain south of Cover Mountain.

The zoned pegmatites are mineralogically and commercially more significant. Most of them have been mined or prospected in the past for mica, feldspar, beryl or columbite. This will be discussed under the section on economic

Plate 30.

Figure A: Large unzoned granitic pegmatite cropping out in region of biotite-sillimanite schist. Near Nash Ranch on flat south of Cover Mountain.

Figure B: Small pegmatite cutting granodiorite near Meyers Ranch pegmatite.





geology. All but two of the zoned pegmatites are in or very near bodies of the granodioritic phase of the Boulder Creek granite. The significance of this spatial relationship is not known.

Criteria have been described for distinguishing pegmatites assignable to different periods of intrusion in the Denver Mountain Parks area (Boos, 1954). Although certain of the characteristics for pegmatites from each intrusive period appear to be present in Guffey area pegmatites, no correlation on this basis seems possible. The writer believes that the pegmatites here are of one genetic affiliation as they are generally uniform in appearance and mineralogy. Also the proximity to granitic bodies of apparently only one age suggests a close affiliation with these; that is, to the Boulder Creek granite.

The lack of disruption in intruded beds indicates that either assimilation or removal of the host rock was general in pegmatite intrusion. On the other hand the stubby, pod-like character of most pegmatite bodies indicates a viscosity in the solutions much greater than that in the hydrothermal solutions which injected broad areas to form much of the biotite gneiss.

A narrow, dark gray quartz vein crops out near Dicks Gulch. Some of the quartz contains abundant schorl needles.

DIABASE

Discontinuous outcrops of diabase were observed along the east side of Current Creek. These extend from two miles south of the southern margin of the Guffey area north to an exposure a mile south of Guffey; a distance of approximately five miles. Float cobbles of a similar rock occur approximately one-quarter mile north of the Skyline Ranch.

The diabase does not resemble hypabyssal intrusives of similar composition associated with the Tertiary extrusives. Spheroidal weathering characteristically reduces exposures to distinctive pebble zones, and as a result outcrops can be observed only on a few steep slopes. The rounded pebbles contain fresh cores encased in thick shells of thoroughly altered material. Thicknesses of the intrusives are variable, but in outcrops observed it averages three feet. The diabase is in the form of dikes transecting the structures of enclosing rocks (see pl. 31, fig. A).

All observed occurrences of the diabase are within the biotite gneiss, with the exception of the pebble zone near Skyline Ranch which is in quartz-biotite-sillimanite schist. Outcrops of the diabase within biotite gneiss follow a general north-northwest line suggesting that they are all parts of one dike.

In hand specimen the fresh diabase is very dark gray, but in its typical weathered form appears reddish because of prominence of iron oxides in the alteration products. Diabasic texture is easily visible.

Plate 31.

Figure A: Diabase intrusive into biotite gneiss. On Colorado State Highway 9 one-half mile southeast of intersection with Guffey road.

Figure B: Skeletal magnetite crystals in diabase. Creek bottom near outcrop shown above.

(-) nicols, x 140.





In thin section the porphyritic character of the rock becomes apparent. It contains phenocrysts of augite and plagioclase with the augite crystals apparently replaced locally by feldspar. The labradorite (Ab 44) phenocrysts are typically zoned and, though they may exhibit Carlsbad twins, albite twins are rare. Much of this labradorite is moderately sericitized.

The matrix contains felted labradorite (Ab 48) laths, which are much larger than those in the Tertiary dike rocks. These are abundantly twinned under both the Carlsbad and albite laws. The feldspar laths show pilotaxitic textures around phenocrysts. Skeletal crystals of magnetite (see pl. 31, fig. B) are abundant, exhibiting an unusual variety of forms. Small augite grains and some rounded olivine grains also appear in the matrix. The olivine has been partially altered to serpentine and chlorite, and the augite also has been altered to chlorite to a minor extent. Veinlets and patches of secondary hematite and calcite are common.

Although absolute proof is not available, the writer believes this diabase may be the youngest pre-Cambrian rock in the area. In all observed associations with other pre-Cambrian rocks it has been injected across their structures. It is essentially non-metamorphosed, whereas the granitic intrusives and even the pegmatites show evidences of some metamorphism. Heinrich (1948, pp. 430-431 and personal communication) observed similar diabases in the Eight Mile

Park area. He concluded that this was the youngest pre-Cambrian rock present, as it is widely exposed in the area cutting pre-Cambrian rocks, including Pikes Peak granite, but nowhere intrudes overlying Cambrian or younger sediments.

The diabase may be of Laramide or even Tertiary age, as similar rocks of both ages occur in the Front Range. However, the restriction of this rock type to the pre-Cambrian areas seems more than fortuitous, particularly inasmuch as dikes obviously associated with Tertiary extrusives have been injected into pre-Cambrian rocks only rarely. The coarser matrix material in this than in the Tertiary dike rocks suggests that it was injected at greater depth and as a result crystallized more slowly. The skeletal magnetite development is peculiar to this rock type.

PALEOZOIC (?)

FOUNTAIN FORMATION (?)

History and Distribution

Sedimentary rocks that crop out in the western part of the Guffey area are believed to be equivalent to the lower Pennsylvanian Fountain formation present elsewhere on the flanks of and probably within the Front Range. Outcrops of the Fountain formation are almost continuous along the east side of the range from the Wyoming line to Canon City but are much scarcer along the west side. Non-fossiliferous red micaceous grits occur along the eastern sides of North Park and Middle Park and probably belong within the Fountain

formation (Lovering and Goddard, 1950, p. 33).

The type locality for the Fountain formation is along Fountain Creek near Manitou (Cross, 1894, p. 2), and the maximum thickness of the formation is about 4,500 feet near Colorado Springs (Finlay, 1916, p. 6). It is described as being composed of unjointed coarse red gritty conglomerate (near base), arkosic sandstone and minor reddish and greenish shales. Fenneman (1905, pp. 22-23) described conglomerate layers higher in the formation composed primarily of white quartz pebbles. The grits, arkoses and conglomerates typically contain pre-Cambrian rock fragments and quartz, feldspar and mica grains presumably also derived from pre-Cambrian rocks. Near Colorado Springs a basal unit known as the Glen Eyrie shale is present, containing a black, plant- and Lingula shell-bearing horizon considered equivalent to the lower Pottsville formation of Pennsylvania (Finlay, 1916, p. 7). Darton (1905, pp. 162-163) considered the Fountain formation to be equivalent to the lower Wyoming formation of eastern Colorado and to the Sangre de Cristo formation.

In the Guffey area outcrops that will henceforth be referred to as the Fountain formation occur along the west flank of Chumway Park and on to the south across Thirty-one Mile Creek. This sedimentary block was brought into its present position by major faulting (pl. 2). The total exposure length is approximately three miles and the maximum width about two miles. The formation may continue on to the

southern boundary of the map area, but as no outcrops were observed, this cannot be substantiated. As float boulders in this southern extension are exclusively of Boulder Creek granite, this area was mapped as the latter rather than as Fountain formation. Also the soil here does not exhibit the bright red color typical of that in most of the verified Fountain formation outcrop areas.

The outcrops are chiefly conglomeratic, unjointed, and have a very bright red matrix (pl. 32, fig. A). Along Paris Creek (pl. 32, fig. B) and Thirty-one Mile Creek these grade into pebble conglomerates and arkoses. The boulders are primarily granite, gneissic aplite and biotite gneiss with minor schist and black vein quartz. A few of the granite boulders are Silver Plume granite, but almost all of them are Boulder Creek or Pikes Peak granite. With weathering these develop boulder-strewn slopes (pl. 33, fig. A), with some of these boulders as much as 15 feet in their maximum dimension. No outcrops of the Glen Eyrie shale member or any other fossiliferous beds were found. In some of the finer-grained red-beds, narrow zones of bleaching of the sediments have developed locally, with the ferric iron removed, cutting across the bedding for a number of feet.

Extrusive rocks overly the Fountain formation, and a number of rhyolitic dikes cut through it. Some of these dikes have caused a strong induration and blackening of the sediments along contacts in zones as much as 10 feet wide. The sediments have been consolidated with a glassy matrix.

Plate 32.

Figure A: Moderately coarse Fountain formation conglomerate cropping out near Black Mountain Road.

Figure B: Medium-grained to fine-grained Fountain formation arkosic sandstone interbedded with conglomerate. Paris Creek.





Blocks of the sediments also occur within these dikes near their margins.

The finer-grained sediments examined microscopically show poorly sorted and strongly arkosic character. Angular quartz and unaltered microcline grains are the dominant coarser constituents (pl. 33, fig. B), although rock fragments, altered plagioclase and the micas are also prominent. Minor magnetite and zircon are also present. The matrix material is very fine-grained and apparently consists of a rock flour of the same constituents as described above. Interstitial calcite, sericite, kaolinite and iron oxides, chiefly hematite, have been added during and since sedimentation.

Origin and Age

Source materials for the Fountain formation in the Guffey area undoubtedly originated in the erosion of an exclusively pre-Cambrian terrain. The general conglomeratic character, lack of sorting, angular fragments and presence and freshness of the microcline all indicate deposition near the source. The pre-Cambrian rock fragments in the conglomerate are somewhat more varied than the rock types now exposed in the Guffey region. This may indicate either a somewhat larger provenance or perhaps a somewhat different pre-Cambrian character of the section above the present erosion surface.

Unfortunately the formation cannot be accurately dated

Plate 33.

Figure A: Typical boulder-strewn slope from weathering of conglomeratic Fountain formation. North of Black Mountain Road.

Figure B: Angular quartz and fresh microcline grains in arkosic Fountain formation sandstone near Paris Creek. (+) nicols, x 60.





either by fossil or stratigraphic data. Certain relationships are present, however, which place very rough boundaries on the time of deposition:

1) Obviously the rock is younger than the pre-Cambrian formations which contributed boulders to its conglomeratic facies.
2) No rock fragments younger than pre-Cambrian occur within the formation.
3) The formation is overlain by Tertiary rocks.
4) The formation is intruded and metamorphosed by Tertiary dike rocks.

Perhaps the most significant evidence is the remarkable lithologic similarity of this formation to exposures of the Fountain formation elsewhere. It is almost identical in appearance with Fountain formation outcrops along the west base of Skyline Ridge near Canon City. It also is closely similar to exposures of the same formation in the Manitou area near Colorado Springs.

TERTIARY IGNEOUS ROCKS

History and Distribution

Two widely separated areas of post-Eocene extrusive and hypabyssal rocks occur in the Colorado Front Range. One area is in the northwestern part of the Rocky Mountain National Park and the other in the southwestern part of the Front Range (Lovering and Goddard, 1950, pp. 50-51). The writer is concerned with the latter area.

Cross (1894, p. 2) states that the Florissant Lake beds are water-laid volcanic ash derived from the earliest eruptions of the volcanic center lying west of the Pikes Peak quadrangle. He dates these beds as Oligocene on the basis of their extensive fossils. Following this earliest ash eruption a complex series of basic to acidic tuffs and flows originated in the Guffey volcanic area. These extended outward in all directions from this center, but large volumes of the eruptive material have subsequently been removed by erosion. The central position of the Guffey area is indicated by the dips of flow surfaces as described in the section concerning structure.

Exposures of the upper section of these volcanics continue northward into southern South Park. The latter is separated from the Guffey area by Thirty-nine Mile Mountain. On the south side of this ridge a 2000-foot section of this upper part of the volcanics crops out. Stark (1949, pp. 101-103) refers to these rocks as the Thirty-nine Mile volcanic series or Thirty-nine Mile andesite series and cites evidence (p. 103) indicating the youngest member of the series is early Oligocene. It is to be questioned whether all of the Oligocene volcanics in the Guffey area should be referred to the Thirty-nine Mile volcanic series as Stark's description is only of the younger, more basic members. Perhaps only the upper more basic part should be considered Thirty-nine Mile andesite, and the complete group should be referred to as the Guffey volcanics. The more acidic lower members

are given the group name, Chumway rhyolite.

In the Guffey area the general sequence of Tertiary igneous rocks is:

4. Basalt and basaltic breccias.
3. Andesite porphyry and breccia.
2. Trachyte porphyry.
1. Felsite tuffs and breccias. Many of these are too fine-grained to permit accurate mineral determination. Others contain mineral grains large enough to be identified, and such rocks are rhyolitic to andesitic in composition.

Local departures from this sequence are common, particularly with regard to small basaltic and andesitic exposures. The tuffs and flows listed above are intruded by hypabyssal dikes of rhyolitic, andesitic and basaltic composition, and by at least one monzonite porphyry stock. Because of the complexity of relationships, the characteristics of these rocks are discussed in order of decreasing acidity (which roughly parallels age) rather than chronologically.

Rhyolite

In the central part of the Guffey area where Currant Creek and its tributaries have cut a deep canyon a large area of extrusive rhyolitic rocks is exposed. Generally these rocks are tuffs and agglomerates, although some small flows also occur. These rocks and the rock fragments contained in tuffaceous members are characteristically very

fine-grained and contain dominant glassy material.

Very fine-grained ash occurs in a number of exposures bordering Chumway Park. Some is poorly consolidated, as on the north slope of Baldy, whereas some has been compacted into a very dense porcelain-like rock. One exposure on Currant Creek one and one-half miles north of Black Mountain Road consists of ash, apparently deposited in a shallow lake as indicated by their very regular stratification and sorting (pl. 34, fig. A). Most exposures are much coarser, however, with aphanitic rhyolite fragments as much as three centimeters in diameter enclosed in an aphanitic rhyolite groundmass. In many places these fragments impart a "knotty" structure to outcrops (pl. 34, fig. B). The color of these rocks ranges from white through light green, blue, pink, buff and gray to very dark gray.

Two throat breccia pipes crop out as conical hills approximately 60 feet high near the western margin of Chumway Park. These occur within the Fountain formation at or near the contact with overlying basalt. They have been intruded through the Fountain formation and through light greenish rhyolite ash beds. The constituents of these pipes are fresh angular pre-Cambrian fragments in a matrix of glassy rhyolite (pl. 35, fig. A).

Many rhyolite dikes, some of them strongly brecciated, intrude earlier Tertiary extrusive rocks and the Fountain formation. Intrusion into the pre-Cambrian rocks is minor, although some does occur. Many of the denser dikes crop out

Plate 34.

Figure A: Very fine-grained rhyolite tuff beds, probably deposited in a shallow lake. Currant Creek near Spring Gulch.

Figure B: Rhyolite containing "knotty" rhyolitic fragments. One-half mile north of Guffey.





very sharply (pl. 35, fig. B), but most show little topographic expression.

Microscopically nearly all of the rhyolitic rocks show a tuffaceous character and are typically cryptocrystalline to vitreous; bath matrix and included rock fragments. Some show generally angular fragments of quartz, potash feldspar and some oligoclase. A few of these are subhedral to euhedral. Some of the glassy rocks show partial devitrification. Flow and bedding structures are general (pl. 36, fig. A), appearing either through color differences or through variable grain size. The tuffaceous varieties show shards and blocky fragments, many of which show perlitic textures (pl. 36, fig. B).

A true perlite, which has been prospected by Luther Clark of Pueblo, is present in patches along the east side of Chumway Park near Spring Gulch (pl. 37, fig. A). This contains abundant feldspar spherulites, a few crystal fragments and abundant cavities. It shows well developed perlitic and flow structures microscopically.

Trachyte

Cross (1894, p. 3) described trachyte in the eastern part of the area near Wicher and Cover Mountains. As shown in plate 1, a large number of narrow exposures of essentially identical rock occur in the western part of the area.

All exposures of this rock are at approximately the same elevation above sea level except for the small patches

Plate 35.

Figure A: Boulder of rhyolitic breccia containing pre-Cambrian xenoliths. From volcanic pipe in Chumway Park.

Figure B: Rhyolite dike cutting andesite and basalt. North of Walby Ranch on south flank of Thirty-one Mile Mountain.



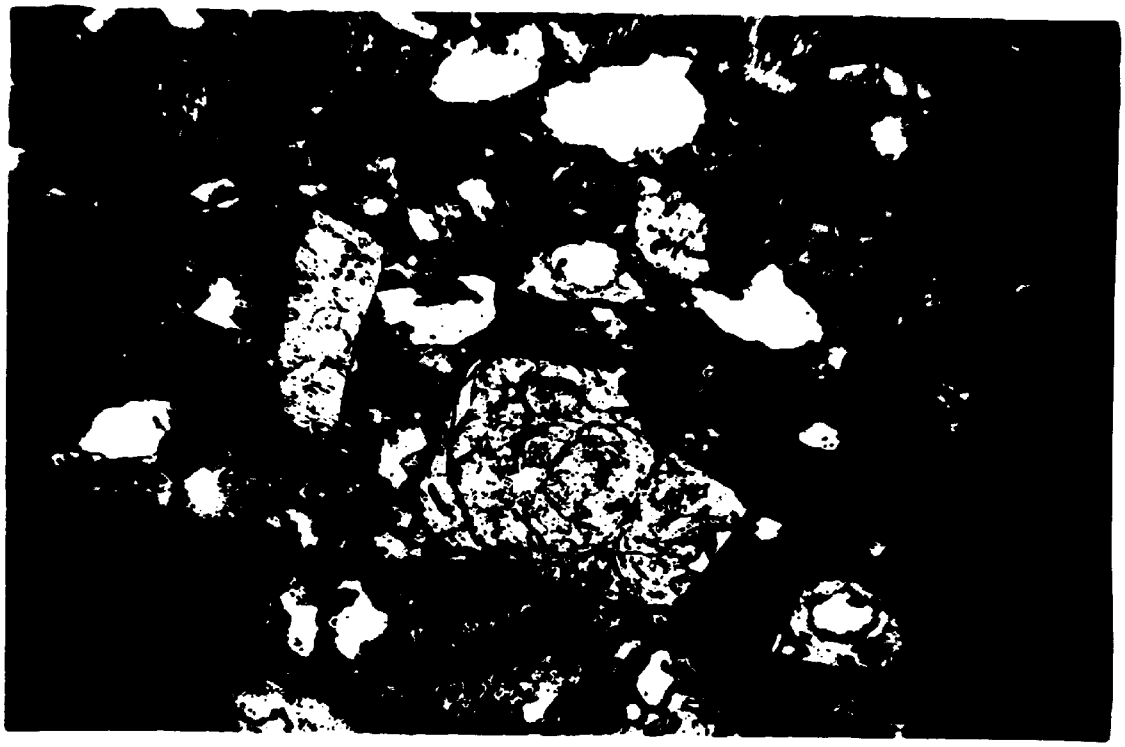


Plate 36.

Figure A: Flow structure in rhyolite dike from east margin of Chumway Park.

Figure B: Fragmental character of rhyolite tuff from east of Chumway Park on west bank of Currant Creek.





crossing Currant Creek and Black Mountain road. This group crops out typically in nearly vertical cross-sectional faces of a glassy vesicular porphyritic flow, which acts as a cap rock. The constant elevation and similarity in character of most outcrops suggest that they are parts of a single flow or flow group of considerable persistence, which now is exposed only as isolated outcrops separated by hills and valleys. This sanidine trachyte porphyry ranges in color from light gray through pink and red to violet.

The phenocrysts in this rock are sanidine, biotite and much less commonly oligoclase. They are as much as 5 mm. long. Microphenocrysts of apatite, zircon and magnetite are present. The groundmass is typically glassy, some showing shards, although locally there is incipient devitrification. All specimens show flow banding.

The sanidine is generally very fresh, somewhat corroded and much has Carlsbad twinning (pl. 37, fig. B). It is typically euhedral to rounded, but some rocks contain angular crystal fragments. Biotite is strongly pleochroic, typically from red brown to black. The oligoclase (Ab 74) is commonly strongly altered to sericite and kaolinite. In most of the trachyte abundant iron oxides are present which impart the pinkish to purplish colors. Some cavities in these rocks contain tridymite.

Plate 37.

Figure A: Prospect pit in perlite deposit just north of Spring Gulch.

Figure B: Fresh, corroded sanidine phenocrysts in trachyte porphyry showing Carlsbad twinning. The rock shows some flow structure. Southern end of Chumway Park. (+) nicols, x 60.





Andesite

Abundant and extensive outcrops of andesite flows and agglomerates occur in the northern, eastern and western parts of the Guffey area. These are intimately intercalated with basalt flows and boundaries between the two are drawn on the basis of the dominant type present. As stated above, a vast section of these rocks occurs covering the northern portion of the Guffey region and on to the north. Undoubtedly an equally great section once covered the center of the area but has subsequently been removed.

The flow andesites, which are more common in the northern and western parts of the area, are porphyritic with a fine-grained matrix. The agglomeratic varieties contain unsorted angular fragments of basalt and andesite with highly variable compaction. Some are markedly scoriaceous, whereas others are dense and well compacted. These rocks show colors on outcrops ranging from gray or lavendar-gray to purplish brown.

Andesine is the dominant phenocrystic mineral. It ranges in composition from Ab 54 to Ab 68, but averages about Ab 56. Normal zoning is common in these crystals, with the rims more sodic than the cores. Where the matrix plagioclase laths can be identified they are also andesine, but are more sodic than the phenocrysts. These laths are commonly oriented around the phenocrysts causing a trachytic texture (pl. 38, fig. A).

Biotite is present in most of these rocks and generally

exhibits the red brown to dark brown pleochroism typical of varieties in extrusive rocks in which the iron has been partly oxidized. Some biotite shows roughly parallel growth with andesine. Much biotite has been partially replaced pseudomorphously by magnetite and in one specimen this has gone nearly to completion (pl. 38, fig. B). Some chlorite-magnetite replacement of biotite has taken place.

Phenocrysts of augite occur in several of these rocks. These show common (100) twinning and some polysynthetic (001) twinning. A number of augite crystals have been strongly replaced by plagioclase, magnetite, epidote, apatite and chlorite as a fine central intergrowth and have resorption borders of magnetite (pl. 38, fig. A). Although no olivine was observed in these rocks, several of them show abundant iddingsite or serpentine-magnetite intergrowths pseudomorphous after olivine. Abundant magnetite and apatite occur as accessories.

The matrix is generally microcrystalline, containing andesine, augite, magnetite, apatite and locally tridymite. Tridymite is abundant in many andesite specimens. In some it occurs disseminated throughout the groundmass, but typically it occurs in cavities. It is commonly twinned along $(10\bar{1}6)$ to form trillings (pl. 39, figs. A and B).

Basalt

Basalt generally occurs as flows and agglomerates overlying the more acidic extrusive rocks in this area, although

Plate 38.

Figure A: Augite twin in andesite strongly replaced by epidote, magnetite, hornblende and serpentine with dominantly magnetite border replacement. Trachytic texture. North end of Thirty-one Mile Mountain. (+) nicols, x 32.

Figure B: Andesite containing biotite resorbed to magnetite in parallel growth with andesine. Near Mill Gulch Mine. (-) nicols, x 32.

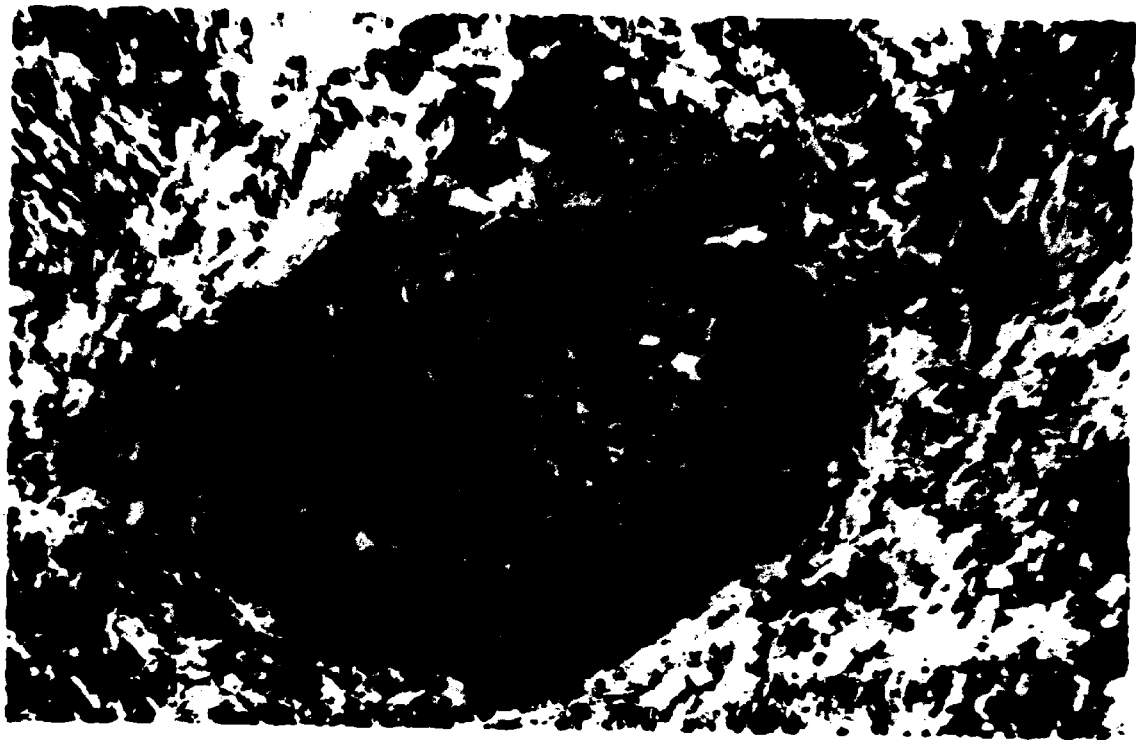
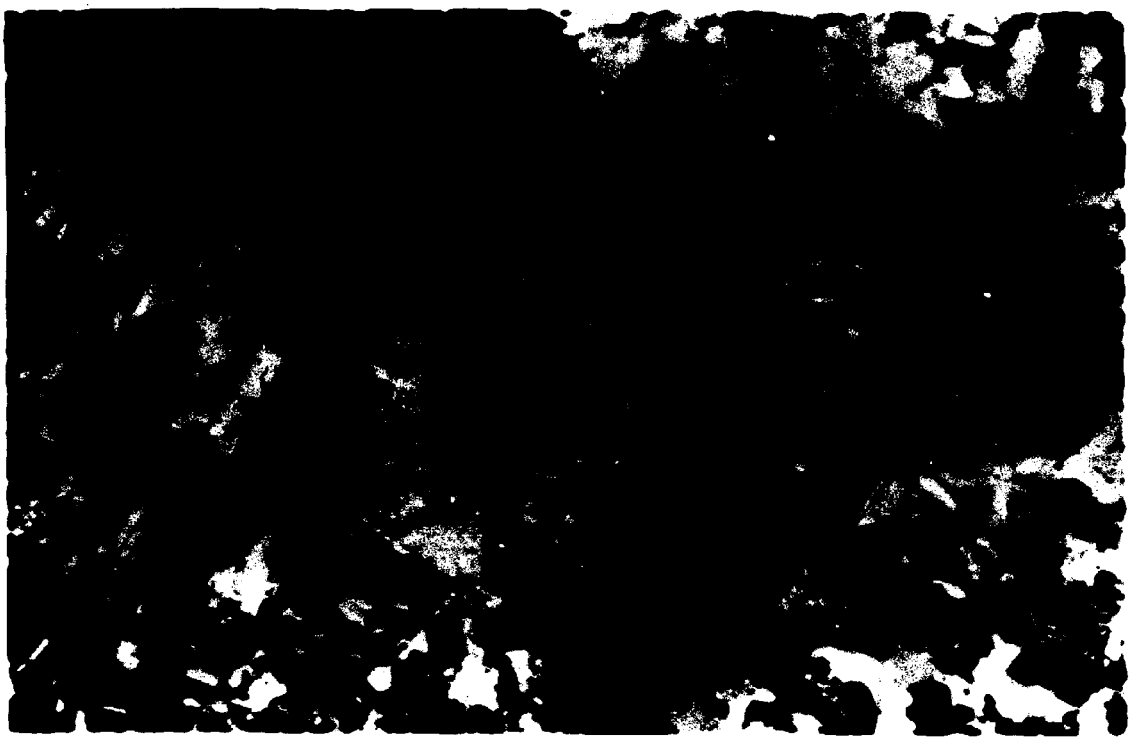




Plate 39.

Figure A: Twinned tridymite crystal in hornblende andesite from Chumway Park. (+) nicols, x 170.

Figure B: Twinned tridymite crystals (trillings) in a vesicle in an altered andesitic vitrophyre. Cover Mountain. (+) nicols, x 170 .





locally it is also intercalated with them and intrudes them as sills and dikes. Consequently it is more common in the higher areas and is the dominant exposed rock in the eastern and northern sections of the mapped area. As the basalt is typically more resistant to weathering than other extrusive rocks, it commonly occurs as sharply defined caprocks. This is particularly well illustrated on and near Thirty-one Mile Mountain (pl. 6, figs. A and B).

Megascopically the basalt is dark-colored, reddish-brown to black, and variable in grain-size. Some specimens are moderately coarse-grained with phenocrysts as much as a centimeter long. Others are much more fine-grained with individual mineral grains nearly indistinguishable to the unaided eye.

Microscopically the rocks generally are porphyritic with phenocrysts surrounded by much finer-grained to glassy matrix material. They commonly show trachytic textures (pl. 40, figs. A and B) and in some places diabasic textures.

Labradorite is the most abundant mineral. The phenocrysts range in composition from Ab 34 to Ab 43, and matrix microlites are generally 5 to 6 units more sodic. Complex zoning of the larger crystals (pl. 40, fig. A), which are stubby to lath-like in form, is common. Kaolinitization and saussuritization are widespread and these replacements are commonly zoned. Some crystals show clouded cores and clear margins, and in some the reverse relationship exists. Locally even an oscillatory replacement, with repeated clear

Plate 40.

Figure A: Zoned, corroded labradorite phenocryst in basalt from near Meyers Ranch pegmatite. Poorly developed trachytic texture. (+) nicols, x 32.

Figure B: Twinned augite phenocryst in basalt from Thirty-one Mile Mountain cap-rock. Well-developed trachytic texture. (+) nicols, x 32.





and cloudy zones, occurs.

Augite or diopsidic augite is abundant. It is typically euhedral and commonly twinned parallel with (100) (pl. 40, fig. B). Some crystals are poikilitic (labradorite and olivine inclusions) and some show oscillatory zoning. Minor alteration to serpentine and hematite has occurred. Olivine is present as euhedral grains in places, but typically has been partially or completely replaced by iddingsite or serpentine.

Magnetite and apatite are abundant accessories and both are commonly euhedral. Some of the apatite contains minute oriented inclusions, possibly magnetite.

The matrix is dominantly labradorite laths, augite, magnetite and serpentine, with vesicular glass aggregates present locally. It is highly variable in grain size. Secondary calcite as veinlets and in iron oxide lined amygdules is common. Some cross-fiber serpentine veinlets also occur. One specimen contains abundant analcite both as crystals and disseminated through the matrix. This may be in part primary as suggested by Jahns (1938, p. 15) in his description of an analcite diabase in South Park. If this is the case, the two occurrences may be genetically related.

Augite-Biotite Monzonite Porphyry

Lovering and Goddard (1950, p. 289) examined this intrusive in 1944 and ascertained that it was a small stock cutting Tertiary andesites and the underlying pre-Cambrian

rocks. They described it (as reported by E. B. Eckel in their publication) as "--moderately fine-grained augite-biotite monzonite somewhat similar in appearance to the biotite andesite .... It contains abundant subhedral crystals of andesine and augite with a few flakes of brownish biotite in a medium-gray fine-grained holocrystalline groundmass of orthoclase."

This stock occurs about a mile north of Guffey and its outcrop forms Stag Mountain. It is approximately half a mile in diameter. The rock is gray and moderately porphyritic. The phenocrysts are subhedral to euhedral andesine (Ab 54), biotite and augite. The matrix contains the above minerals plus abundant magnetite and some orthoclase. The rock is quite fine-grained and was undoubtedly a hypabyssal intrusive.

Origin

This chiefly extrusive igneous complex apparently all originated from volcanic sources in or near the Guffey area. The attitudes of the flow contacts and the bedding of associated sub-aerial deposits appear to represent fundamentally original dips, all of which are away from the center of the region. The coarseness of the volcanic breccias, too, indicates formation near an explosive volcanic center.

The two rhyolite throat breccias give proof of eruptions here and the Guffey (Stag Mountain) stock may have a similar significance. From this evidence it may be assumed that

additional evidence has been obscured by soil and vegetation cover and in some places by extrusive rocks late in the series.

The findings of Cross (1894) clearly indicate an Oligocene age for rocks equivalent to the oldest members of this series. Stark (1948) has demonstrated an Oligocene age for the youngest. Thus Guffey was the center of a strong period of volcanic activity in Oligocene time.

POST-EXTRUSIVE SANDSTONE

One very small exposure of pinkish to banded red and white, even-grained sandstone occurs one quarter mile west of Currant Creek to the north of the Black Mountain road. There are no outcrops but only a small, well-defined float area.

The dominant constituent is sub-rounded quartz grains (pl. 41, fig. A), some of which show minor authigenic overgrowth. Some fresh microcline and moderately altered plagioclase grains are present as well as scattered rhyolitic and cherty fragments and minor zircon and magnetite.

The cement, which is cryptocrystalline to isotropic under high magnification, has an index = 1.54 ± 0.02, suggesting that it is very fine-grained chalcedony.

The location and constituents of this rock suggest that it formed on the banks of Currant Creek relatively early in the development of this drainage. The presence of extrusive rock fragments indicates that sandstone formation was after

the volcanic period, and the presence of younger extensive glacial gravels within the stream channel topographically well below the sandstone indicates formation was before the major glacial period. The sediment is probably Miocene or Pliocene, although it may be younger.

TRAVERTINE

Two small conical travertine mounds occur just north of the Guffey road, about one-quarter mile east of its junction with state highway 9 (pl. 41, fig. B). Deposition is still taking place at both from rising limy waters. The western of these knobs is referred to as Mound Soda Spring, and its waters have been utilized as a source for drink mixes in the area.

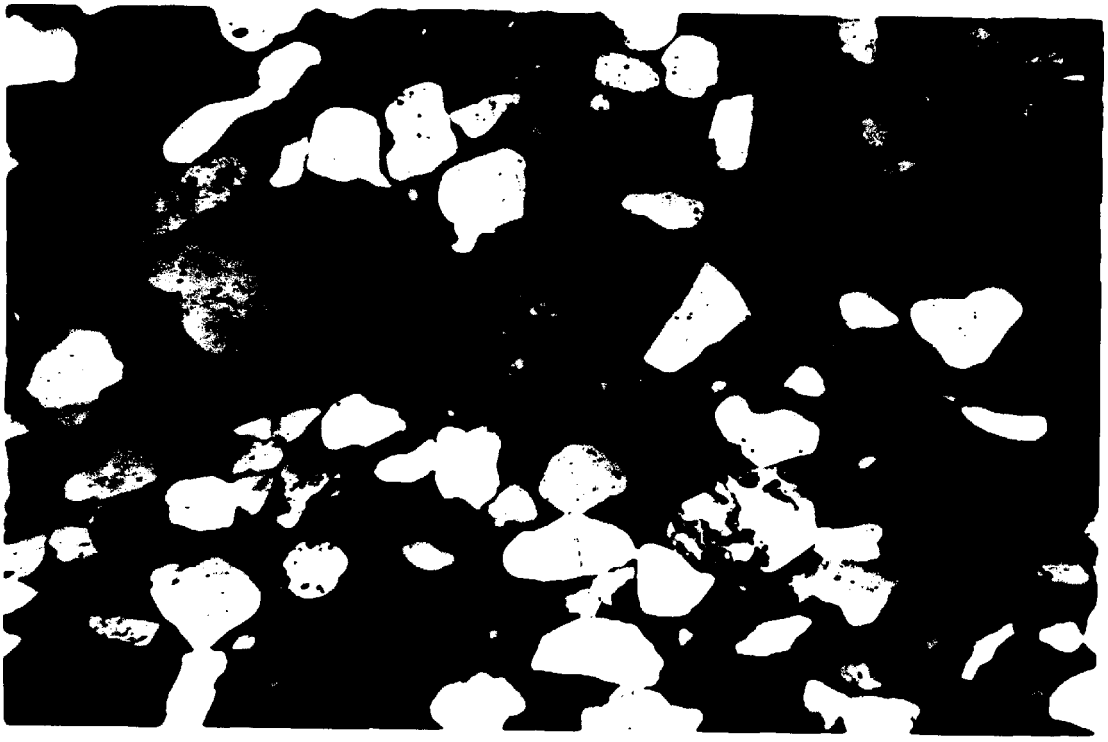
RECENT ALLUVIUM

The channel of Currant Creek and many of its tributaries contain gravels and sands of varying character which have been grouped under the name of recent alluvium in mapping. Some of these deposits lie above the present channel in the form of benches. These may be related to glaciation as discussed in the physiographic section.

Plate 41.

Figure A: Rounded quartz grains, chert and chalcedony fragments, and extrusive rock fragments in a vitreous, ferruginous matrix. Post-extrusive sandstone from west of Currant Creek near Black Mountain Road.
(+) nicols, x 53.

Figure B: Mound Soda Spring travertine deposit on Guffey Road near intersection with Colorado State Highway 9.





GEOLOGICAL HISTORY

The oldest Guffey area exposures are metamorphic rocks of the Idaho Springs formation. These have been tentatively correlated with the Algonkian Huronian series. Sedimentary rocks formed during that period comprised dominantly shales, which were locally sandy, limy, dolomitic or chloritic, impure limestones, dolomites, and minor sandstones, arkoses and arkosic sandstones. These attained an estimated maximum thickness of at least 25,000 feet. The character of these sediments suggest that they were derived from the denudation of a mature low-lying granitic land mass with deposition in a bordering shallow sea. No exposures of this land mass remain. Volcanic flows may have been interbedded with these sediments, and hypabyssal dikes and sills intruded into them, but there are no clear evidences for these here.

Regional metamorphism of these sediments converted them to schists, lime-silicate rocks, hornblende gneisses and paragneisses. This metamorphism and concomitant strong, commonly isoclinal folding may have resulted in part from stresses generated by the incipience of a major period of intrusion. More probably, however, metamorphism preceded intrusion as all xenoliths in the intrusive rocks have been markedly regionally metamorphosed. The intrusions were doubtless post-metamorphism, but, where gneissoid, may have been in part synkinematic.

During or following folding, extensive lit-par-lit injection and metasomatism took place. Different combinations of Mg, Fe, Na, K, Ca, CO_2, (OH) and possibly Al were

removed in many rocks and later re-introduced locally. Si, K, Na, W and Mo (?) and perhaps K and Al were introduced by the injected materials. As a result the chemistry and mineralogy of many of the rocks was changed drastically. Some of the schists and gneisses became much more acidic. Sillimanite, muscovite, cordierite, anthophyllite and other minerals developed with strong porphyroblastic growth. Many of the regional metamorphic rocks were converted to injection gneiss.

Gneissic aplite was formed as the first truly intrusive rock and was accompanied or followed by mild metamorphism. Later the Boulder Creek granite (quartz-monzonite) was emplaced as a number of small bodies, representing an early stage in the intrusion of the major Pikes Peak granite batholith. These Boulder Creek bodies were spatially marginal and satellitic to the later Pikes Peak batholith. Some members of the Boulder Creek group apparently formed through syntexis, which may account in part for their more basic character. Associated pegmatites and aplites of several ages and various characteristics were formed. Only minor metamorphism has occurred since this major intrusive period. Diabase dikes were intruded as the youngest pre-Cambrian (?) rocks.

In the late pre-Cambrian or early Paleozoic elevation of much of the Front Range took place. Intermittent strong erosion occurred during and following this, with resultant exposure of deep-seated pre-Cambrian metamorphic and intru-

sive igneous rocks. With one exception, no Paleozoic or Mesozoic sediments are exposed in the Guffey area. To the east and south, however, sediments ranging in age from Cambrian to Cretaceous overly the truncated edges of pre-Cambrian metamorphic and igneous rocks. Thus it is very likely that in this area these formations were deposited and subsequently removed.

The Fountain (?) formation, deposited here during the Pennsylvanian period, consists of coarse red arkosic sandstones and conglomerates. The character of these rocks indicates a very rapid erosion and deposition very close to the source -- a pre-Cambrian positive area, probably part of the Ancestral Rockies. As stated, there is no evidence of earlier Paleozoic sedimentation here; however, at no place was the basal contact of the Fountain (?) formation observed, and other sediments may lie beneath it.

At the close of the Mesozoic, Laramide folding and faulting took place with the Front Range becoming an anticlinal uplift. The down-faulted block in which Paleozoic sediments are exposed in Chumway Park probably assumed essentially its present position at that time.

During the early Tertiary period several peneplains were developed in this area. Those in the Guffey area are considered to belong to the Upper Eocene Cheyenne Mountain peneplain and the upper and lower Overland Mountain peneplains of Lower and Middle Oligocene respectively. Upon somewhat dissected remnants of these plains the Oligocene

volcanics from the Guffey volcanic center were deposited.

The Guffey volcanics and associated hypabyssal intrusives were formed in the Oligocene epoch. They are comprised of sub-aerial and water-laid ash, tuffs and agglomerates, flows, sills, dikes, pipes and a stock. The upper section includes the Thirty-nine Mile volcanic series and the lower section the Florissant lake beds. Although there are many local exceptions, generally as these rocks became younger they became more basic. They range in composition from rhyolite through trachyte and andesite to basalt. These volcanics were derived from an intrusive source not yet exposed in this area.

A major uplift occurred during the Miocene and Pliocene epochs. Subsequently large volumes of rock have been removed by erosion. In major drainages streams have cut completely through the Tertiary volcanics and deep into the underlying pre-Cambrian rocks. Strong erosion is still proceeding. Very steep banks have developed along many streams in the last fifty years. These, however, are probably a result of deforestation and overgrazing.

No major formations have been developed in the Guffey area since the end of the Oligocene epoch. One small patch of post-extrusive sandstone occurs about sixty feet above the present Currant Creek channel. Sands and gravels occurring as much as fifteen feet above the channel may in part be associated with outwash during the Wisconsin glaciation.

ECONOMIC GEOLOGY

SILLIMANITE

Sillimanite is an abundant constituent of many of the pre-Cambrian rocks in this area. The significant deposits are:

1. The Meyers sillimanite deposit. This is on Colorado State Highway 9 one mile southeast of the Guffey turn-off. This is an iron-stained cellular quartz-sillimanite rock with feldspars, zircon, magnetite and apatite. It appears to be of hydrothermal origin and occurs at the contact of biotite gneiss and Boulder Creek granite. The maximum dimensions of the deposit are approximately 200 feet long (NE-SW) by 30 feet wide. The best material may run as much as 50 per cent sillimanite but the average is much lower. The deposit has two small (3 foot) pits prospected by J. E. Meyers of Canon City, who is the owner.
2. The Betty Mine. This is approximately one and one-half miles west of Currant Creek between Thirty-one Mile Creek and the Black Mountain Road, from which it may be reached by a branch road. Large blocks of nearly pure fibrous sillimanite occur on the mine dump (pl. 50, fig. B). The total quantity present is, however, not known, as the underground workings were inaccessible.

3. Sillimanite schist. Many areas contain small to large exposures of sillimanite schist. Some of these rocks contain as much as 30 per cent or more sillimanite. The west and southwest flanks of Cover Mountain are richest in these rocks.

No sillimanite was being mined in this country at the time of publication of the latest reports. Kyanite, which is used for the same refractory material purposes, is chiefly imported. Minor kyanite occurs at Dicks Creek. The prices quoted for kyanite are variable, with a minimum of $26 per ton. At these prices and using current milling techniques, probably neither kyanite nor sillimanite is mineable at a profit in this area.

PEGMATITES

The only economically significant mineral production in the Guffey region has come from pegmatites. The minerals produced include mica, feldspar, beryl, columbite and very minor quantities of complex bismuth minerals. Only a brief general resume of the district will be given here, as much detailed published information is available. A few newly prospected pegmatites and a few of those already described that have unusual characteristics or that have yielded significant new information will be discussed in more detail.

The earliest description of pegmatites in this area was published by Sterrett (1923, pp. 51-55). His examination (1908 and 1913) was confined to the Micanite group. Hanley,

Heinrich and Page re-examined these pegmatites during World War II (1942 and 1944) and also described for the first time additional pegmatites in the area. They published detailed maps and descriptions (1950, pp. 43-55, 105-107).

The Micanite group of pegmatites is on and near Micanite Ridge, a prominent north-south trending topographic feature along the east side of Mac Gulch partly in Fremont County and partly in Park County. Hanley et al. (1950, p. 42) described these pegmatites in two distinct groups. "The northern group includes the Star Girl, Rose Dawn, Rosemont, Tickon, Climax, and Whopper pegmatites.....The southern group includes the Lower and Upper South, Rowe's North, Rowe's No. 2, Rowe's South, and three small pegmatites."

The United States Mica Company located the northern group and the Upper and Lower South pegmatites in 1902 and 1903. These were mined for mica between 1904 and 1907 to supply an adjacent fabrication mill. These mines were acquired by the Colorado Feldspar Company of Canon City in 1934 and operated for feldspar and scrap mica recovery from then until 1942. Frank Rowe located the Rowe pegmatites in 1902 and on his death these are believed to have become the property of his brother Gene Rowe of Guffey.

The Beryllium Lode pegmatite, located by J. E. Meyers in 1936, is on the northern extension of Micanite Ridge west of Mac Gulch, approximately two miles north of the county line. Only assessment work has been performed.

An interesting pegmatite was located and prospected in

1950 by a Mr. Baumer, whose first name and residence are unknown. This is situated on the west bank of Mac Gulch approximately three-quarters of a mile north of the county line. The pegmatite, which has a small exposure area (about 10 by 30 feet), displays a quartz core, a core-margin feldspathic unit with unusual mineralization including much biotite, magnetite, columbite-tantalite and euxenite, and an outer zone. The euxenite occurs in bladed crystals as much as two centimeters long, whose freshly broken surfaces are glassy and brownish-black in color (Bever, 1953, pp. 138-139).

The Famous Lode, Little Joe from Kokomo, Copper King and Meyers Ranch pegmatites, all in Park County, have been described by Hanley et al. (1950, p. 105). Two zoned pegmatites just to the north of the Guffey road near its intersection with Colorado State Highway 9 have been mined by George West for feldspar. These have no replacement units and have a very simple mineralogy. In addition, the East West and West West pegmatites are described here for the first time.

Meyers Ranch Pegmatite

General

The most interesting pegmatite and probably the one most productive economically of this northern group is the Meyers Ranch pegmatite. It is about fifteen miles northwest of Guffey on the west bank of Currant Creek. It is a zoned pegmatite with a moderately complex hydrothermal replacement

mineral assemblage.

This deposit has been known since 1908, at which time it was first worked for mica which was sold to the U.S. Mica Company of Micanite, Colorado. At this time the property was owned and worked by Alonzo MacDonald of Guffey. J. E. Meyers of Canon City purchased the property in 1930, and worked it until 1931. In 1939 the property was leased to Matt Reed of Guffey, who worked it for two months. Robert Yard of Canon City worked the pegmatite in 1950 and 1951, primarily for beryl.

During World War II this pegmatite was examined on two occasions by United States Geological Survey parties. Heinrich (Hanley et al., 1950, pp. 105-107) visited the locality in October 1942 and sketched the deposit. He and Hanley (op. cit.) revisited the pegmatite in June 1943, when they did detailed mapping and estimated reserves. It was recommended that the property be leased and worked by the Minerals Separation North American Corporation, but this was not done.

The pegmatite is enclosed in a mafic phase of the Boulder Creek quartz monzonite (Boulder Creek granodiorite). Basalt of the Thirty-nine Mile Mountain volcanic series covers granodiorite a few hundred feet to the north, east and west of the pegmatite.

The pegmatite body, which is intrusive into the granodiorite, is lenticular in shape, with a long axis that trends northeast-southwest. It is 375 feet long, and ranges

in width from 30 to 130 feet. A large part of the dike has been removed by erosion, the remainder forming a tree-crowned knob about 60 feet high (pl. 42, fig. A). This knob has been mined by tunnels and open cuts from all sides. The general shape of the pegmatite shows two prominent thick pods connected by a relatively narrow neck. The contacts with granite dip generally inward indicating that the pegmatite probably has a bowl-shaped keel; this apparently plunging to the southwest. Contacts between the pegmatite and the surrounding quartz monzonite are very slightly gradational.

Zones and units

The following internal structural units have been recognized:

A. Wall zone, consisting of a generally fine-grained granitoid pegmatite. The minerals present are quartz, microcline, muscovite, and albite (Ab 92). Clear early quartz occurs with feldspar in a graphic to granitoid intergrowth. A later generation of quartz occurs graphically intergrown with muscovite, the aggregate of which cuts across the earlier feldspar intergrowth. This somewhat later quartz is distinctly gray in color. Graphic granite is rare.

B. Intermediate zone, consisting of blocks and crystals of microcline as much as three feet in

Plate 42.

Figure A: Meyers Ranch pegmatite from the southeast.

Figure B: Fracture zone with development of large muscovite books above and normal to the fracture plane (center of picture).





diameter, which is not continuous but appears only locally around the periphery of the larger quartz core-pod. Much of this unit has been removed through mining, and its former location is marked by the position of the larger pits.

C. Quartz core-pods, in the two wider portions of the pegmatite. The larger pod to the northeast is 80 feet long and 40 feet wide, whereas the smaller one to the southwest is 30 by 50 feet in outcrop area. Both consist of pure quartz which is white or light to deep rose in color.

D. Core-margin unit, which is generally wrapped around the quartz core and averages about five feet in thickness, with a maximum thickness of seventeen feet. Albite (Ab 99), quartz, microcline, muscovite, biotite, beryl, columbite, tourmaline, garnet, apatite, bismuth carbonate, and a radioactive mineral (uranothorite or fergusonite?) occur in this unit. The grain size is extremely variable. Muscovite varies from fine-grained flakes to books as much as two feet in diameter, and beryl crystals range in length from a fraction of an inch to one crystal reportedly ten feet long (11 tons).

The core-margin unit appears to have been formed by partial replacement of:

1) Wall zone

2) Intermediate zone

3) Outer parts of the core

In structure it lies across zonal contacts. The most conspicuous structural elements within it are strongly developed veins and fracture-controlled replacement bodies of muscovite which appear as:

1) Small flakes plastered on simple curved fractures.

2) Large tabular masses of comb-structure books of "wedge-A" muscovite set at right angles to fracture planes, principally along their hanging wall sides (pl. 42, fig. B).

3) A more general mica formation. This has been caused by replacement from closely spaced sub-parallel fractures. Associated with the vein muscovite are flattened garnet crystals (pl. 43, fig. B) and tourmaline. Locally along the margin of the core, a shard-like structure has resulted from fracturing of the core-quartz and subsequent formation of biotite leaves along these closely-spaced curving cracks.

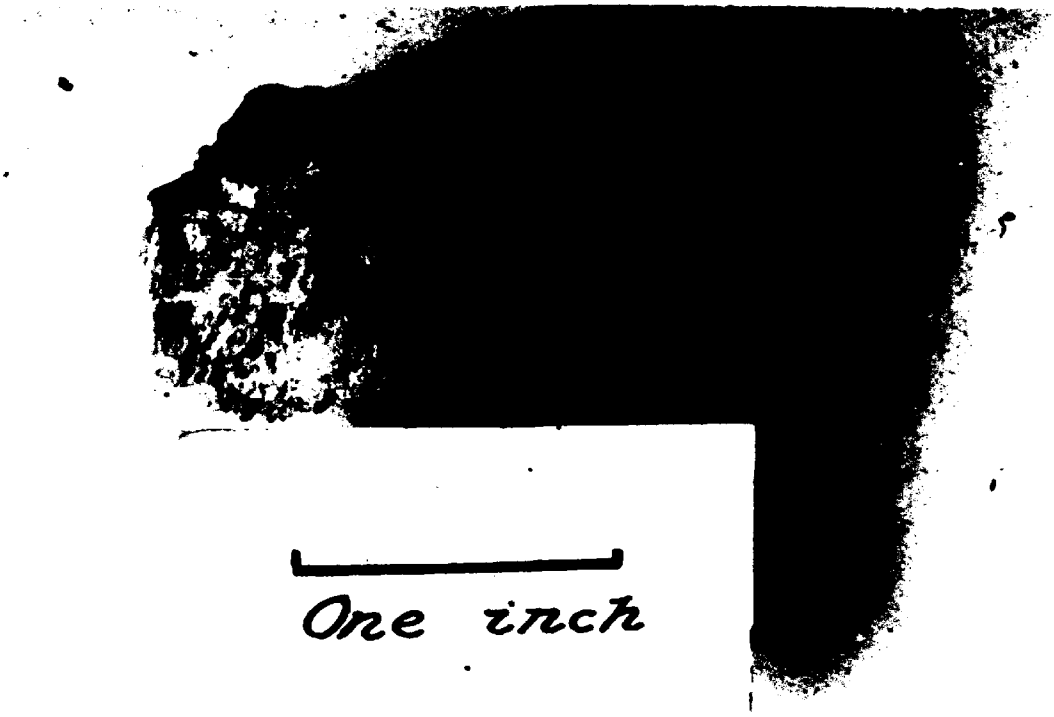
E. Fracture zones cut across the replacement unit along its flanks, entering the quartz core. Intense shattering has taken place, and core quartz is locally strongly brecciated and recemented by

Plate 43.

Figure A: Strained, patchy core-quartz in Meyers Ranch pegmatite. (+) nicols, x 43.

Figure B: Flattened garnet in microcline associated with muscovite veins.




One inch

albite (Ab 99) and sericite. Very patchy extinction is general in this quartz (pl. 43, fig. A). Where these zones cut the replacement unit, mica books have been crumpled, and beryl, feldspar, and quartz have been granulated and cemented by mylonitic albite and sericite. Some of the beryl crystals are offset by small faults.

Mineralogy of the outer zones

Microcline.--This occurs as pink to red grains as much as three inches in diameter, commonly intergrown with colorless quartz and albite.

Quartz.--Appears to be of two different types and ages. Colorless quartz, apparently the same age as the closely associated microcline and albite, occurs as irregular grains in these minerals, showing no apparent structural or cleavage control. Milky to gray quartz occurs as later veins transecting both the feldspars and the earlier quartz. This quartz is locally associated with muscovite in a graphic, or plumose intergrowth. This texture may have been developed in one of three ways:

a) Muscovite replacement of quartz, controlled by fractures and grain boundaries.

b) Simultaneous formation of the quartz and muscovite.

c) Quartz replacement of muscovite, partially controlled by its cleavage.

Muscovite replacement of the quartz is favored by the writer.

Microscopically these intergrowths are essentially identical in appearance with the typical porphyroblastic muscovite textures of the metamorphic rocks.

Albite.--This is apparently of primary origin, and is considerably more calcic than the albite (Ab 99) of the replacement unit. It occurs as grains as much as two inches in diameter associated with microcline, and also commonly intergrown with the early quartz.

Muscovite.--A little muscovite appears to be of about the same age as the early quartz and feldspar in this zone, occurring as small, rum-colored flakes as much as one-half inch in diameter. Most of the muscovite, however, is in sub-graphic to graphic intergrowths with the quartz as described above. This later mica varies in color from a grayish white to rum-colored.

Mineralogy of the core

Minerals here are limited to massive colorless to deep rose quartz, and a few small scattered books of muscovite and crystals of microcline, apparently all of approximately the same age.

Mineralogy of the replacement unit

Quartz.--The early quartz (which is in part relict core quartz, and in part relict quartz from other units) which is colorless to rose, has been shattered and replaced by albite,

muscovite, tourmaline, garnet, apatite, and bismuth carbonates along fractures. Dense grayish quartz occurs as late veins, forming along fractures in the earlier quartz, microcline and albite, and cementing broken beryl and tourmaline crystals. It shows fracture and cleavage controlled replacement of feldspars, and encloses all of the earlier replacement minerals. Part or all of the period of its formation appears to overlap that of the late muscovite.

Microcline.--This mineral appears chiefly as relicts, for most of it has been replaced by albite. The relicts can be seen microscopically in the centers of the grains of replacement albite. A strong structural control was effective, and the twin lamellae of the albite are commonly parallel with those of the earlier microcline. The remaining microcline occurs as blocks as much as two feet in diameter, and is pale pink to red in color. Much of it has been replaced by gray quartz, whose formation has been controlled by the microcline cleavage as well as by fracture planes.

Albite.--This mineral has replaced the microcline to a considerable extent, but also it occurs as fracture veins in early quartz and microcline. It varies in color from white to pinkish-red. Locally cleavage traces of adjacent muscovite have been impressed on albitized microcline, indicating that some of the albitization followed the muscovite formation.

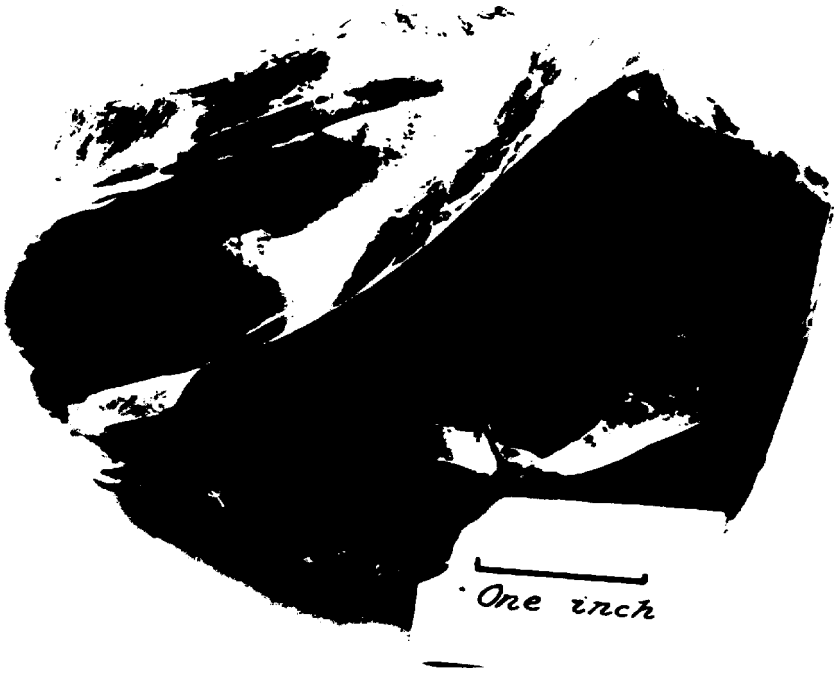
Muscovite.--Early muscovite occurs as small, hard,

rum-colored books, which seem to be contemporaneous with or a little earlier than the quartz core and bordering block microcline. Small books of this muscovite have been included in later beryl crystals (pl. 45, fig. B). A later, fracture-controlled muscovite, silvery-green to bright green, has formed books as much as two feet in diameter. Much of this mica has been intensively crumpled since its formation (pl. 44, fig. A). Mica of this type has impressed its cleavage traces on bordering quartz, albite (Ab 99), and columbite, which were formed later. Late muscovite occurs as small flakes, and also as large aggregates as much as six feet in diameter of clear books. It occurs with late quartz as a border surrounding columbite crystals, and is found as small flakes oriented parallel with the crystal faces of beryl closely adjacent to them. It cements fractures in the crystals of schorl that have replaced late quartz and feldspar, and also cross-fractures in beryl crystals. In thin fracture planes in feldspar, muscovite has formed as small plates, oriented parallel with the plane of the fracture. In larger fractures, a strong development of books as much as a foot in diameter oriented at right angles to the fracture planes has taken place (pl. 42, fig. B). Books of late muscovite include crystals of beryl, columbite, and small books of early muscovite. A combination of fine-grained muscovite, albite, and sericite has formed in some of the more intense fracture zones. Excess of solution over deposition results in a vuggy character of this rock.

Plate 44.

Figure A: Crumpled muscovite from core margin of Meyers Ranch pegmatite.

Figure B: Columbite crystal from Meyers Ranch pegmatite with (001), (010), (100), (110), (130), (150), (111) and (211) faces developed.


One inch



Sericite occurs in very fine green flakes, and is commonly associated with late quartz and muscovite. In the fracture-controlled replacement of microcline, sericite is common in the narrow outer extensions of the veins, and grades into quartz and small books of muscovite, where the veins widen. It is common as a border to quartz-muscovite replacement veins, and may be found as a fine border around quartz where it has replaced microcline controlled by the cleavage of the latter.

Biotite.--This occurs locally as blades in the strongly sheared parts of the quartz core. It is black in color, and the plates are as long as two feet. Quantitatively, however, it is a minor constituent.

Columbite.--This occurs in rounded and distorted grains as well as in euhedral crystals as much as six inches long (pl. 44, fig. B, and pl. 45, fig. A). It is generally later than early replacement muscovite, as shown by the muscovite cleavage traces impressed upon it. It is later than beryl and is found wrapped around beryl crystals. Small euhedral crystals of columbite are found as inclusions in books of a later replacement muscovite. The average specific gravity is 5.62. Hanley et al. (1950, p. 107) report an analysis made for the Metals Reserve Company by Ledoux and Company showing Cb_2O_5 = 48.28%, Ta_2O_5 = 26.53%, TiO_2 = 2.64% and SnO_2 = 0.19%. One remarkable crystal was found which exhibits unusually excellent euhedral development (pl. 44,

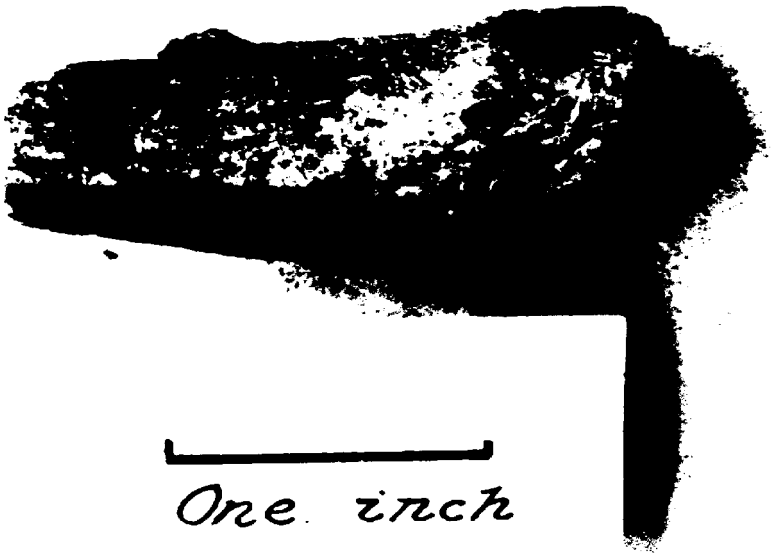
Plate 45.

Figure A: Large columbite crystal from Meyers Ranch pegmatite.

Figure B: Tapered beryl crystal with inclusion of small muscovite book. Meyers Ranch pegmatite.



One inch



One inch

fig. B). The (001), (010), (100), (110), (130), (150), (111) and (211) faces are represented.

Beryl.--Crystals of beryl are abundant, varying in length from a fraction of an inch to ten feet, the average being two to three inches. Although some are gemmy, they are too fractured to be truly gem material. The colors range from white, through yellow, yellow green, to blue green, with a corresponding increase in the indices of refraction (for w) from 1.568 to 1.575. This increase is reported to correspond to an increase of alkali content (Winchell, 1933, pp. 212-213), and perhaps corresponds to a decrease in age as colors change and indices rise as the center of the replacement unit is approached. The crystals are commonly tapered and show striations and basal rounding. These tapered crystals are typically oriented nearly normal to the contact between the unreplaced core and the hydrothermal replacement unit with the larger ends of the crystals toward the core. In vuggy replacement areas, kaolinite forms pseudomorphs after beryl, and indistinct zonal central replacement implies a compositional zoning. Completely brecciated crystals of beryl are found in the cemented fracture zones, mixed with brecciated quartz and bonded by albite and mylonitized feldspar. Small books of hard, rum-colored muscovite are included in the beryl (pl. 45, fig. B), and thin plates of later muscovite coat the beryl crystals and aid in cementing fractures across the crystals. The beryl crystals are included in books of later mica and

and crystals of later columbite. Large nests of beryl crystals are the most interesting mineralogical (and economic) features of this pegmatite (pl. 46, figs. A and B).

Tourmaline.--All of the tourmaline is of the schorl variety, occurring in crystals as much as three inches in length, and also as granular aggregates. It occurs in and near late fractures, replacing gray quartz and albitized microcline. It prefers to replace quartz, in which it forms moderately large, well-developed crystals. Where it has replaced feldspar, however, it has developed either a network of fine, flattened crystals, parallel with fracture planes, or as a massive aggregate of minute, felted crystals. It is found as euhedral inclusions in some small muscovite books. Late quartz and fine-grained muscovite are found cementing cross-fractures in the crystals, some of which are displaced.

Garnet.--Occurs as subhedral to euhedral crystals as much as an inch in diameter, and as fine-grained seams along fractures in quartz. Its color is a deep reddish to clove brown. Its average index is 1.815 $\pm$ 0.002 and the specific gravity is approximately 4.20. This indicates a dominantly spessartite (with almandite) composition (Fleischer, 1937, pp. 754-757). Thin black manganese oxide alteration films support these findings. Garnet shows a strong preferential replacement of quartz, but also has replaced the albitized microcline along fractures. Commonly the crystals are

Plate 46.

Figure A: "Nest" of beryl crystals at core margin. Meyers Ranch pegmatite.

Figure B: Beryl in same "nest" as figure A after some removal of material. Meyers Ranch pegmatite.





markedly flattened, particularly where they have formed in feldspar (pl. 43, fig. B). Some of the fracture and cleavage controlled replacement quartz in feldspar has been selectively replaced by garnet, leaving only a thin border of quartz around the garnet crystals. In other places, fine seams of garnet have formed in narrow fracture planes in quartz. Locally these widen out to pods of large, closely intergrown garnet crystals. In some graphic intergrowths of quartz and muscovite, garnet has replaced the quartz selectively, resulting in a sub-graphic muscovite-garnet intergrowth.

Apatite.--Minor amounts of glassy apatite of dull gray green color are associated with the garnet. Some of it is euhedral in crystals about one-fourth inch in diameter, but most is badly weathered to carbonate. It appears to be approximately the same age as garnet, and also prefers to replace quartz.

Bismuth carbonate.--This is found in the shattered margins of the quartz core as a blocky fracture-controlled replacement deposit. Locally it is found in a pseudomorphous elongate prismatic form in needles as much as two inches long, and one-fourth inch in diameter. Both bismutite and beyerite are present and have been described by Heinrich (1947, pp. 660-669). Much of the bismutite is a powdery yellow green along its margins, and a darker gray green centrally. This may be an indication that it has formed through

the alteration of earlier bismuthinite, as is also suggested by the pseudomorphous prismatic shape. Minute olive green crystals are associated with the bismuth carbonate. These show an index of refraction greater than 1.80, and are uniaxial and optically negative. They may represent a find of rare bismutite crystals, none of which have been previously reported but they are too small for goniometric or Weisenburg photograph study.

Radioactive mineral.--This has been tentatively identified as uranothorite or fergusonite. It is observed as one platy, olive green crystal about two inches in diameter, with a strongly developed brown alteration halo due to radioactivity. It is earlier than the later replacement books of muscovite.

Paragenetic history

1. Intrusion of the pegmatite magma into the gneissic granodiorite.
2. Initiation of crystallization of the wall zone with sequential deposition of:
    a) Muscovite
    b) Albite (Ab 92)
    c) Quartz and microcline

    Somewhat later more quartz and muscovite formed, either by:
    a) Reaction of uncrystallized magma remaining in this unit, or

b) Much later replacement associated with the core-margin mineralization.

3. Crystallization of segregated masses of microcline around the core.

4. Crystallization of the core.

5. Fracturing, and reaction either of remaining pegmatitic liquids or later hydrothermal solutions with parts of the core, intermediate zone, and inner parts of the wall zone. Wholesale replacement of these units is apparently guided by their contacts with the quartz core. Two somewhat separate general stages appear to be present:

   a) Fracturing, followed by fracture-controlled deposition of beryl, biotite, muscovite, albite, quartz, garnet, apatite, tourmaline, columbite, fergusonite (?), and bismuthinite (?) in approximately that order (see fig. 7).

   b) Renewed fracturing with local breaking and distortion of all previously formed minerals, followed by the deposition of sericite, albite, quartz, and the formation of bismutite and beyerite by the alteration of bismuthinite. Renewed fracturing.

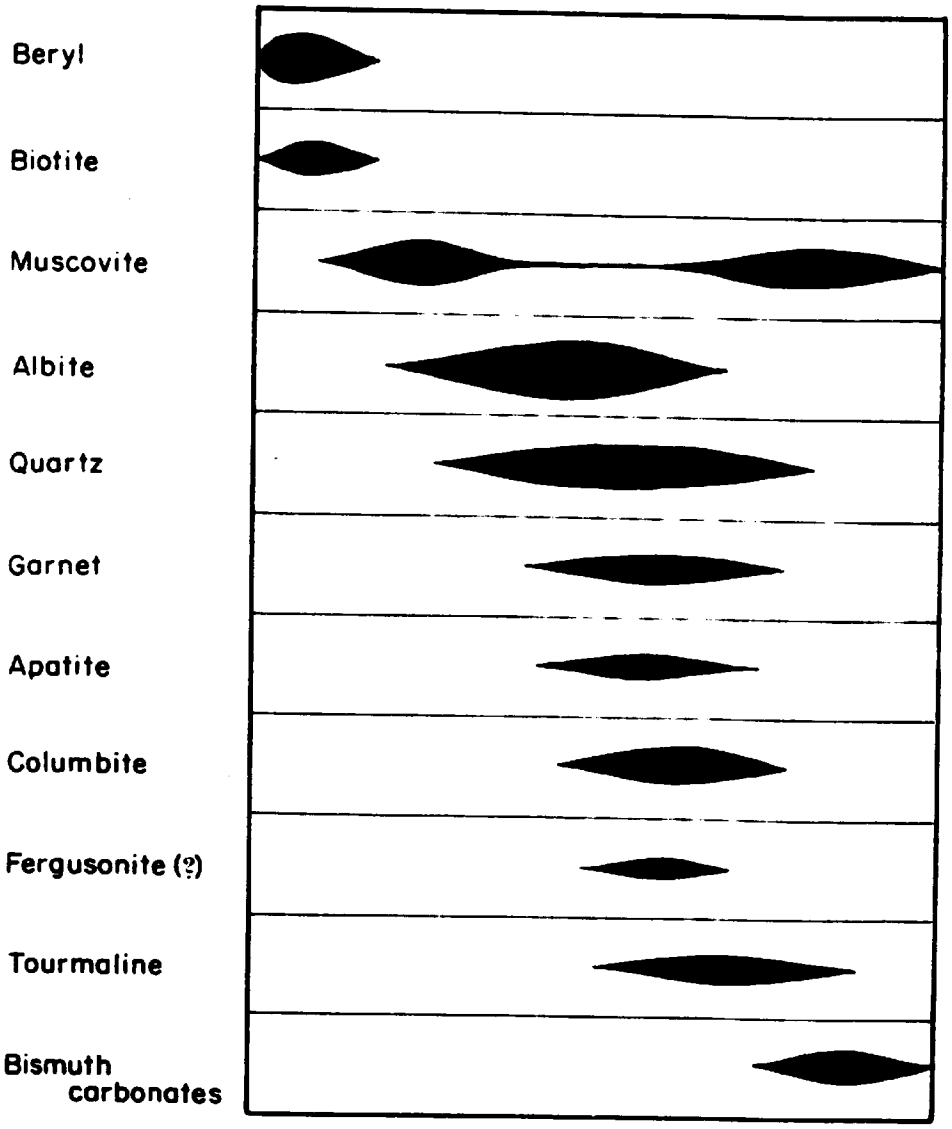


FIG. 7 Paragenetic relationships of replacement unit minerals in Meyers Ranch pegmatite.

Production

No figures are available on the early production, but the total quantity of pegmatite ore removed from the 12 cuts and tunnels is between 2500 and 3000 tons. The production recorded since 1930 includes:

beryl	40 tons (est.)
columbite	1 1/2 tons (est.)
feldspar	200 tons
mica	155 tons (est.)

Reserves

At this time the deposit might be workable at a profit, considering the high market price offered for beryl and columbite. In the event of an increase in demand for the economic minerals present, which might be coupled with the cutting off of foreign sources of supply, this pegmatite would be valuable reserve, although the tonnages of economic minerals are not great.

The reserves as estimated in 1951 are:

beryl	50 tons
columbite	5 tons
mica	1500 tons
feldspar	5000 tons
bismuth carbonate	several hundred pounds.

These estimates, derived in part from Hanley et al. (1950, p. 107), are considered to be conservative.

Whopper Pegmatite

Hanley et al. mapped and described the Whopper Mine on Micanite Ridge (1950, pp. 48-50), and reported (p. 48) the presence of "Granular magnetite in masses as much as 3 inches in size" in the wall zone "in small quantities." The writer found symplectitic quartz-magnetite aggregates as much as 15 centimeters in diameter to be rather abundant in a selvage at the contact between the pegmatite and the intruded biotite sillimanite schist.

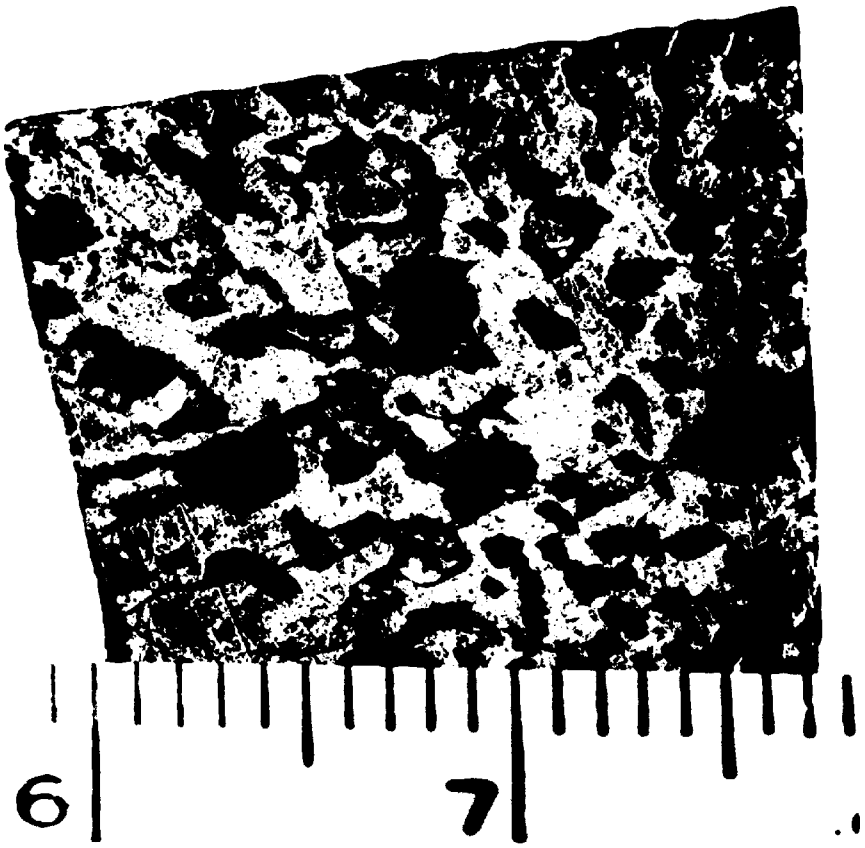
The magnetite commonly shows octahedral outlines, although in many cases these are interfered with by adjacent quartz. Individual magnetite octahedra as much as 3 centimeters on edge are present. The origin of the graphic quartz-magnetite intergrowth (pl. 47, fig. A) was of mineralogical interest, and the writer conducted an examination of a number of polished sections with vertical and inclined reflected illumination. This showed that between the quartz and the magnetite a narrow shell of muscovite is almost invariably present. In many cases this mica has been replaced by thin magnetite veinlets, and in a few cases magnetite replacing muscovite has retained the mica form, and relict cleavages are still apparent (pl. 47, fig. B).

Originally this pegmatite apparently contained quartz-muscovite symplectite which is so common, not only in other pegmatites, but also in the schists and gneisses of the area. A late stage reaction with hydrothermal solutions rich in iron resulted in a pseudomorphous symplectite with muscovite

Plate 47.

Figure A: Graphically intergrown quartz (dark) and magnetite (light). Whopper pegmatite.

Figure B: Photomicrograph of intergrowth pictured above. Dark gray is muscovite, medium gray is quartz and light gray is magnetite. The magnetite retains muscovite cleavages locally (right margin). Whopper pegmatite. (-) nicols, x 128.


6
7



having been preferentially replaced.

Some of the magnetite has been converted to martite, probably as a final reaction in these rocks. A source for the iron is easy to find in the material removed in the injection of the metamorphic rocks.

Climax Pegmatite

The Climax pegmatite (pl. 48, fig. A) on Micanite Ridge has been described at length by Sterrett (1923, pp. 52-54) and Hanley et al. (1950, pp. 43-45). The unusual aspect of this deposit is that cordierite crystals (Hanley, p. 44) "2 feet wide and as much as eight feet long, extend across the intermediate zone into the core. The crystals are almost completely altered to muscovite."

Heinrich (1950, pp. 173-184) discussed this occurrence in detail and compared it with similar occurrences elsewhere. He concluded that "The theory of crystallization from an uncontaminated pegmatite magma has favorable supporting arguments, but crystallization from a magma contaminated through assimilation of aluminous rock at depth cannot be dismissed in all cases." In this occurrence the location is ideal for aluminous contamination to have been a genetic factor. In addition the writer found cordierite gneiss outcropping a short distance from the pegmatite.

As noted by prior investigators the cordierite has been intensively altered to pinite, including muscovite, biotite, chlorite, garnet and tourmaline. The intensity of

Plate 48.

Figure A: Climax pegmatite on Micanite Ridge. The main cut is shown.

Figure B: The West West pegmatite with the block microcline unit in the background.





alteration, as concluded by Heinrich (1950, pp. 183-184), suggests that it was of a hydrothermal nature. Plate 49, figure A shows the typical pinite appearance in hand specimen and figure B shows the microscopic appearance of this alteration.

East West and West West Pegmatites

Two pegmatite deposits were exploited for the first time in 1951 by George West and sons. They are remarkably similar in mineralogy to other pegmatites in the area. These are located approximately 200 yards apart, a mile west of the Meyers Ranch pegmatite.

The East West pegmatite which strikes N.42°E. is about 430 feet long by 360 feet wide and, as it is on a steep hillside, it has a nearly 50-foot vertical exposure. The contacts with the biotite gneiss country rock are not exposed.

The pegmatite is poorly zoned. Major rock types that it contains are:

1. Biotite-quartz-microcline rock with some muscovite.
2. Graphic granite.
3. Milky to smoky quartz pods not more than one foot in diameter. With these "core" units some wedge "A" muscovite occurs. Some flesh-colored perthitic block microcline is adjacent to the quartz.

Crystals and crystal fragments of monazite, euxenite, columbite, beryl and black tourmaline were found on the dumps.

Plate 49.

Figure A: Pinite fragment (about nine by twelve centimeters) from replacement of cordierite in Climax pegmatite.

Figure B: Pinite alteration development in cordierite (white) in Climax pegmatite. (+) nicols, x 40.





A new road follows the lower (north-west) margin of the pegmatite and above it two flat benches have been cut by bulldozer for the removal of feldspar. The poorly zoned character of the pegmatite made it difficult to mine and operations stopped shortly after the completion of developmental work.

The West West pegmatite (pl. 48, fig. B) is a dike intruded into hornblende gneiss. This pegmatite is better zoned than the neighboring East West deposit, but many of the unit relationships are obscured by large volumes of dump and road material. This was mapped with Brunton compass and tape (Fig. 8).

The pegmatite strikes approximately N.30°E. It is approximately 335 feet long by 260 feet wide. It has exposed:

1) A uniform quartz-feldspar-muscovite wall zone.
2) An intermediate zone of block microcline. This light pink feldspar unit is as much as 30 feet wide and occurs adjacent to the quartz core, both above and below it. Much of the microcline has been albitized.
3) A discontinuous quartz core. This elongate unit is approximately parallel with the strike of the pegmatite. It dips west at a high angle (approximately 60°). Most of the quartz is white to light rose, but some smoky quartz crystals occur in the unit.

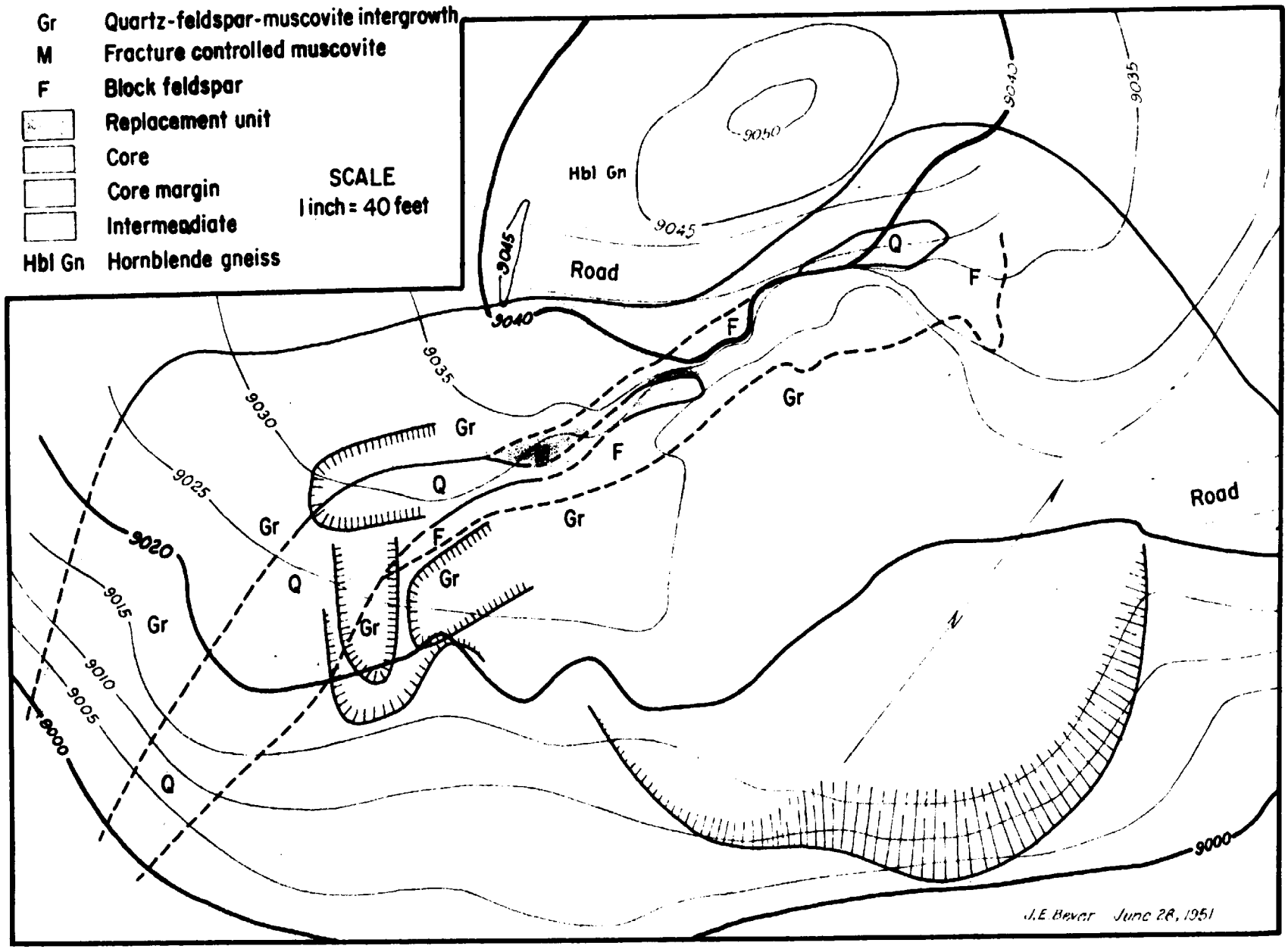


FIG. 8 Map of the West West Pegmatite. Mapped by tape and Brunton compass. Assumed datum is 9000'.

4) A core margin unit of fracture-controlled hydrothermal replacement origin. This contains crumpled muscovite and minor fractured beryl. It is small and in all of its exposures is adjacent to and above the quartz core.

The only economic mineral found in commercial quantities is feldspar. Possibly more beryl or mica will be uncovered as the pegmatite is exploited.

COPPER, LEAD AND ZINC

Three mines have been operated for copper in this area, but to date none has ever been able to operate continuously for any significant period. E. B. Eckel visited the Betty (Lone Chimney) mine in 1932 but did not examine the others, as their workings were reported to be inaccessible (Lovering and Goddard, 1950, 55. 69-70). The workings of the Mill Gulch and Copper King mines are inaccessible. Native copper was reported from these, however, and secondary copper minerals are present on the dumps. Although the workings at the Betty mine were being kept in good repair, the mine was not being operated at the time of the writer's investigations and he was unable to conduct an underground inspection.

The Betty mine is about a quarter of a mile south of the Black Mountain Road and one mile west of Currant Creek. It is in a small lens of giant-grained lime-silicate rock enclosed in pre-Cambrian biotite gneiss. This rock has

been intruded by an Oligocene rhyolite breccia dike associated with the Guffey volcanic series. Eckel states (Lovering and Goddard, 1950, p. 69) "(the dike) can be traced southwestward for a distance of about 4 miles to the Mill Gulch mine. It is resistant to erosion and forms a well-defined ridge." This is not the case, and apparently Mr. Eckel was the victim of misinformation given to him by local "experts". The breccia dike actually ends a few hundred feet southwest of the Betty mine, and is present neither at the Copper King mine nor the Mill Gulch mine. These latter two mines occur in rocks closely similar to those at the Betty mine, but, although relatively near extrusives, these have not been cut by dike rocks.

Both the biotite gneiss and breccia dike are cut by a fine-grained basaltic dike. There is no significant mineralization or alteration associated with either the rhyolitic or basaltic intrusions. This, in addition to the absence of Oligocene intrusives at the other two mines, suggests that the ore is of pre-Cambrian rather than Tertiary origin.

The gangue minerals of the ore deposit as exposed on the dump include those typical of similar giant-grained lime-silicate rocks elsewhere in the area, except they exhibit purer segregations and larger grain size. Cordierite is abundant as large masses and also as a few unusual large, euhedral prismatic crystals (pl. 50, fig. A). Quartz, calcite, fresh glassy gray anorthite (An 99), gray anthophyllite, sillimanite, epidote and spinel are also abundant

along with minor grossularite and hornblende. The sillimanite is typically present in a fibrous form intergrown with anthophyllite, but large pure columnar masses are also present (pl. 50, fig. B). The spinel is present as large crystals as much as 2 centimeters on edge, but also as fine disseminated grains which impart a greenish cast to some of the rocks. Some alteration of spinel to talc has taken place. This spinel may represent the vesuvianite identified in hand specimens by Eckel (Lovering and Goddard, 1950, p. 69).

The ore minerals are later in origin than the gangues, occurring as veinlets, small cleavage and fracture replacements and massive replacements. Their textures are commonly controlled by those of the replaced silicate minerals, particularly anthophyllite (pl. 51, fig. A). Galena, chalcopyrite and sphalerite are typically localized along grain boundaries or cleavages of fibrous anthophyllite. In some places the form of replaced anthophyllite is retained in pseudomorphs (pl. 51, fig. B).

The sequence of ore mineralization as determined in polished section was:

6) Malachite and azurite (alteration of primary copper minerals).
5) Sphalerite.
4) Chalcopyrite (dominant ore mineral).
3) Galena and bornite (not observed in same section).
2) Pyrite (as ragged relicts).
1) Gangue minerals.

Plate 50

Figure A: Prismatic cordierite crystal (two centimeter diameter) in quartz. Betty mine.

Figure B: Large mass of columnar sillimanite from Betty mine.



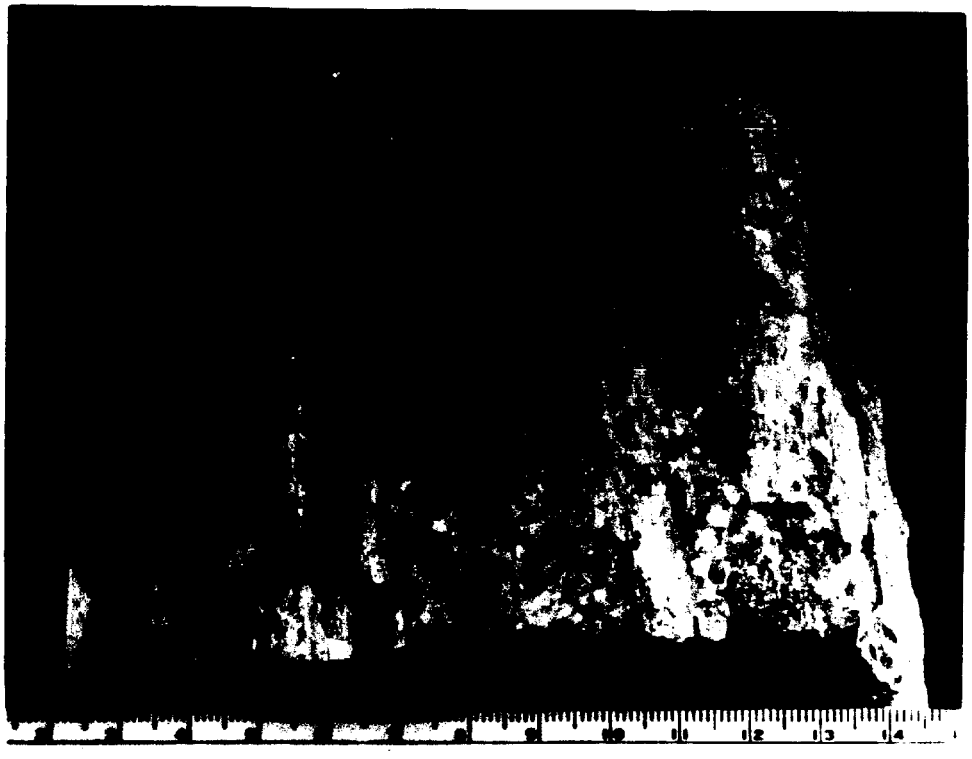
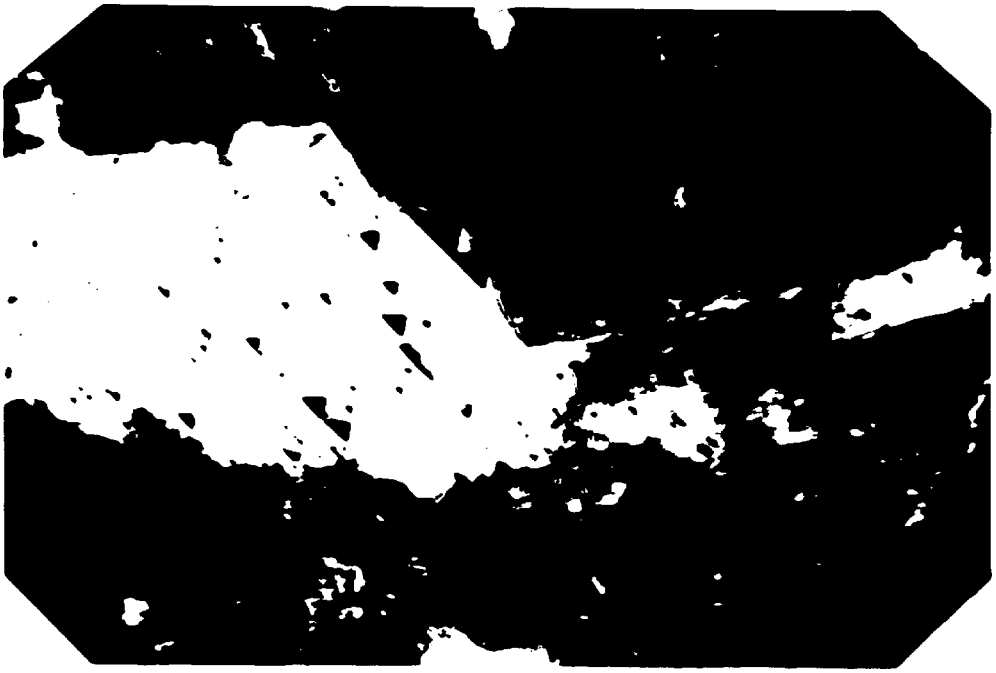
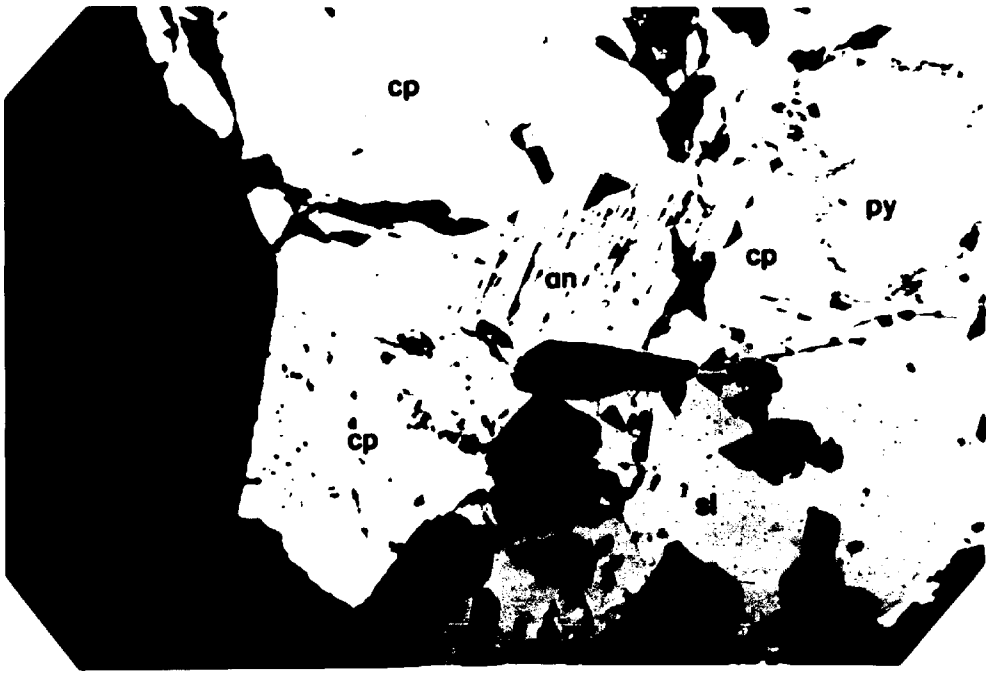


Plate 51.

Figure A: Galena (white) development controlled by cleavage of anthophyllite. Betty mine. (-) nicols, x 128.

Figure B: Ragged pyrite relict (py) in chalcopyrite (cp). Sphalerite (sl) replacing chalcopyrite. Pseudomorphous anthophyllite (an) outline and cleavage retained by chalcopyrite which has replaced it. Betty mine. (-) nicols, x 128.




cp
py
cp
an
cp
sl

The Betty mine is owned by A. B. Dell and his sons, Buford and Charles. The Howell shaft has been sunk to 300 feet but only minor drifting has been done from this. Other small openings have been made, but these are not significant. Construction was started on a small mill at the mine site in 1951, but no ore was being mined. The only reported production for mines in this group was in 1945-1947, as reported in the Minerals Yearbook for those years. Not subdivided for individual producers, this totaled 11 ounces of gold, 168 ounces of silver, 8500 pounds of copper, 2600 pounds of zinc and 3700 pounds of lead. Generally, it can be stated that on the basis of what is known about these mines to date they are sub-marginal producers at best.

TUNGSTEN

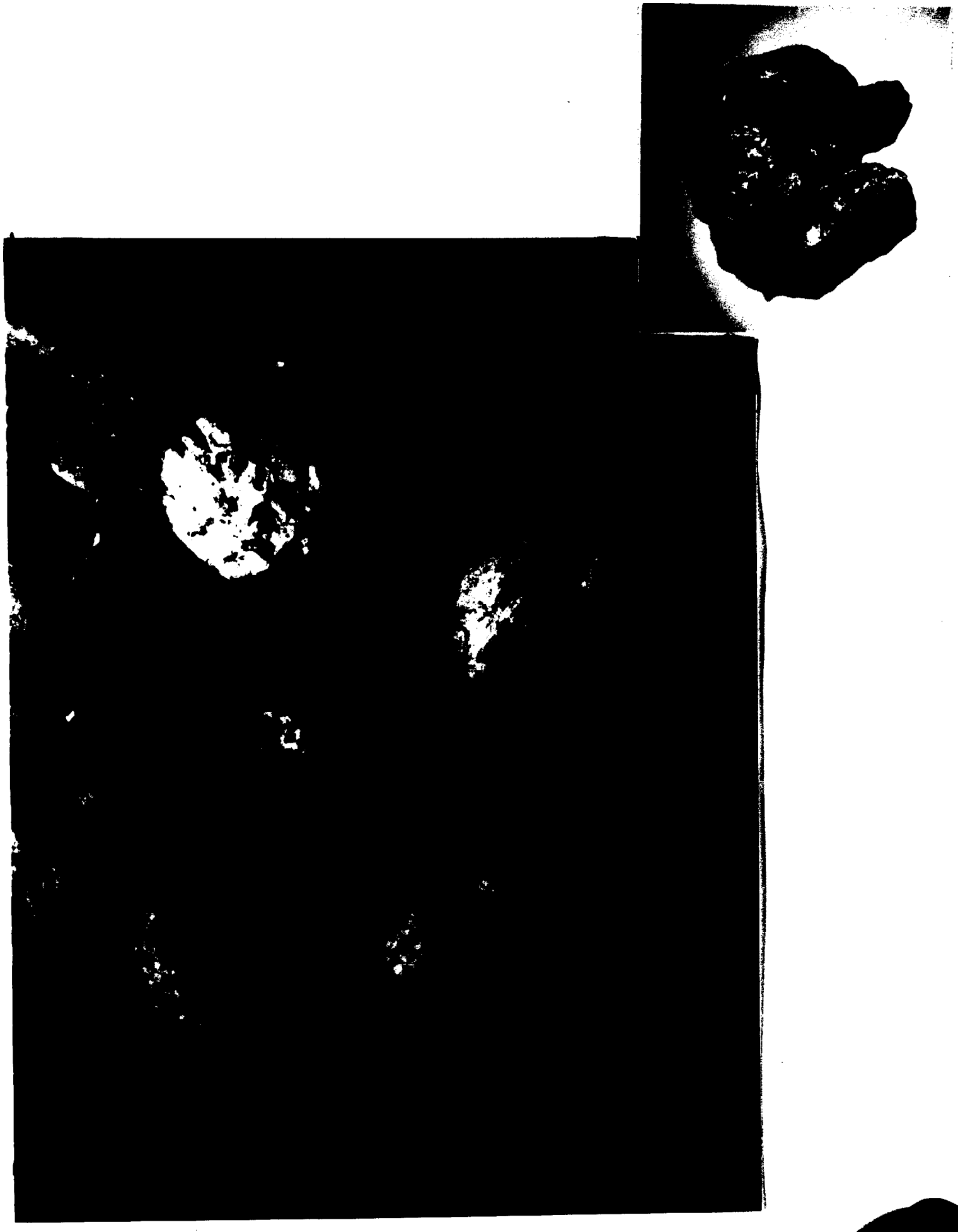
Tungsten mineralization has heretofore not been reported from this area, but scheelite occurs as disseminated grains and crystals in possible commercial concentrations at the West tungsten prospect along the ridge about one-quarter mile northeast of the West ranch. This is at the junction of Colorado State Highway 9 and the Guffey road. The scheelite occurs in a coarse-grained crystalloblastic aggregate of epidote, hornblende, quartz, calcite and garnet formed by the metamorphism and metasomatism of impure calcareous sediments. This is one of the giant-grained lime-silicate rocks. The scheelite is milky white, and occurs in subhedral to euhedral crystals as large as 2

centimeters on edge. Some of the crystals are unusual in showing a pronounced zonal variation in fluorescent colors (pl. 52).

The centers of the crystals fluoresce blue-white, whereas the narrow margins exhibit a yellow fluorescent color (pl. 52). In view of the studies by Cannon et al. (1942, p. 65) and by Greenwood (1943, pp. 56-64), this indicates a core of tungsten-rich material and a molybdenum-rich margin although Greenwood (p. 61) indicates that manganese and copper may have a somewhat similar effect. The Scheelite Fluorescence Analyzer prepared by Cannon and Murata and described in the above reference indicates that the crystal showing the greatest variation has less than 0.1% molybdenum by weight in the central part of the crystal (pronounced blue-white) and well in excess of 5% at the margin (pronounced yellow). The color (and chemical) change is very abrupt indicating either a molybdenum-rich reaction rim or late, oriented molybdenum-rich overgrowth. Many of the crystals are unzoned and near white in color, and these average slightly less than 1.0% molybdenum. The indices for these are $w = 1.925 \pm 0.001$ for the blue-white, $w = 1.922 \pm 0.001$ for the white and $w = 1.924 \pm 0.001$ for the yellow. Research by Zambonini, as reported by Palache et al. (1951, pp. 1074-1080), indicates that the indices increase with substitution of molybdenum for tungsten in the scheelite-powellite series; a major discrepancy is apparently involved here, and additional research on these specimens seems

Plate 52.

Zonal fluorescence of scheelite from West tungsten deposit as displayed under ultra-violet radiation. The insert at upper right shows the same fragments under normal illumination. The largest specimen is approximately twenty centimeters in its maximum dimension.



desirable.

This deposit is not rich enough to be mined profitably at existing prices. It may, however, become mineable in the future, and also its presence may indicate that other, better deposits remain to be discovered.

GOLD

Many prospect holes were dug for gold in the Guffey area around the turn of the century. The major impetus in this exploration was a similarity, real or fancied, to the volcanic terrain at Cripple Creek. Although some gold was found and a number of shafts and adits developed, no venture showed an overall profit. The gold reportedly occurred native and as gold tellurides in quartz veins in the extrusives.

The largest openings in the area were at the Carbonate King and Susannah mines, which are approximately one mile north of Guffey. The former reportedly has a 300 foot shaft and 600 feet of drift along the vein. There is no activity or apparent interest in any gold properties in the area at this time. All workings are long deserted, caved and inaccessible.

SUMMARY

As reported in this section, the only currently profitable mining operations are for pegmatite minerals. These operations are all on a small scale and conducted intermittently. In all probability exploitation will remain on this basis.

Gold and the aluminum silicate deposits seem to have very poor potentialities. Tungsten and complex copper ores, however, could conceivably become important, particularly if further exploration resulted in new discoveries.

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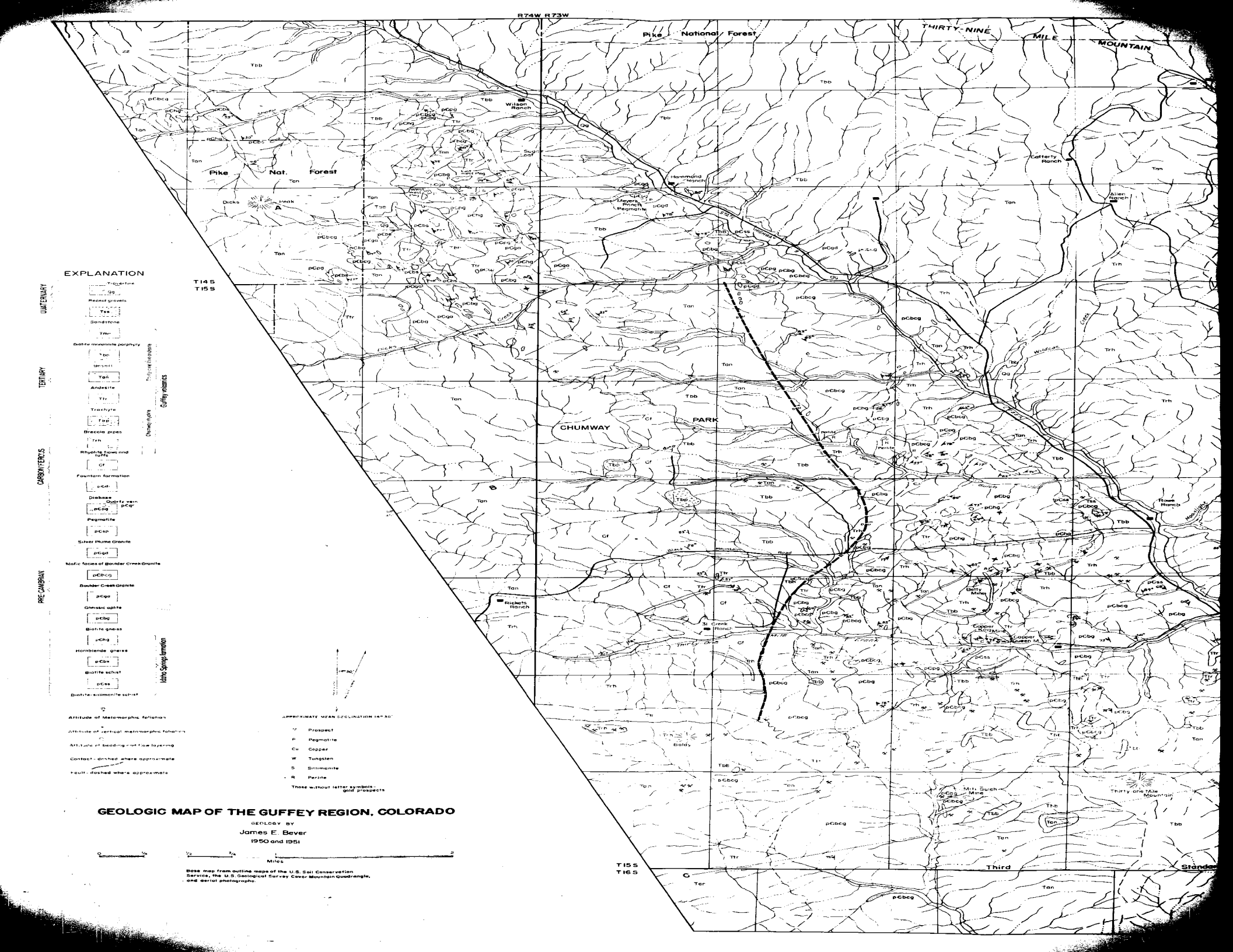
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R74W R73W
Pike National Forest
THIRTY-NINE MILE MOUNTAIN
Pike Nat. Forest
T14S
T15S
T15S
T16S
CHUMWAY PARK
Wilson Ranch
Hammond Ranch
Lafferty Ranch
Allen Ranch
Rowe Ranch
Rickets Ranch
Dicks Peak A
Baldy
Thirty one Mile Mountain
Mitt Gulch Mine
Copper Queen Mine
Third
EXPLANATION
QUATERNARY
TERTIARY
CARBONIFEROUS
PRE-CAMBRIAN
Travertine
Qg
Recent gravels
Tss
Sandstone
Tmp
Dolite mesonite porphyry
Tbp
Tbb
basalt
Tan
Andesite
Ttr
Trachyte
Tbp
Breccia pipes
Trh
Rhyolite flows and tuffs
Cf
Fountain formation
pCd
Diabase
Quartz vein pCqr
pCpg
Pegmatite
pCgp
Silver Plume Granite
pCgd
Mafic facies of Boulder Creek Granite
pCbcg
Boulder Creek Granite
pCgg
Gneissic aplite
pCbg
Biotite gneiss
pChg
Hornblende gneiss
pCbs
Biotite schist
pCss
Biotite-sillimanite schist
Devils Head
Thirty-nine Mile
Guffey volcanics
Idaho Springs formation
Attitude of Metamorphic foliation
Attitude of vertical metamorphic foliation
Attitude of bedding and flow layering
Contact - dashed where approximate
Fault - dashed where approximate
APPROXIMATE MEAN DECLINATION 14° 30'
Prospect
P Pegmatite
Cu Copper
W Tungsten
S Sillimanite
R Perlite
These without letter symbols - gold prospects
GEOLOGIC MAP OF THE GUFFEY REGION, COLORADO
GEOLOGY BY
James E. Bever
1950 and 1951
Miles
Base map from outline maps of the U.S. Soil Conservation Service, the U.S. Geological Survey Cover Mountain Quadrangle, and aerial photographs.

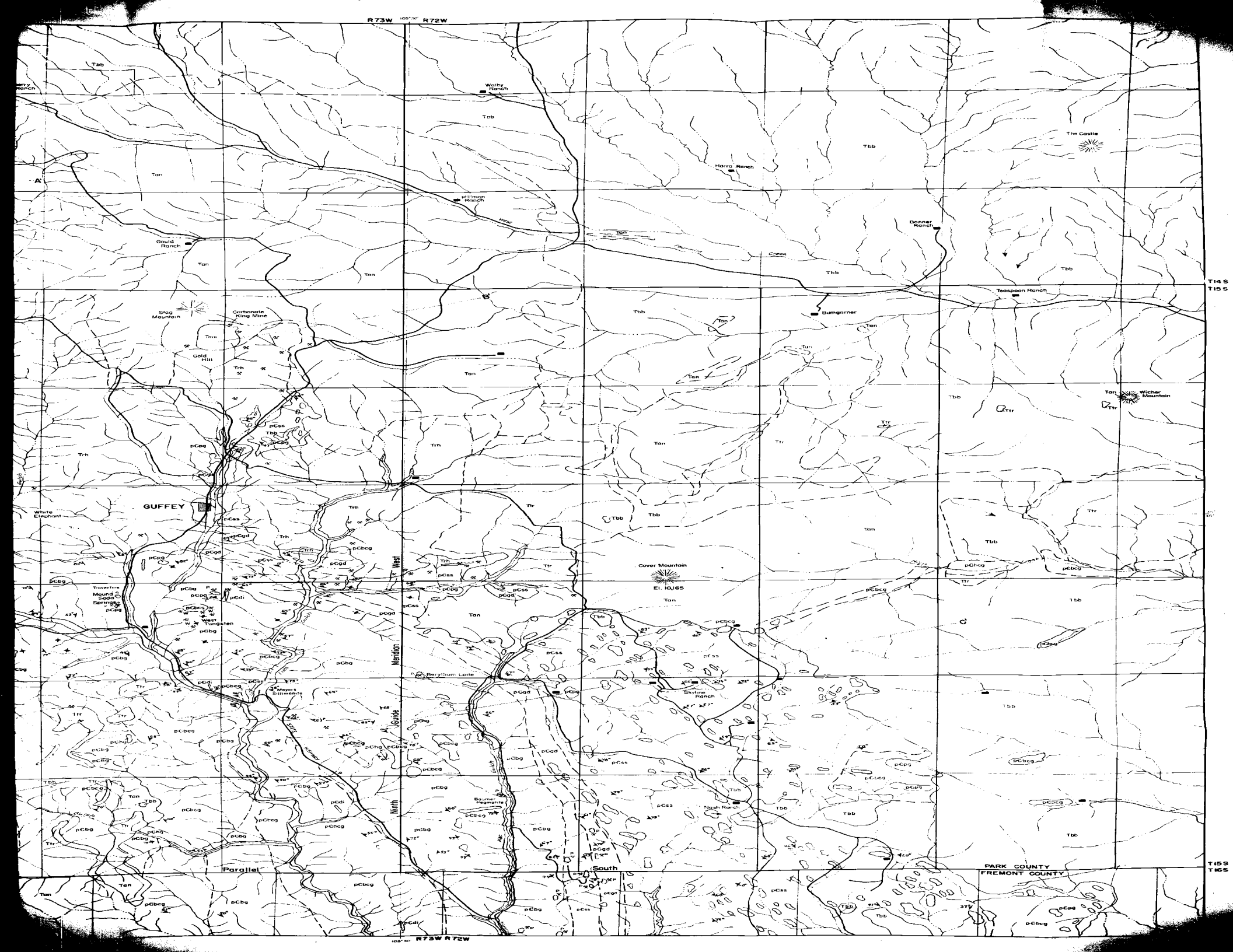
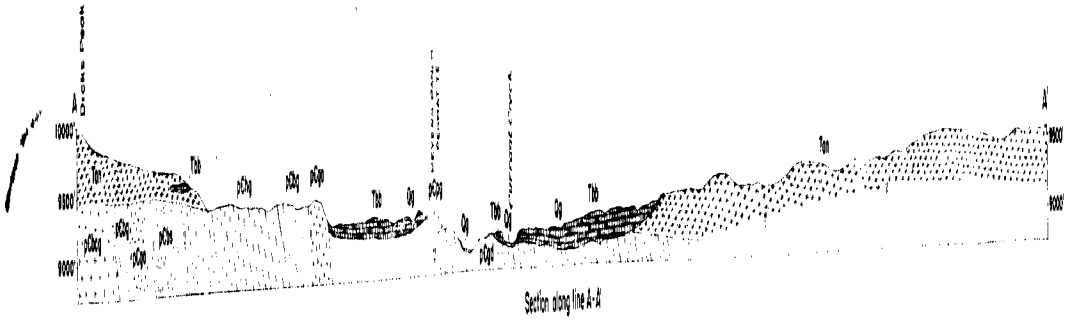
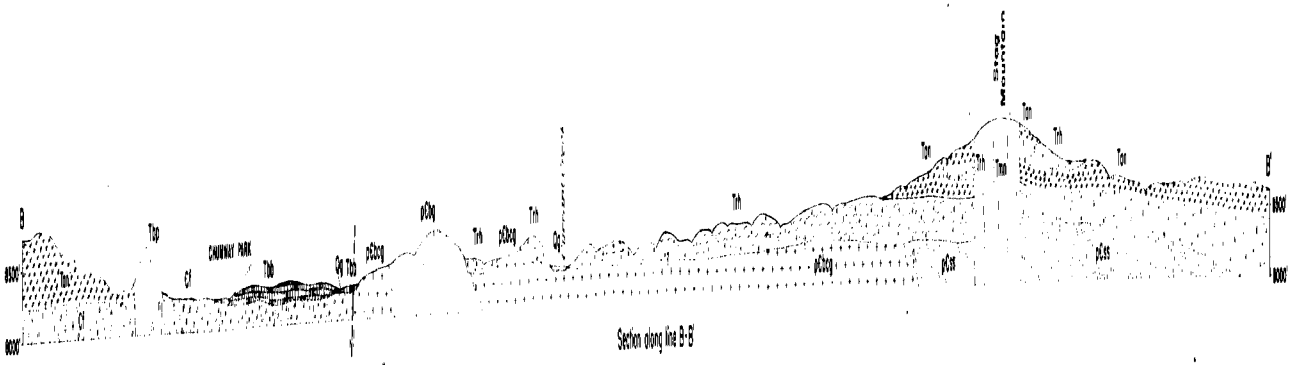
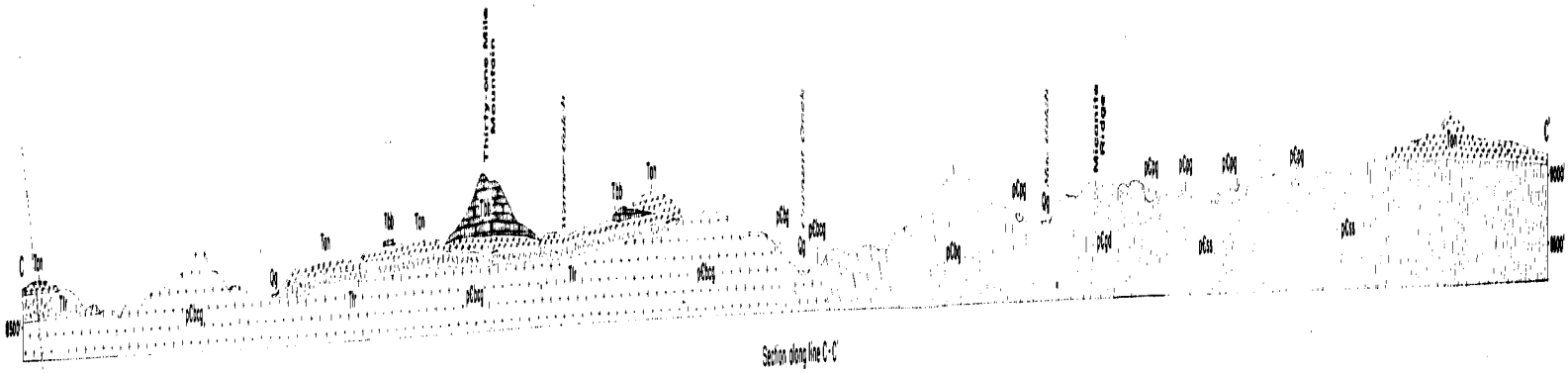

R73W
R72W
T14S
T15S
T15S
T16S
GUFFEY
Parallel
South
Meridian
West
Ninth
Cover Mountain
El. 10,165
Beryllium Lode
Skyline Ranch
Nash Ranch
Bumgarner
Teaspoon Ranch
Bonner Ranch
Harrg Ranch
Walby Ranch
Hillman Ranch
Gould Ranch
Stag Mountain
Carbonate King Mine
Gold Hill
Wicher Mountain
The Castle
White Elephant
Mound Soda Springs
Meyers Stillwater
Baumer Pegmatite
PARK COUNTY
FREMONT COUNTY

PLATE 1







GEOLOGICAL CROSS SECTIONS ALONG LINES A-A', B-B', C-C'

(TO ACCOMPANY PLATE 1)



EXPLANATION

pCss-biotite-sillimanite schist, pCb-biotite schist, pCbg-hornblende gneiss, pCgs-granitic gneiss, pCbcg-Boulder Creek granite, pCgd-metamorphosed Boulder Creek granite, pCpg-pegmatite, Cf-Fountain formation, Tri-rhyolite, Tbr-breccia pipes, Tn-trachyte, Tan-andesite, Tbb-basalt, Tmp-biotite-muscovite porphyry
Qg-gravels