Geology of the Northern Part of the Tenmile Range, Summit County Colorado

GEOLOGICAL SURVEY BULLETIN 1162-D

Prepared in cooperation with the Colorado State Metal Mining Fund Board

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By MAX H. BERGENDAHL

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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GEOLOGY OF THE NORTHERN PART OF THE TENMILE RANGE, SUMMIT COUNTY, COLORADO

By Max H. Bergendahl

ABSTRACT

The Tenmile Range is in north-central Colorado, about 80 miles west-southwest of Denver, and is a north-trending mass of contorted Precambrian metasedimentary rocks, overlain on its eastern flank by gently folded Paleozoic and Mesozoic sedimentary rocks. These rocks were invaded by small plugs and stocks of igneous rocks, which range in age from Precambrian to Tertiary.

This report emphasizes the petrography, stratigraphy, and structure of the Precambrian rocks. The Precambrian metasedimentary rocks consist of a series of crystalline gneisses representative of the sillimanite-almandine subfacies of the amphibolite metamorphic facies. These gneisses occur in a recognizable stratigraphic sequence, the lowermost unit of which is granulite, a quartz-oligoclase-microcline gneiss with minor amounts of biotite and hornblende. This granulite is overlain by a banded gneiss, which consists of alternate light and dark layers composed of quartz-plagioclase and hornblende-plagioclase. The banded gneiss is overlain by migmatite, another two-component gneiss, composed of discontinuous biotite-hornblende-plagioclase-quartz laminae and pods and layers of quartz-plagioclase-microcline. A unit called pink migmatite, also of Precambrian age, is apparently younger than the migmatite, but the relations are not clear. The intrusive rocks of Precambrian age are all younger than the migmatite and consist of diorite, red oligoclase aplite, granite similar to the Silver Plume Granite, alaskite, and dikes of pegmatite, aplite, and alaskite.

Sedimentary formations appear on the east flank of the Tenmile Range, where they lie unconformably with the Precambrian rocks and with one another. Included among these formations are the Sawatch Quartzite of Cambrian age, the lower part (Pennsylvanian) of the Minturn Formation, the Maroon Formation of Pennsylvanian and Permian age, the Morrison Formation of Jurassic age, and the Dakota Sandstone of Cretaceous age.

Rocks of Cretaceous(?) or Tertiary age consist of a stock and smaller masses of quartz monzonite. The dike rocks of porphyritic monzonite are classified as Pando Porphyry, Elk Mountain Porphyry, and Lincoln Porphyry; they are of early Tertiary age.

The Precambrian rocks were subjected to at least two periods of plastic deformation during Precambrian time. The most prominent of these resulted in the formation of northwest-trending folds. The second deformation was along a shallow plunging axis trending S. 70°–80° E. During Paleozoic and Mesozoic

time vertical tectonic forces were dominant, and the area was alternately elevated and depressed. These movements resulted in numerous unconformities having extreme local relief.

The major faults in the area trend north, northeast, and northwest and are of the high-angle variety. The Precambrian rocks in the fault zones are downgraded to the greenschist facies, and their textures are cataclastic. Some faults displace sedimentary formations of Mesozoic age.

The principal ore deposits of the area are in quartz veins containing variable amounts of pyrite, chalcopyrite, galena, sphalerite, and small amounts of silver sulfides, native gold, and molybdenite. The minimum total production has been 1,750 ounces of gold, 406,300 pounds of lead, 15,770 ounces of silver, 81,800 pounds of copper, and 920 pounds of zinc. None of the mines were operating during the time that fieldwork was done in the area.

INTRODUCTION

The Tenmile Range is located in north-central Colorado, in the southern part of Summit County, about 80 miles west-southwest of Denver. A region of extreme relief, the Tenmile Range is the northern extension of the Mosquito Range; it lies between the Gore Range on the west and the Front Range on the east. The area shown on the map comprises about 50 square miles, more than two-thirds of the entire range. Fieldwork was done during the summer months of 1957 and 1958 and about 5 weeks in 1959. The writer was ably assisted by J. A. Randall in 1957 and by R. J. Lutton in 1958.

This report emphasizes the petrography, stratigraphy, and structure of the Precambrian rocks. The sedimentary rocks are given only superficial treatment, mainly because other authors have previously described them in nearby areas where more complete sections occur in normal stratigraphic sequence. References to these reports are made in appropriate sections of this report.

PREVIOUS WORK

In years past, many geologic studies have been made in the areas bordering the Tenmile Range, but the Precambrian core of the range has never been mapped in detail. The first work in this general area was by Emmons (1896), who studied the ore deposits of the Kokomo district. His map slightly overlaps the southern edge of plate 1 of this report. The Breckenridge district, which is immediately east of the Tenmile Range, was studied by Ransome (1911) and by Lovering (1934). Butler and Vanderwilt (1933) reported on the geology of the Climax molybdenum deposit at the south end of the Tenmile Range. R. S. Cannon, Jr., (written communication, 1933) was the first to study details of the petrography of the Precambrian rocks, but his work did not include any detailed mapping, and was never published. The Kokomo district was restudied and mapped in considerable detail by Koschmann and Wells (1946). The present report is an extension of their work. The geology and ore deposits of the Upper Blue River area, which borders this area on the southeast, were described by Singewald (1951). Paragenetic relations of the minerals of the Precambrian rocks of the Tenmile Range were studied by Koschmann (1960), and a generalized picture of the structure and stratigraphy was briefly reported by Koschmann and Bergendahl (1960).

GENERAL GEOLOGY

The oldest rocks of the northern part of the Tenmile Range are of Precambrian age and consist of contorted gneisses and a variety of intrusive rocks. On the east flank of the Range, the Precambrian rocks are unconformably overlain by sedimentary rocks of Paleozoic and Mesozoic age that dip moderately to the east. A stock and numerous dikes and sills of several textural varieties of quartz monzonite of Late Cretaceous(?) or Tertiary age cut the older rocks.

PRECAMBRIAN METAMORPHIC ROCKS

The Precambrian metamorphic rocks consist of high-grade metasedimentary gneisses and granulite, which, although tightly folded, are arranged in a recognizable stratigraphic sequence, in which the granulite is overlain by banded gneiss and the banded gneiss is overlain by migmatite (Koschmann and Bergendahl, 1960, p. 250). A unit mapped as pink migmatite is possibly younger than the migmatite, but the relations are not clear. This sequence is not clearly shown on the map because of the steep dips; but in numerous exposures outside of the area, where dips are on the order of 45° or less, the relations are consistently as stated.

In parts of the area it was necessary to map several Precambrian units as an undifferentiated unit because of small-scale intercalation of different rock types. Units were also combined where float contains mixtures of several rock types that made it impossible to locate contacts.

GRANULITE

The term "granulite" as used here follows the usage of Harker (1939, p. 246–248) to designate a high-grade foliated metamorphic rock consisting mostly of quartz and feldspar. The term denotes a lithologic type and should not be confused with the granulite facies of metamorphism.

The lowermost unit of the Precambrian stratigraphic sequence is granulite, which is exposed in the cores of anticlines in the northwest end of the map area about 1 mile west of Frisco, across the north-central part of the map area (section *B–B′*), and in the extreme southwest corner. A large body of granulite occurs south of the mapped area in the southern part of the Tenmile Range (Koschmann, 1960, p. 1359–1361). The base of this unit is not exposed; hence the true thickness cannot be determined. An approximate estimate of minimum thickness is 6,500 feet.

The granulite of the Tenmile Range is a light-gray, black-streaked medium-grained gneiss composed of quartz, oligoclase, microcline, and small amounts of biotite and hornblende. In some specimens, minor amounts of chlorite, clinopyroxene, epidote, and garnet are present. Accessory constituents, occurring in amounts of considerably less than 1 percent, are apatite, sphene, magnetite, rutile, zircon, muscovite, and—locally—carbonate and garnet. The biotite occurs in clusters of grains which cause the rock to be foliated in most places. Ellipsoidal quartz grains are oriented with their long axes in the plane of foliation, and—locally—these impart a faint lineation to the rock.

Oligoclase, microcline, and quartz make up the bulk of the granulite. Potassium feldspar is extremely variable in amount, ranging from only a trace in some samples to more than 40 percent by volume in others. The quartz content is fairly constant, composing from 22 to 45 percent by volume. The amount of oligoclase by volume varies inversely with the amount of microcline, ranging from 13–33 percent in the rocks containing the most microcline to 50–55 percent in those containing the least microcline. Locally, oligoclase is converted to epidote and muscovite.

Quartz, the most common mineral, occurs as anhedral grains, as clusters of grains with sutured contacts, as poikilitic grains in oligoclase, and as large elongate grains recrystallized in the plane of foliation. Almost all the quartz shows wavy extinction due to strain, and in some specimens the larger grains have cataclastic borders. Most of the plagioclase is oligoclase, but sodic andesine is present in a few specimens. Almost all the oligoclase is sericitized to some extent, and some of it is converted to epidote. Numerous grains have clear albite rims. In samples with a minor amount of microcline, the oligoclase is antiperthitic. Potassium feldspar occurs as microcline and microperthite. It is a late mineral, filling interstices between quartz and oligoclase in some specimens and replacing those minerals in others. Myrmekite is a fairly common feature in the granulite, although it does not occur on a large scale.

The mafic constituents of the granulite, biotite and hornblende, aggregate less than 15 percent of the volume. Clinopyroxene, present in a few samples, is in various stages of decomposition to hornblende, and locally, biotite has downgraded to chlorite.

BANDED GNEISS

The banded gneiss, a relatively thin unit which overlies the granulite, is well exposed in the gorge along U.S. Highway 6, about 1½ miles west of Frisco, 3½ to 4½ miles southwest of Frisco, in the lower reaches of Miners Creek, and across the north-central part of the map area.

Two varieties of banded gneiss have been combined in this unit. One is composed of alternate black and white layers ranging from half an inch to several feet in thickness; the other is characterized by layers 1/32 to ½ inch thick. In both types the dark layers consist of amphibolite and the white layers are of oligoclase-andesine and quartz. Aside from the difference in thickness of the layers, the thin- and thick-banded varieties are identical, and no consistent stratigraphic or areal patterns could be ascertained in mapping them.

The banded gneiss has a maximum thickness of 1,600 feet; it seems to be thinner, in general, on the limbs of folds and thicker near the crests and troughs. It is absent locally, owing possibly to rupture during folding or perhaps to nondeposition or erosion of its sedimentary counterpart. Both upper and lower contacts of this unit are gradational. Near the base, the layers of amphibolite and felsic material are thicker, and the contact is drawn where the thick amphibolite bands are engulfed in granulite. Near the top of the banded gneiss, biotite becomes more abundant and hornblende decreases. Individual layers of amphibolite only an inch or two in thickness can be traced for distances of as much as 150 feet along the outcrop before they are ruptured or pinch out. Other layers are severely contorted and broken and show excellent boudinage structure. It is clear that the felsic material yielded to stress by flowage; the amphibolite, by fracture. Hornblende and biotite grains have a preferred orientation in some specimens, giving the rock a faint lineation, usually in the "b" direction, or parallel to small fold axes.

The chief minerals in the dark layers are euhedral to subhedral hornblende and subhedral andesine-labradorite arranged in a lepidoblastic fabric. Minor constituents are quartz, biotite, clinopyroxene, chlorite, and epidote. Accessory minerals are magnetite and apatite. Most of the quartz in the dark layers occurs as poikiloblastic inclusions in plagioclase, as rounded blebs forming sieve texture with hornblende, and as a late mineral in thin stringers along cleavage and grain boundaries of biotite, plagioclase, and hornblende. Wherever clinopyroxene is present, it is in various stages of decomposition to hornblende. In some specimens the biotite is converted to chlorite and the hornblende to epidote and chlorite. Such samples are commonly cut by numerous paper-thin fractures filled with fine-grained epidote and chlorite.

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The light layers contain dominantly anhedral quartz and subhedral andesine-labradorite, but oligoclase was noted in a few samples. Some quartz and plagioclase is poikiloblastic and contains small rounded quartz grains.

In both the light and dark layers, the plagioclase is moderately to intensely sericitized; in some specimens it has been converted to a fine mixture of epidote, zoisite, and albite (saussurite). The following table summarizes the distribution of the major minerals in both varieties of banded gneiss.

Distribution of quartz, plagioclase, and hornblende in banded gneiss

	Percent by volume		
	Thin-banded gneiss (felsic and mafic layers combined)	Thick-banded gneiss	
		Felsic layers	Mafic layers
Quartz	<20	30–40	<10
Plagioclase	30–50	49–59	17–44
Hornblende	31–57	----------	50–67

AMPHIBOLITE

A few lenses of amphibolite were found in the granulite near the contact with the banded gneiss. Most of them occur in the large body of folded granulite in the north-central part of the map area. The largest lens of amphibolite is 1,700 feet long and 200 feet thick; the smallest shown on the map is 200 feet long and less than 50 feet thick. Smaller lenses were found, but could not be shown at the map scale. The top and bottom contacts of the amphibolite are sharp, but the ends interfinger with the granulite.

Although its mineralogy is identical to that of the dark bands in the banded gneiss, the amphibolite does not display any distinct foliation, and its grains are slightly coarser than those of the banded gneiss.

MIGMATITE

The term "migmatite" in this report refers to a foliated rock composed of biotite-hornblende-plagioclase-quartz laminae alternating with pods or discontinuous layers of quartz, plagioclase, and microcline. The mafic layers are medium grained; most of the felsic material is medium to coarse grained. Much of the latter is pegmatitic. The migmatite is characterized by wavy foliation produced by alternation of wispy layers of biotite and by clots and boudinagelike septa of pegmatitic quartz-microcline-plagioclase. Lineations are well developed in this rock and are expressed by axes of drag folds, alined minerals, slickensides, and crinkles.

The migmatite overlies the banded gneiss and is the most widely distributed unit in the Tenmile Range. It is well exposed in the cirques in the southern part of the range and in the northern part of the Tenmile valley, and it is folded into a large east-trending syncline in the central part, just east of Wheeler Junction.

Lenses containing as much as 5 percent sillimanite and others containing 10 percent garnet occur locally in the migmatite half a mile southwest of Royal Mountain but are too small to be mapped as separate units; however, lenses of lime-silicate gneiss and porphyroblastic migmatite were mapped as separate facies of the migmatite.

Anhedral quartz, subhedral oligoclase-andesine, and euhedral to subhedral biotite are the main constituents of the migmatite. In some specimens they are present in equal amounts; in others any one of the three may predominate. Potassium feldspar composes as much as 40 percent of the volume of some specimens but is absent from most. Other minerals—garnet, sillimanite, muscovite, apatite, epidote, and sericite—compose, in aggregate, less than 15 percent of the migmatite.

The quartz in the migmatite occurs as subrounded grains with sutured contacts, as clusters of grains, and as crosscutting stringers and elongated lenses. In some rocks it is clearly an early mineral, but in others it crystallized late, replacing biotite, crosscutting plagioclase grains, and extending along cleavages of chlorite. Other late quartz forms large lenticles in optical continuity, which have their long dimensions in the plane of foliation.

The plagioclase ranges in composition from calcic oligoclase to sodic andesine. Most of it is moderately sericitized. Near the margins of plagioclase grains adjacent to microcline, myrmekite occurs on a small scale.

Biotite forms a stable assemblage with sillimanite, plagioclase, garnet, and quartz in this rock, but in samples with a cataclastic texture the biotite is in various stages of decomposition to chlorite. Garnet is a minor local constituent, occurring usually as somewhat fractured porphyroblastic crystals. Sillimanite is sparsely distributed throughout the rock, composing less than 5 percent of the volume. It occurs as sheaves of fine fibers (fibrolite) or as scattered groups of fine needles similarly oriented. Sillimanite cuts across other minerals; apparently it was one of the last minerals to form during the high-grade metamorphism.

Microcline occurs locally as microperthite, and it also occurs as antiperthitic blebs in plagioclase, as interstitial fillings between quartz and plagioclase, as granoblastic grains, and as porphyroblasts. The most common accessory minerals are apatite and magnetite. These are most abundant in the biotite-rich layers of the migmatite.

Shear zones that cut migmatite less than half a mile south of Royal Mountain and about three-fourths mile north of Wheeler Junction transform the rock into a cataclasite. Ragged-edged grains of quartz and plagioclase are engulfed by pulverized and comminuted quartz and feldspar. Twin lamellae of plagioclase are bent, offset, and re-cemented by secondary plagioclase, and remnants of plagioclase grains are rimmed by later clear plagioclase. Strain has produced undulatory extinction in both quartz and plagioclase. The rock is interlaced by numerous fractures filled with fine-grained chlorite and epidote, and chlorite has completely replaced biotite.

LIME-SILICATE GNEISS

Along the western margin of the area, the migmatite contains several small concordant lenses of lime-silicate gneiss, a facies which is rich in calcium and magnesium and deficient in silica, alumina, and alkalies. On the outcrop the rock is a greenish-gray to pinkish-gray pyroxene-epidote-garnet-carbonate gneiss. Some layers are richer in carbonate than others, and these weather more rapidly and thereby accentuate the foliation.

Clinopyroxene, clinozoisite, carbonate, garnet, and epidote are the chief constituents of the lime-silicate gneiss. Quartz and scapolite are minor components. The clinopyroxene shows polysynthetic twinning. Some of the clinopyroxene is comparatively fresh, but most of it is in the form of ragged grains in various stages of decomposition to carbonate, garnet, and fine-grained epidote and clinozoisite. The garnet is fractured, and the fractures are filled with very fine grained carbonate, quartz, and zoisite. Carbonate is a late mineral which fills intergranular voids and engulfs pyroxene.

PORPHYROBLASTIC MIGMATITE

A large mass of porphyroblastic migmatite occupies the southeast corner of the map area. This is a sinuous body about 1¼ miles long and as much as 2,200 feet wide. It is concordant with the regional strike and dip and interfingers with the normal migmatite at its northern end. The southern end of this body extends beyond the mapped area.

The rock is a biotite-quartz-plagioclase gneiss, characterized by plagioclase porphyroblasts that range in composition from calcic oligoclase to sodic andesine and in long dimension from less than ½ inch to more than 2 inches. Many of these are elongated sufficiently to produce a lineation that seems to be in the "b" direction, or parallel to fold axes. In other respects the mineral composition and texture of this rock are identical with those of the migmatite discussed previously.

PINK MIGMATITE

Pink migmatite was reported to compose the uppermost unit of the Precambrian metasedimentary sequence in the area (Koschmann and Bergendahl, 1960, p. 250, 252). It is exposed along the western border of the mapped area (see geologic map) and is in fault contact with the granulite, banded gneiss, and normal migmatite throughout most of its outcrop area; however, it seems locally to be in normal contact with the granulite. South of the mapped area, a rock that seems to be the same as the pink migmatite overlies the normal migmatite. In view of these inconsistent relations, the pink migmatite cannot be assigned a definite place in the stratigraphic sequence. In the mapping it was distinguished from the normal migmatite because of its pink color, the consistent fresher appearance of biotite, and the paucity of sillimanite.

The rock is typically composed of wavy discontinuous layers of biotite and plagioclase ranging from less than half an inch to several inches in thickness that alternate with layers of medium- to coarse-grained quartz and pink plagioclase, some of which are pegmatitic. Locally the layering is extremely contorted and wrinkled. Lineations are well developed in this rock and are expressed by alined biotite flakes, wrinkles, and drag-fold axes. Another variety of pink migmatite, less abundant than the rock just described, has about the same mineral composition, consisting of a fairly homogeneous black-and-pink-speckled medium-grained quartz-plagioclase-biotite gneiss. This rock is not banded, and the foliation is indistinct.

The chief minerals of the pink migmatite are quartz, oligoclase, and biotite. Microcline is a minor constituent which composes less than 2 percent of the volume of some samples and is absent from others. Much of the quartz is granoblastic, but in some slides it is recrystallized into grains elongated along the foliation. Other quartz engulfs oligoclase and occurs as stringers along cleavages of biotite. The fact that some of the larger quartz grains contain poikilitic quartz inclusions suggests two generations of quartz. The oligoclase is moderately to intensely sericitized and cloudy with hematite dust, which imparts the pink color to the rock. Myrmekite occurs near the margins of some oligoclase grains adjacent to microcline. Biotite is subhedral to euhedral; the grains have a preferred orientation. In some samples the biotite is partly replaced by muscovite and a little magnetite and chlorite. In these same samples both microcline and oligoclase are intensely sericitized. Sillimanite is a minor constituent of the pink migmatite; only a few very fine needles were found. Accessory minerals are sphene and zircon, occurring as tiny euhedral grains. In one thin section a trace of carbonate was seen associated with biotite.

ORIGIN AND METAMORPHISM

The Precambrian metamorphic rocks were probably originally of sedimentary origin, as suggested by the following evidence:

1. A persistent stratigraphic sequence in areas where dips are less than 60°; the granulite is overlain by banded gneiss, and the banded gneiss is overlain by migmatite.
2. Strong evidence of relict graded bedding in some samples of migmatite.
3. The close resemblance of the layers in the banded gneiss to sedimentary strata. Many of these layers, although only a few inches thick, can be traced for more than 150 feet before they are ruptured. Adjacent layers are of variable thickness; that is, a layer a foot or more thick may be in contact with a layer or several layers only an inch thick. This evidence suggests that the banding represents the original sedimentary units of variable thickness and composition rather than metamorphic differentiation.

The sedimentary rocks were subjected to intense dynamothermal metamorphism and were thereby altered to gneisses of the sillimanite-almandine subfacies of the amphibolite facies. The stable assemblages of hornblende-plagioclase-biotite-microcline-quartz, and sillimanite-garnet-biotite-plagioclase-microcline-quartz, which characterize the gneisses of the Tenmile Range, indicate this metamorphic grade. Clinopyroxene, which was formed in some of the more lime-rich layers of banded gneiss and in the lime-silicate gneiss, is not in chemical equilibrium. It is rimmed and incompletely replaced by hornblende or by carbonate, garnet, fine-grained epidote, and clinozoisite. This decomposition could be due to a later metamorphism, still within the amphibolite range, in which hornblende was stable but the previously formed clinopyroxene was not.

Other retrograde metamorphism is related to shear zones. The rocks in these zones have downgraded to the greenschist facies; biotite has altered to chlorite, plagioclase to epidote and zoisite, and hornblende to epidote and chlorite. Many joints and fractures that crosscut the earlier foliation are filled with epidote. The unstable clinopyroxene in the lime-silicate gneiss also seems related to temperatures and pressures in shear zones.

The origin of the porphyroblastic migmatite is difficult to explain in terms of its field relations to any centers of intrusion that may have been a source of metasomatizing solutions. Possibly this facies developed in a local environment that had a slightly slower rate of cooling, which enabled the large crystals to form.

PRECAMBRIAN IGNEOUS ROCKS

The metasedimentary rocks are intruded by small masses of quartz monzonite that is similar to the Silver Plume Granite of the Front Range (Ball, 1906) and by other small bodies of diorite, alaskite, aplite, and pegmatite. None of these rocks cut the Paleozoic or Mesozoic sedimentary rocks; therefore, it is assumed that they are of Precambrian age.

DIORITE

In the central part of the mapped area, the Precambrian metasedimentary rocks are invaded by a number of small irregular plugs of diorite that occur in a generally east-trending belt. A few very small bodies were found in the vicinity of Crystal Peak in the southern part of the area.

The diorite is a dark-gray medium- to coarse-grained eucrystalline rock consisting chiefly of hornblende and plagioclase; quartz is a minor constituent. The rock has no evident planar or linear structures and is therefore assumed to be younger than the regional metamorphism. Nevertheless, it is probably of Precambrian age, because it does not cut any of the Paleozoic or Mesozoic sedimentary rocks. Although none of the plutons in the east-trending belt are in contact with younger rock, the belt ends abruptly at a large area of Dakota Sandstone in the east-central part of the map area.

The texture of the diorite in thin section is hypidiomorphic granular. Hornblende is the chief mafic mineral, and it is usually accompanied by a colorless amphibole. Some of the hornblende is sieved with quartz. Other hornblende contains tiny flakes of magnetite along the cleavage. Small amounts of clinopyroxene are scattered through the rock, and all the clinopyroxene is rimmed and partly replaced by hornblende. Locally, the hornblende is altered to chlorite and epidote.

Quartz makes up about 5 percent of the volume of this rock. It seems to be a late mineral, in that much of it crystallized either as tiny blebs along cleavage in hornblende or as large grains that engulf plagioclase and hornblende. The plagioclase is sericitized to such an extent that the twinning is obliterated, and the refractive indices are changed so that the plagioclase cannot be identified.

Tiny crystals of sphene and apatite are accessory minerals in the diorite.

RED OLIGOCLASE APLITE

Several small bodies of red oligoclase aplite intrude the Precambrian metasedimentary rocks on the northeastern flank of the Tenmile Range in the vicinity of Miners Creek. In outcrop the aplite is a pink to red medium- to fine-grained rock having typical saccharoidal texture. It weathers along joints to rounded residual boulders.

The texture of the rock under the microscope is dominantly xenomorphic granular. The chief minerals are quartz and oligoclase. Potassium feldspar is common but extremely variable in quantity; in some specimens it is abundant enough to make the rock a granodiorite. Most commonly, however, potassium feldspar occurs in amounts less than 5 percent of the volume, predominantly as interstitial fillings or as microperthitic or antiperthitic blebs in oligoclase. The quartz and oligoclase are for the most part equidimensional anhedral grains, but locally either mineral may be poikilitically included in the other. Most of the oligoclase is somewhat cloudy, owing to sericite alteration and to inclusions of hematite or limonite dust.

Magnetite, biotite, and hornblende make up less than 5 percent of the volume of the rock and are normally finer grained than the quartz and oligoclase. Biotite forms feathery rims around magnetite grains and replaces hornblende, releasing fine-grained magnetite. The fact that, locally, sphene is associated with magnetite suggests that ilmenite was originally present at a higher temperature phase of the rock. Very fine grained zircon is another common accessory mineral.

GRANITE SIMILAR TO THE SILVER PLUME GRANITE

In the southern part of the area, on the west flank of Crystal Peak and just north of the large stock of Cretaceous(?) or Tertiary quartz monzonite, the migmatite is intruded by small stocklike bodies and numerous tiny pods and stringers of an igneous rock similar to the Silver Plume Granite. The pods and stringers are only a few feet to a few tens of feet in maximum dimension and in places are so abundant as to form a composite of migmatite and of granite similar to the Silver Plume. Such areas are shown on the map as: migmatite and granite similar to the Silver Plume Granite, undivided.

In hand specimen the granite similar to the Silver Plume is light-gray and black-speckled medium- to coarse-grained granitic rock, characterized by coarse-grained euhedral laths of microcline. Actually, the rock is a quartz monzonite rather than a true granite, for it is composed of almost equal amounts of oligoclase, quartz, and potassium feldspar. Modes of this rock are almost identical with published modes of Silver Plume Granite (Koschmann, 1960, p. 1364) and of biotite-muscovite granite in the Front Range of Colorado (Harrison and Wells, 1956, p. 55; 1959, p. 19). Biotite and muscovite are minor constituents; each composes from 4 to 8 percent of the volume of the rock. The two micas seem to be in equilibrium, this evidence indicates that the temperature and pressure of the quartz monzonite magma were low enough to permit muscovite to form and were lower than those of the earlier sillimanite-almandine environment of the enclosing migmatite.

The texture of the rock is hypidiomorphic granular. Quartz occurs as anhedral isolated grains and small masses of sutured grains surrounded by oligoclase and microcline. The quartz is permeated with numerous needlelike inclusions which appear to be rutile. Oligoclase occurs as euhedral to subhedral grains, many of which are moderately sericitized. Some grains contain spherical inclusions of quartz. The microcline in this rock occurs partly as large euhedral phenocrysts, many of which show carlsbad twinning, and partly as anhedral to subhedral grains which are the same size as the quartz and oligoclase grains. The large laths of the twins contain rounded inclusions of oligoclase and quartz. A few tiny crystals of accessory apatite were found. The granite similar to the Silver Plume Granite is a fairly fresh and unaltered rock, but locally some of the biotite is partly replaced by chlorite.

ALASKITE

Along the southern margin of the quartz monzonite stock, at the head of the west cirque of Peak 10, is a small mass of alaskite that invaded the migmatite.

On the outcrop, the alaskite is a light-gray to tan medium-grained leucocratic granitic rock. It crosscuts the regional foliation and has a faint foliate structure of its own, which may be protoclastic. Numerous dikes and apophyses branch out into the enclosing migmatite, producing an extremely irregular contact that could not be shown at the map scale.

The alaskite consists of orthoclase, quartz, albite-oligoclase, and muscovite, which, excluding muscovite, are equigranular and xenomorphic in texture. The muscovite is euhedral, slightly coarser grained, and seems to have a preferred orientation. Fine-grained biotite, magnetite, pyrite, and chlorite are very minor constituents. The texture of some specimens is characterized by patches of fine-grained granulated quartz and feldspar, interspersed with the medium-grained components, which show evidence of strain, such as bent plagioclase lamellae and undulatory quartz extinction.

PEGMATITE, ALASKITE, AND APLITE

The Precambrian rocks are cut by numerous dikes and irregular podlike bodies of pegmatite, alaskite, and aplite. These are particularly abundant in the vicinity of Peak 10 and Crystal Peak, where the migmatite on the cirque walls is veined and streaked by scores of light-colored dikes, sills, and amoeboid pods. These bodies show a variety of ages, because they cut across or intrude one another; nevertheless, they are all probably Precambrian, as none have been observed to intrude the Paleozoic or Mesozoic sedimentary rocks.

The pegmatite has a simple mineralogy and consists mostly of quartz, microcline, andesine, and minor biotite. Much of the microcline is microperthitic, and some of the andesine contains blebs of potassium feldspar along the cleavage. The andesine is somewhat sericitized.

The aplite and alaskite dikes are similar in composition but differ texturally. The aplite is a pink granitic rock with a distinctive fine-grained sugary texture, whereas the alaskite is a medium-grained granoblastic rock. Both are similar in mineral composition to the alaskite body in the Peak 10 area.

SEDIMENTARY ROCKS

Sedimentary rocks that range in age from Cambrian to Recent occur on both flanks of the Tenmile Range, in the cirque floors, in stream valleys, and—locally—in patches on the crest of the range in fault contact with the Precambrian rocks. They are irregular in distribution or fragmentary, and variable in thickness; nowhere are any complete sections exposed.

What is now the central part of the Tenmile Range was a high area intermittently during the Paleozoic and Mesozoic eras; consequently, the sedimentary formations are interrupted by considerable gaps in the normal sequence caused by erosion or nondeposition. In the northeastern part of the area the Dakota Sandstone of Early (?) and Late Cretaceous age overlies the Precambrian rocks in sedimentary contact. Locally, remnants of Morrison Formation of Jurassic age are found beneath the Dakota, and in one place a part of the Pennsylvanian and Permian sequence is preserved beneath the Morrison and Dakota Formations. Thus it is clear that the sedimentary record is one of interrupted deposition and (or) frequent intervals of uplift and erosion during Paleozoic and Mesozoic time, with a progressive overlap of younger beds to the north and a gradual thickening of the normal sequence of formations to the south. This is further elaborated on by Singewald (1951, p. 10). In the southeastern part of the mapped area, remnants of the Sawatch Quartzite of Cambrian age, an undifferentiated Paleozoic limestone, and the Minturn Formation are faulted against the Precambrian rocks.

Table 1 presents a summary of the sedimentary rocks in the Tenmile Range; however, Tweto (1949) gave a complete account of the stratigraphy of the Paleozoic rocks in the Pando area about 10 miles to the west, and Lovering (1934, p. 6–10) described in considerable detail the Mesozoic rocks in the Breckenridge district a few miles to the east.

TABLE 1.—*Sedimentary rocks in the northern part of the Tenmile Range, Summit County, Colo.*

Age	Formation or type of deposit	Description
Quaternary	Talus and landslide debris	Unconsolidated deposits, composed chiefly of fragments of Precambrian rocks.
Quaternary	Alluvium	Unconsolidated stream deposits of sand and gravel.
Quaternary	Moraine	Unconsolidated glacial deposits of sand and gravel; includes terminal, lateral, and ground moraine.
Early(?) and Late Cretaceous	Dakota Sandstone	Quartzite, light-gray, weathers to buff; highly fractured, mineralized locally; thickness in area, 100–200 ft.
Jurassic	Morrison Formation	Variegated silty claystone, with a few very thin white limestone beds; thickness in area, 50–100 ft.
Pennsylvanian, and Permian	Maroon and Minturn Formations, undivided	Red arkose and mudstone, grading downward into grayish micaceous arkose and grit; thickness in area, 150–200 ft.
Pennsylvanian	Minturn Formation, lower part	Gray micaceous arkose and grit; thickness in area, 700–800 ft.
Early Paleozoic	Unknown	Thin fault slices of compact white limestone of undetermined age.
Cambrian	Sawatch Quartzite	White fine-grained quartzite in thin fault slices.

CRETACEOUS(?) OR TERTIARY IGNEOUS ROCKS

QUARTZ MONZONITE

A stock of quartz monzonite of possible Late Cretaceous or early Tertiary age invaded the migmatite in the south-central part of the Tenmile Range, in the vicinity of Peak 9; the stock was described briefly by Crawford (1924, p. 372) and by Singewald (1951, p. 16). It extends down both flanks of the range and cuts the Minturn Formation of Pennsylvania and Permian(?) age just west of the mapped area. Locally, intrusive breccia was found along the border of the stock and in association with small outliers of quartz monzonite beyond the mapped area. The quartz monzonite is older than the Lincoln Porphyry, but its age relations with the Elk Mountain, Pando, and unnamed porphyries were not determined.

The quartz monzonite is a light-gray black-mottled medium-grained holocrystalline rock, with numerous phenocrysts of euhedral plagioclase and potassium feldspar. Locally, the rock weathers to a buff color due to disseminated fine-grained pyrite. Where the rock is fractured, pyrite fills fine seams and cracks.

The microscopic texture of the quartz monzonite is hypidiomorphic granular. The principal minerals are quartz, oligoclase-andesine, and microcline microperthite. Biotite, hornblende, and magnetite are minor minerals that make up less than 10 percent of the volume of the rock. Apatite and sphene are the common accessory minerals, and in one thin section a few grains of staurolite were found.

The quartz occurs as irregular masses and aggregates of grains which in some places enclose euhedral plagioclase and elsewhere assume the form of small round grains in the plagioclase and potassium feldspar. This evidence suggests two generations of quartz, one earlier and the other later than the plagioclase. The oligoclase-andesine occurs as subhedral grains and as faintly zoned euhedral phenocrysts, 5 to 7 times as large as the subhedral grains. Where plagioclase grains border potassium feldspar, myrmekite occurs. The microcline phenocrysts, which are similar in size and outline to the plagioclase phenocrysts, show carlsbad twinning.

Very minor contact metamorphism, not detectable in the hand specimen, produced cordierite and andalusite locally in the migmatite at the contact with the stock.

TERTIARY IGNEOUS ROCKS

PANDO PORPHYRY, ELK MOUNTAIN PORPHYRY, LINCOLN PORPHYRY; UNNAMED PORPHYRY

Dikes and sills of at least four different varieties of monzonite and latite porphyry of early Tertiary age are exposed throughout the Tenmile Range. These are summarized in table 2.

TABLE 2.—*Dikes and sills of early Tertiary age in the Tenmile Range, Summit County, Colo.*

↑ Decreasing age	Lincoln Porphyry	Named by Cross (1886, p. 78–80). Quartz monzonite, with fine-grained gray matrix, characterized by large euhedral phenocrysts of potassium feldspar and quartz.
	Elk Mountain Porphyry	Named by Emmons (1896, p. 2). Quartz monzonite with fine-grained gray matrix containing phenocrysts of quartz, biotite, and plagioclase.
	Pando Porphyry	Named by Tweto (1951, p. 510). Quartz latite, with tiny quartz phenocrysts. In this area it is a white dense very fine grained dike rock.
Unnamed porphyry		Quartz monzonite with dark-gray fine-grained matrix and abundant phenocrysts of quartz and feldspar. Similar to Elk Mountain porphyry, but darker in color. Age relations with other porphyries are unknown.

STRUCTURE

The gross structure of the Tenmile Range is a north-trending homocline that dips 10° or less to the east and is cut by numerous north- to northwest-trending faults. In detail, the Precambrian rocks that make up the core of the range are extremely contorted, and their structures do not conform to the homocline. These rocks were deformed repeatedly throughout geologic time, whereas the homocline is a fairly recent feature.

During regional metamorphism the Precambrian rocks were subjected to at least two periods of plastic deformation, producing a series of steeply plunging anticlines and synclines. The larger folds can be recognized on the map by the attitudes of foliation and by the areas of granulite, which, as the lowermost stratigraphic unit, forms the central part of the anticlines. One anticline is located 1 mile west of Frisco; another crosses the crest of the range in the vicinity of the large cirques at the head of Miners Creek. The large area of migmatite southeast of Wheeler Junction is folded into a large syncline, whose attitude can be roughly determined from the predominant northwest trend of the foliation. In the northern and northwestern parts of the map area, the axis of folding plunges 25°–45° N., 20°–30° W., defined by "b" lineations (drag-fold axes and mineral lineations parallel to drag-fold axes). Only one set of lineations can be found in the rocks in this area. About 2 miles west-northwest of Wheeler Junction, on the south limb of the large east-trending anticline, two distinct sets of lineations are found in the banded gneiss. One of these plunges 70°–80° N., 30°–40° E., and the other plunges 5°–20° S., 70°–80° E. Both sets are mineral alinements and warps, and their relation to fold axes cannot be determined at this locality. Less than a mile south of the mapped area, however, the set that trends S. 70°–80° E. is strongly developed as drag-fold axes and mineral alinements parallel to the drag-fold axes. This, then, establishes the axis of folding as S. 70°–80° E., and the set that trends N. 30°–40° E. is considered to be in the "a" direction. The ages of the set trending N. 20°–30° W. and the set trending S. 70°–80° E. relative to each other could not be determined, for both sets could not be found on the same outcrop.

The structure of the Precambrian rocks in the southeastern corner of the mapped area is complicated, and additional detailed work is needed for a reasonable interpretation.

The Precambrian rocks are cut by numerous high-angle faults and shear zones, most of which can be grouped into three major trends—north, northeast, and northwest. The shear zones are hundreds of feet in width; the Precambrian rocks in them have downgraded to the greenschist facies, and the mineral components are crushed. Many of the faults displace sedimentary rocks of Cretaceous age.

During Paleozoic and Mesozoic time the Tenmile area was alternately elevated and depressed, resulting in an incomplete stratigraphic section of sedimentary rocks and in unconformities with considerable local relief. Along the eastern edge of the area, the Dakota Sandstone is in normal sedimentary contact with the Precambrian rocks, but—locally—patches of Morrison Formation are found beneath it; at one locality along the eastern edge of the mapped area, about 3½ miles southeast of Frisco, part of the Minturn Formation underlies a low hill that is capped by the Dakota. The normal thickness of this sedimentary section would be a minimum of 2,500 feet, but here the section is only 300 feet. The uppermost part of the Paleozoic and the lower Mesozoic sedimentary section is missing, owing to nondeposition or erosion, or both.

Near the end of the Cretaceous period the area was uplifted during the Laramide orogeny, and the sedimentary rocks were tilted eastward to form the north-trending homocline that comprises the Tenmile Range. Part of this uplift occurred as renewed movement along north- and northwest-trending Precambrian faults which opened avenues for intrusion of numerous monzonitic magmas and later mineralizing solutions.

ORE DEPOSITS

The rocks of the Tenmile Range are cut by numerous quartz veins that contain variable amounts of metallic sulfides, some of which have been successfully mined in the past. Most of the deposits, however, are too small and too low in grade to be minable at present costs.

The history of mining and ore production in the Tenmile district is difficult to ascertain, because the production of the district was always overshadowed by and often combined with the adjacent Kokomo district. Moreover, there was never a consistent large producer to focus attention to the district. The earliest recorded activity was at the Excelsior mine in 1898. By the early 1900's several mines were shipping ore rich in gold, silver, lead, and copper. Among these mines were the Excelsior, King Solomon, Masontown Mining and Milling Co., Foremost, and Lead King. The Briar Rose mine, in the southern part of the area, produced silver ore worth a minimum of $10,000 (Singewald, 1951, p. 51). Unpublished data compiled from U.S. Bureau of Mines records of individual mines credit the northern part of the Tenmile Range with a minimum total production of 1,750 ounces of gold, 406,300 pounds of lead, 15,770 ounces of silver, 81,800 pounds of copper, and 920 pounds of zinc. Most of this was mined during the period 1905–25 and in the midthirties. In recent years the mining activity in the area has been practically dormant. The Excelsior mine closed down in 1940; the Briar Rose, in 1949. As recently as 1956, however, there was a trickle of base-metal production from the district, probably from the Alexander mine, 4 miles southwest of Frisco.

Veins are of two general types, mixed sulfide and hematite-quartz; the hematite-quartz veins are of no economic importance. The principal metallic minerals of the mixed-sulfide veins are pyrite, chalcopyrite, galena, sphalerite, and small amounts of silver sulfides, native gold, and molybdenite. Gangue consists of quartz, ankerite or siderite, and potassium feldspar. Most of the veins occupy shear zones, and the mineralization was probably related to the Laramide orogeny, for many of the veins are in fault zones along which Pennsylvanian and Cretaceous rocks are displaced. Some of the molybdenite prospects are in veins or disseminated deposits containing pyrite in the quartz monzonite stock.

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