U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

# MINERALOGY, GEOCHEMISTRY, METAMORPHISM, AND PROVENANCE OF THE EARLY PROTEROZOIC METAMORPHIC ROCKS OF THE CENTRAL FRONT RANGE, COLORADO

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**OPEN-FILE REPORT 96-522**

**1996**

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## ILLUSTRATIONS

[All illustrations are included following the text. Original photographs and photomicrographs are on file at the U.S. Geological Survey Library, Field Records Section, Denver Federal Center, Denver, Colorado]

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# ABSTRACT

The central Front Range of Colorado is underlain by a thick series of Early Proterozoic supracrustal rocks that are predominantly biotite gneiss of graywacke and shale origin. Finely and grossly interlayered with the biotite gneiss are variable units of calc-silicate gneiss, mostly of limestone origin, and mafic hornblende gneiss and amphibolite chiefly of tholeiitic basalt origin. Chemical data revealed that the trace elements chromium, cobalt, thorium, uranium, scandium, and yttrium are anonymously high in the central Front Range metasedimentary rocks.

Polymetamorphism in rocks of the central Front Range is recognized by mineral fabrics and mineral associations, and by the presence of intrusives of various ages in contact with the gneisses. The highest grade of metamorphism in the area is a Barrovian-type metamorphic terrane, defined by the assemblage of cordierite-garnet-sillimanite biotite gneiss ± K-feldspar ± plagioclase, that occurred at a minimum temperature of 660-690°C at 3.4-4.3 kb water pressure and a ratio of water pressure to total pressure of about 0.5. Metamorphic zoning in the central Front Range is similar to that in the northern Front Range; in both areas the zoning increases from east to west with the lowest metamorphic grade occupying the area just west of the mountain front.

In the central Front Range the highest temperatures and pressures of regional metamorphism span the boundary of the amphibolite-granulite facies. This high-grade metamorphism was at least locally followed by several thermal retrograde metamorphic events. The oldest recognized thermal retrograde event is to the west of the Boulder Creek batholith. The thermal aureole of the 1.7 b.y. batholith, a part of the Routt Plutonic Suite, is marked by conspicuous cordierite coronas on garnet. The pattern of these aureoles and their proximity to the batholith suggest this retrograde metamorphism is Early Proterozoic in age. Thermal changes in other minerals in biotite gneiss throughout the central Front Range are also visible; andalusite has replaced biotite adjacent to intrusions of Silver Plume Granite (or Quartz Monzonite) of the Berthoud Plutonic Suite; and sillimanite-grade K-feldspar-bearing cordierite-garnet-biotite gneiss has been remetamorphosed within the hornblende-hornfels facies in Late Cretaceous-early Tertiary thermal aureoles. The youngest and final pervasive low-grade metamorphism accompanied mineralization in the Colorado Mineral Belt and is marked by the alteration minerals, chlorite, pinite, and sericite.

There are major differences in composition of the Proterozoic rocks north and south of the Idaho Springs-Ralston shear zone that passes through the central Front Range. It is suggested that these metasedimentary and metavolcanic rocks were deposited in two separate basins that were joined along the shear zone. This conclusion is based on differences in rock composition, distribution of the various rock types, and maturity of the sedimentary rocks of the metamorphic sequence. Both basins were part of a larger east-trending basin located behind an island arc that was present to the south of the Archean craton in southern Wyoming. The quartzite of Coal Creek and related quartz-mica schist, because of their synformal position and composition, do not fit into the above picture. The rocks in the Coal Creek synform appear to be the youngest Proterozoic rocks in the central Front Range, and recent studies suggest an eastern source for the sediments.

The youngest Proterozoic deformation and folding is associated with the Idaho Springs-Ralston shear zone. Period III deformation was accompanied by folding and cataclastic shear during emplacement of Silver Plume Granite, especially emplacement of the Mt. Evans pluton.

# INTRODUCTION

In the period 1950-60 the U.S. Geological Survey initiated general studies of the regional geology of the Front Range of Colorado with emphasis on the area of the Colorado Mineral Belt. Investigations along a transect across the Continental Divide have been carried out to help understand the composition and structure of the range and relationships of the ore deposits to Front Range structure. Before this mission was totally accomplished however, other projects took priority and mapping has continued only sporadically since that time, and much of it has been only reconnaissance mapping. The geologic map of the area along the central Front Range incorporated in the study is shown on plate 1.

This report brings together much of the published and unpublished data on the layered Early Proterozoic metamorphic rocks of the central Front Range, especially my work in the northern part of the central Front Range that has not previously been published. Central Front Range is used as defined by Fenneman (1931). Areas mapped in detail, mostly at scale of 1:20,000, were published at 1:24,000; areas of reconnaissance mapping at 1:100,000 were published at 1:48,000. Many of the studies before 1960 included good detailed mineral descriptions and detailed structural interpretations; whereas, many of the studies since 1960 were published mostly as geologic quadrangle maps and had only abbreviated descriptions of the geology. The reconnaissance maps contain little information on the structure and mineralogy.

Published modal, chemical, and spectrographic data on metamorphic rocks and their mineral assemblages in the central Front Range area occur in reports by Sims and Gable (1967), Gable and Sims (1969), and Gable and others (1970). In an effort to further study and describe the metamorphism of the central Front Range many new samples of biotite and metamorphic whole rocks have been studied in thin section and chemically analyzed. Some of the earlier conclusions of Gable and Sims (1969) need revision, especially as cordierite haloes on garnet in the cordierite-garnet-sillimanite-biotite-K-feldspar gneiss are now ascribed to retrograde metamorphism and not to prograde metamorphism as suggested in that report. In this report I present a comprehensive overview of the Proterozoic metamorphism in the central Front Range, distinguish several grades of metamorphism, and define the metamorphic facies of the major prograde metamorphic event.

About 500 new modes, together with an equal number from the published literature and unpublished files, are representative of the layered metamorphic rocks in the central Front Range. Grain size of the rocks in most cases allows at least 800 counts per thin section, and this number is considered adequate to calculate relative mineral percentages. The numbered localities of samples for both new modes and chemical analyses presented in this report are plotted on plate 2. Generally, the locality numbers increase from north to south, but there are exceptions, for the localities were numbered as they were sampled in the field. Physical changes in metamorphic rocks can be considerable in central Front Range rocks that have been migmatized, therefore the samples that were analyzed were of the least altered or migmatized rocks.

No new mineral analyses, except for biotite, have been published since those of Gable and Sims (1969), Gable and others (1970), and Gable and Smith (1975). Mineral analyses and detailed information on mineral pairs from about 35 rock units in the study area are published in the reports cited.

The Colorado Front Range extends in a northerly direction from near Cañon City on the south to the Wyoming border on the north (fig. 1). This report is only concerned with the central part of the Front Range (fig. 2).

# GEOLOGIC FRAMEWORK

The Colorado Front Range is structurally a broad anticlinal uplift that exposes in its core Proterozoic metamorphic and intrusive rocks (figs. 1 and 2). In the central Front Range exposures of Early Proterozoic rocks are good to excellent due to uplift, erosion, and the presence of canyons hundreds of meters deep, wherein layered sequences can be observed that has preserved a record of sedimentation, later metamorphism, deformation, and plutonism.

To date no one has found sound evidence to consistently define the tops of individual units in the stratigraphic succession in the central Front Range due mainly to the intensity of metamorphism and deformation. Wells and others (1964) determined that the graded bedding and low-angle crossbedding of quartzite in the Eldorado Springs area indicate that the unit is right side up, and Johnson (1984) described small sedimentary structures in biotite gneiss in Clear Creek Canyon that are upright.

Intense folding and regional metamorphism in the area converted the original rocks to a series of schist and gneiss that suggests moderate pressures and high temperatures prevailed in the Early Proterozoic. Plutons intruded on three occasions during the Proterozoic and once during the Late Cretaceous-early Tertiary. The earliest plutons of the Routt Plutonic Suite (pl. 1) were emplaced late in the dominant period of regional metamorphism 1.8-1.7 b.y. (Peterman and others, 1968; DePaolo, 1981). The area was locally deformed again during emplacement of the 1.5-1.4 b.y. Berthoud Plutonic Suite of rocks. Most 1.5 to 1.4 b.y.-old rocks were of anorogenic origin; however, in the central Front Range there is considerable evidence this is not so, for there is good evidence that emplacement was accompanied by shearing and displacement especially along the Idaho Springs-Ralston shear zone (pl. 1). This shear zone is a major structural feature in the central Front Range that dissects the Front Range in a northeast-southwest direction. The Idaho Springs-Ralston shear zone is part of the Colorado lineament described by Warner (1978). The youngest Proterozoic intrusives of 1.0 b.y. age, located predominantly in the southern part of the Front Range, are called the Pikes Peak Granite. This granite had minimal effect on the central Front Range, and its structural and thermal effects on the study area have not been studied.

Little geologic evidence is found in the Front Range Precambrian to indicate what events occurred during the period from late Precambrian to the end of the Cretaceous. It is known the area was uplifted during the Paleozoic (Tweto, 1980), followed by erosion. Volcanic rocks both to the west in the Middle Park Formation (Upper Cretaceous and Paleocene) and to the east of the mountain front in the Denver Formation (Upper Cretaceous and Paleocene) suggest the Front Range was at least partially covered by volcanics during the latter part of the Laramide orogeny (Tweto, 1980). The Precambrian rocks were also uplifted and faulted, and old Precambrian faults were reactivated during Laramide deformation. Emplacement of porphyritic igneous rocks (pl. 1) and an intrusive series of vein deposits are associated with this period of uplift.

During the Pliocene and the Pleistocene, glaciers eroded the region, leaving a rugged topography in the high country and moraines and outwash deposits along many of the lower stream valleys.

## EARLY PROTEROZOIC METAMORPHIC ROCKS

Early Proterozoic metamorphic rocks in the central Front Range are composed roughly of 65 percent biotite gneiss, 20 percent feldspar-rich gneiss, 10 percent hornblende gneiss, and 5 percent of other rock types including quartzite, varieties of calc-silicate gneiss, and mica schist. Feldspar-rich gneiss and hornblende gneiss, as shown on the state geologic map (Tweto, 1979), are much more abundant north, south, and southwest of the central Front Range. Minor felsic gneiss, hornblende gneiss, and amphibolite are interlayered with biotite gneiss and assorted calc-silicate gneiss, and minor quartzite. This metamorphic series represents an original sedimentary sequence of graywacke, shale, sandstone, and minor amounts of limestone and conglomerate interlayered with what appears to have been basaltic flows and felsic to mafic tuffs. In general the metamorphic sequence in the central Front Range becomes less varied from west to east and from south to north. The metamorphic rocks are much more varied in the area south of the Idaho Springs-Ralston shear zone (pl. 1), where biotite gneiss and schist are interlayered at various scales with many other types of metamorphic rocks, including calc-silicate gneiss and amphibolite. North of the shear zone, from about Idaho Springs north to Nederland, the rocks consist of a thick series of biotite gneiss and schist interbedded with layers of feldspar-rich gneiss, hornblende gneiss, and amphibolite. The feldspar-rich gneiss, hornblende gneiss, and amphibolite become more scarce northward. Calc-silicate gneiss and quartzite are rare north of the shear zone and where present, are generally thin and discontinuous.

## BIOTITE GNEISS

Biotite gneiss in the central Front Range occurs as mappable units of biotite gneiss and schist. Although schist layers may locally be dominant, overall the unit is gneissic. Biotite gneiss is rich in quartz and ubiquitously migmatitic, but migmatite is more abundant in certain areas of the central Front Range. Migmatite, as used here, follows the definition of Mehnert (1968), "migmatite is a megascopically composite rock consisting of two or more petrographically different parts, one of which is the country rock generally in a more or less metamorphic stage, the other is of pegmatitic, aplitic, granitic, or generally of plutonic appearance." Migmatite in veins, pods, and lenses increases in abundance westward from the mountain front; in the western part profuse pegmatites occur within the gneiss as well as along most contacts.

All biotite gneiss in the central Front Range has been divided into two major rock types based on the presence or absence of sillimanite. Each of these two rock types is further divided according to the presence of garnet, cordierite, gedrite, and the occurrence of more than 5 percent magnetite. Gedrite is restricted to sillimanite-free biotite gneiss. Modal analyses of the biotite gneiss are listed in tables 1 and 2 and 4-11 of Appendix I and are graphically summarized in figure 3. Trends for most minerals in sillimanite-free biotite gneiss, except for plagioclase and quartz, are less variable than in sillimanite-biotite gneiss, especially the trends in magnetite, K-feldspar, and biotite. Except for the amount of sillimanite and the greater abundance of garnet in some sillimanite-biotite gneiss, the average mineral trends are not significantly different between sillimanite-free biotite gneiss and the biotite gneiss containing sillimanite.

### Sillimanite-Free Biotite Gneiss

Sillimanite-free biotite gneiss consists predominantly of biotite-quartz-plagioclase gneiss, but it includes minor layers of garnet-biotite or garnet-quartz-plagioclase-biotite, cordierite-garnet-gedrite-biotite, cordierite-biotite-quartz-plagioclase, and cordierite-garnet-biotite gneiss. Biotite-quartz-plagioclase gneiss is relatively scarce in the northern part of the central Front Range, but from Central City southward it is commonly interlayered with sillimanite-biotite gneiss, and, where thick enough, the unit was mapped separately. Garnet-biotite-quartz-plagioclase gneiss and cordierite-biotite-quartz-plagioclase gneiss are rarely of mappable thickness but locally are common as lenses or layers in biotite-quartz-plagioclase gneiss. Mappable layers of cordierite-garnet-gedrite-biotite gneiss are only found in the Morrison-Evergreen area, but mappable lenses or pods are located in the Central City area and in an altered mafic dike in the Nederland area.

#### Biotite-quartz-plagioclase gneiss

The biotite-quartz-plagioclase gneiss, which commonly contains K-feldspar, is mineralogically the simplest biotite gneiss in the central Front Range area. Its major minerals average 39 percent quartz, 30 percent plagioclase, 16 percent biotite, and 8 percent K-feldspar, although K-feldspar is locally rare (table 1). The accessory minerals include apatite, allanite, xenotime-monazite, ores (mainly magnetite but includes hematite, ilmenite, pyrite, and chalcopyrite), and tourmaline. All occur in smaller amounts (table 1). Apatite is more abundant in this gneiss than in the other biotite gneisses. Tourmaline in biotite-quartz-feldspar gneiss and schist is found only in the central part of the area especially in the Black Hawk and Ralston Buttes quadrangles. Secondary minerals include muscovite-sericite, chlorite, sphene, calcite, epidote, corundum, and spinel. The amount of secondary muscovite-sericite is quite variable, and corundum and spinel generally occur only in cordierite-bearing layers.

Biotite-quartz-plagioclase gneiss is a fine- to medium-grained, equigranular, foliated, and distinctly layered, gray and white rock. The grain size generally is more uniform than other biotite gneisses due to the absence of porphyroblasts of garnet, sillimanite, and cordierite. Biotite-quartz-plagioclase gneiss has a typical crystalloblastic texture. Plagioclase, quartz, and biotite crystals are commonly intergrown. The plagioclase is predominantly sodic-andesine with an average of $An_{32}$; rims on this plagioclase are as sodic as $An_{10}$. Plagioclase in biotite-quartz-feldspar gneiss in the Morrison area, however, averages about $An_{21}$ and lies within the "peristerite gap" (Orville, 1974). This is the lowest known anorthite content for any sillimanite-free biotite gneiss in the central Front Range. In the Central City area plagioclase in similar rocks has the highest anorthite content, the average $An_{45}$. It is not clear why rocks from these two areas vary so much from the average.

K-feldspar in sillimanite-free biotite gneiss is microcline or microperthite, rarely orthoclase. K-feldspar is uncommon, however, in this gneiss in an area from South Boulder Creek on the north to Bear Creek on the south.

**Garnet-biotite gneiss or garnet-quartz-feldspar-biotite gneiss**

Garnet-biotite gneiss or garnet-quartz-feldspar-biotite gneiss is of mappable thickness only in the Morrison-Squaw Pass-Blackhawk areas. It does occur, however, as thin layers in garnet-sillimanite-biotite gneiss throughout the central Front Range. Garnet-biotite gneiss is a gray, fine- to coarse-grained, weakly to strongly foliated and banded rock interlayered with biotite-rich and quartz-feldspar-rich leucocratic layers. Garnets as much as a centimeter in size appear as rusty freckles on some rock surfaces, but in other samples the garnets are so small they are hard to find except by hand lens or in a thin section. In migmatitic areas garnets occur in both the dark and leucocratic layers.

Garnet-biotite gneiss averages 40 percent quartz, 30 percent plagioclase, 9 percent K-feldspar, 14 percent biotite, 2.5 percent garnet, and about a half of a percent ore minerals (mainly magnetite) (table 2). Accessory minerals are zircon, allanite, apatite, xenotime-monazite in trace amounts. The alteration minerals are rutile, muscovite-sericite, calcite, chlorite, epidote, and sphene.

**Cordierite-garnet-gedrite-biotite gneiss**

Cordierite-garnet-gedrite-biotite gneiss occurs as mappable layers and as small pods and lenses in only a few localities in the Colorado Front Range. In the Morrison-Evergreen area it forms a distinct mappable layer, generally several tens of meters thick (Gable, 1968; Sheridan and others, 1973), but at the mouth of Bear Creek Canyon, near Morrison, where the unit is relatively unfaulted, the layer is more than 300 m thick. Mafic lenses and layers occur throughout most of the unit. In the Central City area (Sims and Gable, 1964), cordierite-garnet-gedrite-biotite gneiss is interlayered with mafic and felsic gneisses; near Nederland, a mafic dike contains a thin layer of this gneiss (table 3).

The gneiss in the Morrison-Evergreen area is dark-gray or black, medium-grained to very coarse grained rock containing conspicuous porphyroblasts of garnet and gedrite. It is locally interlayered with cordierite-sillimanite-biotite gneiss that in places also contains garnet; all units lack K-feldspar. In Bear Creek Canyon the unit has been extensively faulted and sheared and generally occurs in fault-bounded wedges. Within these wedges the unit appears layered, as segregated pods, or as thin lenses that are rich in cordierite-gedrite or cordierite-garnet-gedrite. The pods and lenses of the Central City area are very similar to those in the Morrison area (Sims and Gable, 1964; Gable and Sims, 1969).

The cordierite-garnet-gedrite-biotite gneiss is of probable igneous origin, as suggested by its similarity and proximity to altered mafic dikes in both the Central City and Nederland areas. Layers within an altered mafic dike in the Nederland area, as shown by thin section study, are similar to metagabbro or diabase.

**Cordierite-biotite-quartz-plagioclase and cordierite-garnet-biotite gneiss**

These gneisses are difficult to distinguish in the field because the garnets are so tiny that a hand lens is needed to see them. Both gneisses are more leucocratic than the cordierite-garnet-sillimanite-biotite gneiss with which they are often interlayered. These quartz-rich rocks have as much as 36 percent quartz and 14-20 percent feldspar; the percentages of K-feldspar and plagioclase vary greatly (table 4). The gneisses contain variable amounts of garnet, cordierite, and biotite. The anorthite content of the plagioclase in cordierite-biotite-quartz-plagioclase gneiss averages oligoclase ($An_{26}$), and in cordierite-garnet-biotite gneiss it averages oligoclase ($An_{28}$). These anorthite contents are very similar to the average plagioclase in all central Front Range biotite gneisses.

## Biotite Gneiss Containing Sillimanite

Biotite gneiss containing sillimanite is perhaps the major rock type in the central Front Range. In most places this gneiss is migmatitic and locally contains garnet, more than 5 percent magnetite, and much K-feldspar. Sillimanite-biotite gneiss is subdivided into units of sillimanite-biotite, garnet-sillimanite-biotite, cordierite-sillimanite-biotite, cordierite-magnetite-sillimanite-biotite, magnetite-sillimanite-biotite and cordierite-garnet-sillimanite-biotite ± K-feldspar ± plagioclase gneiss. Biotite gneiss containing sillimanite has both primary and secondary muscovite that is shown as muscovite, undifferentiated, in tables 5-11. Profuse muscovite, both primary and secondary, is found in fold structures (fig. 4), mostly south of and in the Idaho Springs-Ralston shear zone. Northward from the zone primary muscovite progressively decreases, and generally is missing in the area north of Central City. Sericite, however, increases noticeably northward, especially in the Nederland and Ward areas.

**Sillimanite-biotite gneiss**

Sillimanite-biotite gneiss is a strongly foliated, fine- to medium-grained rock, containing conspicuous fibrolitic sillimanite, and is more even grained than the garnet, cordierite, or magnetite varieties of sillimanite-biotite gneiss. Sillimanite-biotite gneiss is in conspicuous layers, a few millimeters to centimeters thick (fig. 5), that range from nearly black to silvery-gray biotite-rich layers to white or light-gray leucocratic layers. The rock is very micaceous south of the Idaho Springs-Ralston shear zone (fig. 5*B* and 5*C*-1). Commonly interlayered with the gneiss are mafic layers and sparse, generally thin, discontinuous layers of quartzite. Locally, calc-silicate gneiss in layers, pods, and lenses, a few centimeters to several tens of meters in length, is abundant in the sillimanite-biotite gneiss. Weathered surfaces and fractures generally are dark gray but locally are stained yellowish brown or reddish brown due to oxidation of iron and sulfide ore minerals, especially in and adjacent to the mining districts.

Sillimanite-biotite gneiss has a predominant allotriomorphic granular texture but locally is lepidoblastic. The gneiss (table 5) averages 40 percent quartz, 14 percent plagioclase, 21 percent biotite, 6 percent K-feldspar, 9 percent sillimanite, and 1.5 percent opaque minerals (mostly magnetite). Muscovite, both primary and retrograde, accounts for as much as 20-30 percent of the unit at some localities (fig. 6*A*-6*D*). Accessory minerals include very sparse apatite, and sparse zircon, xenotime-monazite, and very little tourmaline. Muscovite-sericite in modes of samples from the area north of Central City is mostly retrograde muscovite and sericite. The sericite is predominantly found in plagioclase. South of Central City the gneiss contains much retrograde muscovite but some primary muscovite and sericite. Tourmaline and primary andalusite are sparse except locally in the central and eastern part of the area in and adjacent to the Black Hawk and Ralston Buttes quadrangles (fig. 6*C* and 6*D*). Elsewhere, in the central Front Range, as in the Nederland and Ward quadrangles, andalusite in sillimanite-biotite gneiss is a retrograde mineral.

The K-feldspar in the gneiss occurs as microcline and microperthite. Plagioclase averages oligoclase $An_{27}$ but has sodic oligoclase rims as low as $An_{11}$. In the Morrison area, however, the plagioclase has a composition of only $An_{17}$. The considerably lower calcium in rocks from the Morrison area may be due to differences in original rock composition. The sodic rims are due to chemical changes related to retrograde metamorphism.

Modal analyses of sillimanite-biotite gneiss in country rock differ from those of similar rocks in the thermal aureoles of the Late Cretaceous-early Tertiary intrusives in the map area (tables 5 and 6). Within the aureoles K-feldspar, sillimanite, and quartz decrease; whereas, plagioclase and perhaps biotite increase, as in the Gold Hill area (table 6). Biotite ranges from 8 to 46 percent in sillimanite-biotite gneiss, and any increase in amount due to heating by the intrusives is difficult to identify. Late Cretaceous-early Tertiary intrusives are numerous throughout the Nederland-Ward-Gold Hill area, and this, perhaps, accounts for the lack of K-feldspar and low amount of sillimanite (table 5) in many of the sillimanite-biotite gneiss samples from the area.

**Garnet-sillimanite-biotite gneiss**

Garnet-sillimanite-biotite gneiss is present generally as thin lenses (not mappable) interlayered with cordierite-garnet-sillimanite-biotite gneiss. A layer of garnet-sillimanite-biotite gneiss, gradational into and interlayered with cordierite-garnet-sillimanite-biotite gneiss, crops out west of Nederland. This layer is several tens of meters thick, but its outcrop is complicated by folding and faulting, causing the unit to pinch and thicken or to disappear altogether. The unit is not shown on the geologic map (pl. 1).

Garnet-sillimanite-biotite gneiss is a medium- to dark-gray, well-foliated, commonly schistose, migmatitic rock (fig. 7). Profuse lenses of pegmatite, several centimeters thick and tens of meters in length, are associated with the gneiss. Joints, fractures, and foliation planes in the gneiss are characteristically coated with limonite stain. Its schistose character is defined by biotite and fibrous masses of sillimanite. Garnet occurs as gray-black, pink, or reddish-brown crystals averaging 2 mm in size, but crystals a centimeter or more in diameter are common. The gray-black color of some garnets is due to inclusions of biotite and magnetite. In outcrops where sillimanite or garnet is inconspicuous, the rock is a mottled black and white, fine- to medium-grained gneiss.

Garnet-sillimanite-biotite gneiss (table 7) consists of 41 percent quartz, 21 percent biotite, 10 percent sillimanite, 10 percent plagioclase, 8 percent K-feldspar, 3.5 percent garnet, and 0.7 percent opaque minerals (mostly magnetite). The plagioclase is oligoclase with an average of $An_{27}$. The K-feldspar is microcline and microperthite. Accessory minerals are magnetite, zircon, apatite, xenotime-monazite, and allanite. The alteration minerals are muscovite-sericite, spinel, rutile, chlorite, and kaolinite.

**Cordierite-sillimanite-biotite gneiss**

Cordierite-sillimanite-biotite gneiss, as mapped in the central Front Range area, also includes some cordierite-biotite gneiss and cordierite-magnetite-sillimanite-biotite gneiss (fig. 8). These various gneisses are generally minor units and are completely gradational into cordierite-garnet-sillimanite-biotite gneiss in the northern half of the central Front Range. Cordierite-magnetite-sillimanite-biotite gneiss is only found in the Gold Hill-Ward area. In the southern part of the central Front Range several mappable lenses of cordierite-biotite and cordierite-sillimanite-biotite gneiss are exposed in the Squaw Pass-Evergreen-Morrison areas and are easily identified because they are interlayered with rock types other than biotite gneiss. Elsewhere in the southern part of the Front Range, Hawley and Wobus (1977) mapped a lens of cordierite-sillimanite-quartz gneiss, and in the northern part of the Front Range cordierite-garnet-sillimanite-biotite gneiss was described by Cole (1977).

The cordierite-sillimanite-biotite gneiss mapped in the Squaw Pass-Evergreen area is a fine- to medium-grained, light to very dark gray schistose gneiss that occurs as thin layers and lenses interlayered with hornblende gneiss and felsic gneiss. Elsewhere in the central Front Range, it is intercalated with other biotite gneisses, and its presence could only be confirmed in thin section.

Composition of cordierite-sillimanite-biotite gneiss based on modal analyses is as follows: quartz, 37.4 percent; biotite, 15.1 percent; cordierite, 13.6 percent; plagioclase, 11.2 percent; K-feldspar, 8.5 percent; sillimanite, 7.2 percent; muscovite-sericite, 3.3 percent; opaque minerals, 1.9 percent (mostly magnetite) (table 8). K-feldspar is a common constituent throughout most of the map area, but from the Idaho Springs-Ralston shear zone south to Evergreen, it is rare. It is again a common mineral south of the Evergreen area. The plagioclase is oligoclase ($An_{30}$) with rims as sodic as $An_{13}$. The accessory minerals are zircon and xenotime-monazite, and the secondary minerals are chlorite, sphene, and pinite.

**Cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss**

Cordierite-magnetite-sillimanite-biotite gneiss and interlayered magnetite-sillimanite-biotite gneiss in the Ward-Gold Hill area grade into cordierite-garnet-sillimanite-biotite gneiss and sillimanite-biotite gneiss. The contacts between these gneisses, shown on the geologic map (pl. 1), were defined by thin section studies. Cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss in the Ward-Gold Hill area appear to feather out both to the east and to the west into sillimanite-biotite gneiss. Both gneisses are predominantly fine to medium grained but locally are coarse grained (fig. 7*C*). These schistose to gneissic rocks are interlayered with thin layers of biotite-rich and quartz-rich sillimanite-biotite gneiss. The layering is most conspicuous as distinct bands of black and white rock in the Ward area in the vicinity of the Late Cretaceous-early Tertiary stocks.

In both magnetite-sillimanite-biotite gneiss and cordierite-magnetite-sillimanite-biotite gneiss, the K-feldspar content is extremely variable. Some samples have no K-feldspar but others contain 35-40 percent K-feldspar. An average modal composition (tables 9 and 10) is quartz, 27 percent; biotite, 16 percent; cordierite, 14 percent; sillimanite, 11 percent; plagioclase, 9 percent; opaque minerals (mainly magnetite), 6 percent; K-feldspar, 5 percent. The plagioclase has an average composition of oligoclase ($An_{26}$).

**Cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar ± plagioclase**

Cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar ± plagioclase is fine to medium grained, medium to dark gray, foliated, and in places schistose. It contains many conspicuous layers and lenses of migmatite and veins of quartz. Locally, this gneiss is interlayered with cordierite-sillimanite-biotite gneiss. In the cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar ± plagioclase, the foliation has locally been disrupted by profuse garnet porphyroblasts, some 2-5 mm in diameter, fibrous sillimanite aggregates of 1-10 mm in length, and clusters of cordierite and biotite (fig. 7*B*). Weathered outcrops show yellowish-orange limonite, reddish-black hematite and reddish-brown iron oxide stains on foliation planes, fractures, joints, and cleavage.

Cordierite-garnet-sillimanite-biotite gneiss is predominantly a K-feldspar-bearing unit from the Idaho Springs-Ralston shear zone northward into the northern Front Range. Plagioclase in the K-feldspar-bearing gneiss has an average composition of oligoclase $An_{26-27}$; whereas, in cordierite-garnet-sillimanite-biotite gneiss, the average is $An_{18}$. Cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar ± plagioclase averages quartz, 32 percent; biotite, 20 percent; K-feldspar, 11 percent; sillimanite, 11 percent; cordierite, 10 percent; plagioclase, 10 percent; garnet, 4 percent; and opaque minerals (mostly magnetite), 2 percent (table 11).

## QUARTZ-BIOTITE -MUSCOVITE SCHIST

Quartz-biotite-muscovite schist is a local unit in the Ralston Buttes area and described herein only because it is part of a sequence of gneisses that outlines major folds in the area. It is a silvery-gray to dark-gray, fine- to medium-grained, porphyroblastic to nonporphyroblastic schist. Quartz, biotite, and muscovite are the predominant minerals; sillimanite, andalusite, garnet, and tourmaline are locally present.

Plagioclase makes up to 20 percent of the rock and K-feldspar is sparse or absent. Muscovite and biotite are mutually intergrown with no alteration rims, suggesting that the muscovite is a primary mineral.

## FELDSPAR-RICH GNEISS

Feldspar-rich gneiss, locally described as microcline gneiss in and adjacent to the Central City area (Moench, 1964; Sims and Gable, 1964), is a leucocratic, layered, and foliated metamorphic rock. Locally, it contains numerous layers and lenses of biotite gneiss, calc-silicate gneiss, hornblende gneiss, and amphibolite. No new petrographic or chemical analyses are presented in this report; comprehensive descriptions of this unit appear in Moench (1964), Sims and Gable (1964, 1967), Sheridan and others (1967), Braddock (1969), and Taylor (1976).

Rocks similar in composition and texture to the feldspar-rich gneiss of the central Front Range also are described in the Salida area (Boardman, 1976) and in the Gunnison region (Hedlund and Olson, 1975; Olson, 1976a, 1976b). These authors suggest that the rocks are not of sedimentary origin but are primarily of volcanic origin. Feldspar-rich gneiss in the Salida and Gunnison areas, as well as in the central Front Range, is gradational into metavolcanic rocks. This supports the idea that the feldspar-rich gneiss was originally volcanic tuff.

## HORNBLENDE GNEISS AND AMPHIBOLITE

The hornblende gneiss (Xgnh) and amphibolite (Xam) in the central Front Range occur separately in individual layers or lenses or as layers of mixed hornblende gneiss and amphibolite interlayered with biotite gneiss and schist, lesser amounts of calc-silicate gneiss, and minor units of impure quartzite (pl. 1). The hornblende gneiss consists of hornblende and plagioclase and more than 15 percent secondary minerals. The amphibolite may be layered but is more often non-layered; it consists of hornblende and plagioclase but has less than 15 percent secondary minerals and less than 10 percent quartz. The layered appearance of both the hornblende gneiss and amphibolite (fig. 9) is due to segregation of light and dark minerals into bands but on a larger scale to interlayering with various other rock types, such as calc-silicate rock, impure quartzite, biotite-quartz-plagioclase gneiss, and felsic gneiss. Contacts between layers are both gradational and sharp.

Hornblende gneiss in the Front Range was first described by Patton (1909, p. 123-124) from exposures on the west slope of the Front Range. Lovering (1935, p. 10-11) named these rocks the Swandyke hornblende gneiss, but the name was abandoned by Tweto (1977) as the unit has been used indiscriminately and has no stratigraphic usefulness.

Young (1985, p. 7) reported small distorted pillow structures in amphibolite in the vicinity of the Schwartzwalder uranium mine in the Ralston Buttes area. To date, this is the only area where original textures have been found in amphibolite in the central Front Range, but the structures are so bent and distorted that it is impossible to determine whether they are upright. Hornblende gneiss and amphibolite bodies trend predominantly to the west, similar to the biotite gneiss of the area.

Hornblende gneiss and amphibolite are well exposed in Bear Creek, Mt. Vernon, and Golden Gate Canyons, along North Clear Creek, the upper part of Ralston Creek, and in the Eldora area along Middle Boulder Creek. Exposures along North Clear Creek and in the Mt. Vernon and Golden Gate Canyon areas reveal complex interlayering of the two gneisses with the other gneiss units mentioned. Four of the largest layers of hornblende gneiss and amphibolite are herein given local names in order to facilitate the description and comparison of the individual bodies. The Phoenix layer, just northwest of Rollinsville (pl. 1), is named after a now- abandoned mining settlement in the area (pl. 2). The Golden Gate layer is located near the mouth of Golden Gate Canyon. The Clear Creek layer crops out at the junction of Clear Creek and North Clear Creek. The Morrison layers crop out in the Mt. Vernon and Bear Creek Canyon areas. Additional areas of hornblende gneiss and amphibolite have been described in other reports of the central Front Range (Sheridan and others, 1967; Gable 1968; Young, 1985).

## Hornblende Gneiss

The hornblende gneiss is a light-gray to black and light- to medium-green, fine- to medium-grained, generally equigranular layered rock that locally has a salt-and-pepper appearance. Layering is evident both macroscopically and microscopically and defines the foliation. Hornblende-rich bands range from several millimeters to tens of centimeters in thickness, and pyroxene-rich layers range from less than a millimeter to several tens of centimeters in thickness. Lineation, due to the alignment of hornblende crystals, is most evident on fresh surfaces. Locally, the gneiss is coarser grained and has a mottled appearance, especially in areas adjacent to units of calc-silicate gneiss, quartzite, and marble. Migmatite stringers and pegmatites occur within the gneiss and along most contacts between hornblende gneiss and various other metamorphic units (fig. 9*A*). The pegmatites that cut both the hornblende gneiss and the adjacent units are prolific in places, but because of their small size are not mapped separately.

Hornblende gneiss consists mainly of hornblende, plagioclase, and quartz and variable amounts of clinopyroxene, and rare orthopyroxene. It also contains minor biotite, calcite, and ore minerals, consisting of magnetite, ilmenite, hematite, and pyrite. Accessory minerals are apatite, zircon, and sphene (tables 12 and 13). Of the four layers of hornblende gneiss mapped in the central Front Range (table 12), only the Phoenix layer, west of Nederland, has K-feldspar; it is also quartz-rich, has the greatest amount of magnetite, and locally contains biotite. Where sampled, the Golden Gate layer is very rich in hornblende and has only minor biotite and traces of pyroxene. The Clear Creek outcrops vary from interlayered hornblende and minor pyroxene to layers rich in pyroxene and minor hornblende (fig. 9*C* and 9*D*). The Morrison outcrops are similar to the Clear Creek outcrops in that they have little quartz. Individual layers or lenses of hornblende gneiss and amphibolite, where interlayered with biotite gneiss (tables 13 and 14), have more biotite and quartz and also more opaque minerals.

In thin section the hornblende gneiss is equigranular, layered, and has a crystalloblastic texture. The hornblende is light olive green to moderate olive brown. The crystals are generally subhedral, and tend to be somewhat larger than those of plagioclase and quartz, and their alignment defines the lineation in the rocks. The pyroxene crystals are small and corroded. Biotite, generally reddish brown, occurs as overgrowths on the hornblende or along fractures and cleavage. The clinopyroxene is diopside; orthopyroxene is rare. Locally, the pyroxenes are corroded by blue-green hornblende that is in turn mantled by secondary clinopyroxene overgrowths, which suggests variations in temperature during crystal growth. Subhedral to anhedral plagioclase has an average composition of andesine ($An_{36-50}$); plagioclase associated with calcite lenses or calc-silicate minerals is labradorite or bytownite. Sphene, an alteration product of hornblende, occurs as crystals adjacent to hornblende or forms coronas around the opaque minerals magnetite and hematite. Other accessory minerals include apatite, zircon, and pyrite. A pale-green mineral, probably hercynite, locally replaces magnetite.

In the contact aureoles of the Late Cretaceous-early Tertiary stocks hornblende gneiss does not show the effects of thermal metamorphism as markedly as sillimanite-biotite gneiss. Locally, in addition to having a slightly hornfelsic texture, sillimanite-biotite gneiss is recrystallized. Within the contact aureoles hornblende is in part replaced by biotite and magnetite, and the pyroxenes have overgrowths of new hornblende.

## Amphibolite

Amphibolite typically occurs in massive to foliated lenses or layers several centimeters to a few meters thick (fig. 9*B*). Because many units of amphibolite are small, they could not always be mapped separately. Amphibolite in comparison with hornblende gneiss is darker in color, finer grained, commonly schistose, and poorly foliated. Lenses and layers are generally conformably interlayered with felsic gneiss, hornblende gneiss, biotite gneiss, and locally, as in the Central City area, are gradational into a cordierite-garnet-gedrite gneiss (Sims and Gable, 1967). Only rarely is amphibolite found cutting the regional foliation; one such area is along the north side of Clear Creek Canyon ( just west of the junction of

Colorado Highway 119 with U.S. Highway 6). Weathering along joints emphasizes the blocky appearance of the amphibolite.

As altered mafic dikes, amphibolite is found at several localities. The original layering in the dikes is preserved in remnants of biotite-diopside-hornblende gneiss, garnet-hornblende gneiss, or cordierite-garnet-gedrite gneiss. These rock types are commonly gradational into each other or into amphibolite. The compositional modes of gneissic layers in an altered mafic dike in the Nederland area are shown in table 3. This interlayering is characteristic of amphibolite lenses, mapped as cordierite-garnet-amphibolite (gedrite) gneiss, in the Central City area (Sims and Gable, 1967), the Morrison area (Gable, 1969), and the Evergreen area (Sheridan and others, 1972). Amphibolite is also associated with calc-silicate gneiss and impure quartzite.

The amphibolite in thin section has a crystalloblastic texture and the crystals are both anhedral and euhedral. The rock consists principally of hornblende and plagioclase (tables 12-15) but also includes the amphiboles anthophyllite, gedrite, and cummingtonite. Pyroxenes are hypersthene (bronzite) and diopside--both occur mostly as anhedral crystals and are partly altered to hornblende. The plagioclase is distinctly twinned and partially sericitized. Composition varies from $An_{36-40}$ for andesine to $An_{86}$ for bytownite. Biotite, where present, is generally reddish orange or reddish brown, is of small size, and is slightly altered and frayed. Adjacent to Laramide intrusives the amphiboles contain profuse new biotite in clusters, and epidote, quartz, and chlorite are also more abundant (table 15). The increase in biotite and quartz in the altered amphibolites suggests that water and silica were introduced during thermal metamorphism.

## CALC-SILICATE GNEISS

Calc-silicate gneiss is composed of calcium-iron silicates that form a number of mineral assemblages. The calc-silicate gneiss is medium to coarse grained, massive to finely layered, and light grayish green, yellowish green, and green or greenish yellow on weathered surfaces. Weathered surfaces are generally rough and commonly pitted due to exsolved calcic minerals. Calc-silicate gneiss layers are generally associated with clear, white, or dark-stained quartz and with green, dark-gray, or black mafic layers. Foliation varies from moderate to poor.

Interlayered with the calc-silicate gneiss are the following rocks: amphibolite, pyroxene-hornblende gneiss, hornblende gneiss, pyroxene gneiss, diopsidite, feldspar-rich gneiss, marble, and quartzite. All these rock types may be thinly interlayered in a single outcrop; some form mappable layers as in the Ralston Buttes and Evergreen areas. In the Indian Hills quadrangle an unusually thick layer of limestone or marble is interlayered with quartzite (Steve Johnson, independent geologist, oral commun., 1986) and was mapped with the calc-silicate gneiss. The layer is nearly 75 m thick and 600 m in length and is one of the largest limestone outcrops in the area. In the northern part of the central Front Range calc-silicate rocks are sparse. Where mappable, they occur as layers in exposures as much as several tens of meters in length but only several meters in width.

The calc-silicate gneiss contains mineral assemblages of quartz, epidote, plagioclase, scapolite, garnet, hornblende, and clinopyroxene (usually diopside). Variations in composition are shown by modes in tables 16 and 17. Observed in thin section the calc-silicate gneiss has a crystalloblastic texture. Locally, crystals may all be euhedral within a lens, but in general, crystals are not well developed. The layering in the gneiss is not as well defined as in hornblende gneiss. Anhedral plagioclase crystals are both untwinned and complexly twinned. The most common twins are pericline, albite, and Carlsbad twins. The composition of the plagioclase generally varies from oligoclase ($An_{25}$) to labradorite ($An_{58}$), but locally it is as calcic as bytownite or rarely anorthite. Zoned crystals tend to have rims that are less calcic. At some locations, the plagioclase has been sericitized. The hornblende is anhedral and varies in color from a light bluish green to a dark olive green. The pyroxene is generally diopside, but aegirine-augite occurs in rocks that appear to be metamorphosed mafic dikes. The diopside is colorless to pale green and forms large hemihedral to anhedral grains. Nearly colorless aegirine-augite has been extensively altered to hornblende, and hornblende and pyroxene have been extensively altered to epidote. Garnets are only found in calc-silicate gneiss in the Phoenix layer near Nederland and in the Central City area. Those in the Central City area are in skarn, but those at Nederland appear to be part of a metamorphic assemblage. Garnets are characteristically orangish red or mustard in color and form small, subrounded crystals that are free of inclusions. Inclusion-free garnets are unusual in the central Front Range and may have had a different origin from garnets that are crowded with inclusions, as in the biotite gneisses of the area. Biotite in calc-silicate rocks is sparse, small, anhedral, interstitial, and commonly altered to chlorite. Euhedral to anhedral scapolite is common in some rocks and is associated with abundant sphene, although it is not necessary that scapolite be present for there to be profuse sphene. Calcite in a lens of calc-silicate gneiss in the Phoenix layer near Nederland forms clear, well-twinned euhedral crystals. In calc-silicate gneiss that contains plagioclase as well as K-feldspar, the plagioclase is more sodic than that in gneiss without K-feldspar.

One variety of calc-silicate gneiss is the skarn found primarily in the mining districts of the central Front Range and best developed in the Central City-Idaho Springs area. The skarn rocks are massive or poorly foliated and have very rough surfaces. They vary from red to dark gray to greenish gray. The rocks include garnet skarn, spessartite-magnetite skarn, and skarn-like rocks such as cordierite-amphibole gneiss, magnetite gneiss, and quartz gneiss. The pyroxene in the skarn rocks is a clinopyroxene, either diopside or aegirine-augite. The skarns probably formed by the action of hydrothermal fluids on calc-silicate gneiss and amphibolite.

## QUARTZITE AND QUARTZ GNEISS

Quartzite and quartz gneiss are minor rock types in the central Front Range and are of mappable thickness only in the Eldorado Springs-Ralston Buttes area where they intertongue with quartz-mica schist (Wells and others, 1964; Wells, 1967; Sheridan and others, 1967). In the Morrison area quartzite occurs as thin layers in plagioclase-quartz gneiss (Gable, 1968). It is also associated with limestone in the Indian Hills quadrangle (Bryant and others, 1973). Elsewhere, quartzite is thinly interlayered with amphibolite, calc-silicate gneiss, hornblende gneiss, and biotite gneiss (tables 17 and 18). Most quartzite and quartz gneiss display foliation and some are compositionally banded.

The quartzite is fine to coarse grained, locally conglomeratic, and generally gray to white. The quartz gneiss is light gray or tan, fine to medium grained, and has a dull glassy appearance due to its high quartz content. Quartzite and quartz gneiss, except in the Eldorado Springs-Ralston Buttes area, generally occur in layers less than 10 m thick and several tens of meters in length; however, in the Squaw Pass area, Sheridan and Marsh (1976) mapped a quartz-gneiss layer for several kilometers. Contacts with the enclosing gneisses are generally gradational.

Quartzite in the Eldorado Springs-Ralston Buttes area contains the only conglomerate that has been recognized in these gneissic rocks. The pebbles are mostly quartz but a few are quartz-muscovite-magnetite schist, and mafic pebbles are rare. Most quartz pebbles are small, rounded, and scattered throughout the unit. Most of the quartzite contains very fine muscovite which defines the layering, and also small amounts of fine-grained andalusite, rutile, and hematite.

Elsewhere in the central Front Range the quartzite may reflect the mineralogy of adjacent rock units (tables 17 and 18); for example, adjacent to sillimanite-biotite gneiss, the quartzite contains biotite and sillimanite; adjacent to tourmaline-bearing gneiss, it also has tourmaline; and adjacent to calc-silicate rock, the quartzite has pyroxene similar to that in the calc-silicate rock. Contacts between the rock types are both sharp and gradational; where gradational, this suggests interlensing during deposition of the original sedimentary materials. Accessory minerals in the quartzite are zircon, rutile, apatite, magnetite-ilmenite, and hematite. The quartz grains in the quartzite are strain-shadowed and have sutured grain boundaries. In quartz gneiss the quartz grains mostly have mutual boundaries with other mineral grains in the rock.

A unit mapped north of Golden (within the Eldorado Springs and Ralston Buttes areas) in the Coal Creek syncline (pl. 1) is essentially quartzite but contains minor lenses of quartz-biotite-muscovite schist. The quartzite has been considered the same age as the other Front Range Precambrian units (Wells and others, 1964) or younger (Lovering and Goddard, 1950, p. 23). I propose that the quartzite and the quartz-biotite-muscovite schist are younger than the surrounding Precambrian metasedimentary rocks but older than any of the 1.65 b.y. intrusive granitic rocks of the area. The quartzite and quartz-biotite-muscovite schist in the syncline are surrounded by igneous rocks except a small area on the south where the quartzite and quartz-biotite-muscovite schist appear to be in conformable contact with biotite-quartz-plagioclase gneiss. The fact that the quartzite and the quartz-biotite-muscovite schist are associated with much more mature metamorphosed sedimentary units strongly suggests they are not the same age. The quartzite and quartz-biotite-muscovite schist are in fact younger. The source area for the quartzite and quartz-biotite-muscovite schist could have been to the east (Condie and Martell, 1983; Sims and Peterman, 1986), and this would agree with an eastern source proposed for Precambrian quartz-feldspar gneiss and micaceous quartzite found as far to the east as Kansas (Bickford and others, 1981).

Other quartz gneisses include rutile-sillimanite-quartz gneiss, biotite-quartz gneiss, and augen gneiss (Sheridan and others, 1968; Marsh and Sheridan, 1976). These minor units occur on the flanks of folds in the Ralston Buttes and Evergreen-Squaw Pass areas. All, except the augen gneiss, are fine- to medium-grained, gray or grayish-white rocks that contain variable amounts of quartz, biotite, and sillimanite. In the Evergreen-Squaw Pass area several wagnerite-, rutile-, and topaz-bearing quartz gneiss and biotite-quartz-plagioclase gneiss units have been described by Sheridan and others (1968, 1976) and Marsh and Sheridan (1976). These rocks have not been recognized elsewhere in the central Front Range.

Augen gneiss is a cataclastic rock found in the Idaho Springs-Ralston shear zone. It is fine grained, well foliated, pink or pinkish gray, and characterized by white or pink augen of feldspar in a fine-grained matrix. Augen gneiss is composed mostly of quartz, plagioclase, and K-feldspar and minor biotite and muscovite.

## MINERALOGY OF THE METAMORPHIC ROCKS

Characteristics of most major and minor minerals from the Early Proterozoic metamorphic rocks of the area are described in order of importance below. The chemical data, except for biotite analyses, are from previous reports--Gable and Sims (1969), Gable and others (1970), and Gable and Smith (1975). These analyses represent major mineral and major mineral pairs from the dominant metamorphic rocks of the area.

### BIOTITE

Biotite is a major mineral in all pelitic rocks in the central Front Range, and measurable amounts may even be found in hornblende gneiss that is finely intercalated with biotite gneiss. Magnetite-sillimanite-biotite gneiss is the only biotite gneiss assemblage with less than 5 percent biotite (fig. 3). Biotite is predominantly dark olive or reddish brown, but the color varies widely from light olive to pale yellow brown to dark olive brown or dark reddish brown. It mostly occurs as aligned, deformed, or folded laths that are frayed to varying degrees. Many laths have overgrowths of muscovite or chlorite. Biotite is also present as tiny subrounded grains in microcline, as inclusions in plagioclase, and as finely intergrown grains with muscovite. It commonly is replaced by andalusite, muscovite, cordierite, or sillimanite, and it is also altered to chlorite, rutile, and magnetite. Major accessory minerals in biotite are zircon, which generally has a clear rim and radio-haloes, and monazite, which always has a thick rim of dark, granular radio-decayed material.

Biotite is aligned in layers parallel with other minerals, especially sillimanite. The biotite helps to define the foliation, and in folds is shingled about the fold axis. Locally, older biotite laths lying at an angle to the folding deform the foliation and caused younger biotite to flow around them. The biotite compositions of the layered gneisses (table 19) generally reflect the bulk composition and to some degree the mineral assemblages of the rocks. Biotite compositions (fig. 10) show a uniform trend from magnesium rich to magnesium poor. Magnesium is highest in biotite from cordierite-gedrite-biotite gneiss and associated cordierite-biotite gneiss; this biotite is also high in iron and aluminum. Biotite from biotite-quartz-K-feldspar gneiss and feldspar-rich gneiss is high in ferrous iron mostly due to the simple mineralogy of the rocks.

The quantities of minor elements in biotites vary with rock type. Biotite from the more mafic cordierite-gedrite-bearing rocks has a high zinc and rather high zircon and vanadium content (Gable and Sims, 1969); whereas, biotite from cordierite-garnet-sillimanite-biotite gneisses has much less zinc, average zirconium, and moderately high chromium, cobalt, and nickel contents. Copper in biotite gneiss interlayered with hornblende gneiss is consistently higher than in biotite from biotite gneiss found elsewhere. The similarity of minor elements in biotite and in the host rock depends on the rock's provenance, whether igneous, sedimentary, or mixed.

## SILLIMANITE

Sillimanite is the most widespread aluminous mineral in biotite gneiss of the central Front Range, and locally forms as much as 40 percent of the rock (tables 5-11). Where the rock contains that much sillimanite, it contains little else except biotite and quartz. The lack of feldspar in highly sillimanitic biotite gneiss suggests that the rock has been altered by more than regional or thermal metamorphism, perhaps by hydrothermal solutions that accompanied emplacement of igneous plutons or ore deposits. Sillimanite is conspicuous in biotite gneiss outcrops as matted fibrolite stringers, clots, and as individual prisms on the surfaces of foliation.

Observed in thin section sillimanite is seen as individual crystals, clustered, or as streamers that are both conformable and unconformable to the foliation. Sillimanite also occurs as individual grains in K-feldspar, garnet, muscovite, cordierite, and biotite crystals. Sometimes sillimanite cuts across and through quartz, plagioclase, biotite, and garnet crystals.

Most of the sillimanite in biotite gneiss of the central Front Range is conformable with the regional foliation. Some sillimanite and garnet associations suggest polymetamorphism for the sillimanite. Helicitic garnet crystals in biotite gneiss contain sillimanite that is folded; whereas, sillimanite in adjacent country rock is not folded and is aligned with the regional foliation.

In the aureoles of the Late Cretaceous-early Tertiary stocks some sillimanite was destroyed but new sillimanite developed. The new crystals are 100 times larger and cut across fibrolitic sillimanite streamers of regional metamorphic origin. Thin new sillimanite crystals are also found within K-feldspar of the thermal aureoles.

## ANDALUSITE

Andalusite in the central Front Range metamorphic rocks is both a prograde and retrograde mineral. Andalusite as part of a prograde metamorphic assemblage occurs only along the mountain front in the Eldorado Springs, Ralston Buttes, and Morrison areas. This andalusite is in large, generally irregular, poikiloblastic crystals that have inclusions of quartz, magnetite, ilmenite, biotite, and rarely tourmaline. In the Ralston Buttes area prograde andalusite replaced staurolite (Wells and others, 1964, fig. 2; Sheridan and others, 1967, fig. 5) and carries inclusions predominantly of quartz.

Retrograde andalusite in the Eldorado Springs, Ralston Buttes, and Morrison areas is generally nonpoikiloblastic and has replaced biotite and sillimanite in microscopic layers along the plane of foliation (fig. 6*D*). It has few or no inclusions; if present, inclusions are quartz and magnetite. This retrograde andalusite is eroded by cordierite and has a chloritic rim, suggesting it formed after the thermal high of regional metamorphism. Retrograde andalusite is widespread in the northern part of the central Front Range (fig. 11) from Central City northward to the Longs Peak-St. Vrain batholith and westward to Lake

Granby. South of Lake Granby it was not found by the author in biotite gneiss in the Strawberry Lake area nor by Braddock (1969) in the Empire area west of Central City. Also, in biotite gneiss samples obtained between Pine and Evergreen, andalusite was not observed in thin sections of biotite gneiss. This widespread retrograde andalusite generally occurs as small, irregular masses in or at the ends of biotite laths, and it is associated with quartz and small grains of magnetite. Where laths have developed, the laths lie at an angle to the regional foliation (fig. 12).

Andalusite also developed in the thermal aureoles of the Late Cretaceous-early Tertiary stocks (fig. 13). It is associated with scattered new tiny biotite flakes, sparse new acicular sillimanite clusters, orthocase, and magnetite in very small subrounded grains. It is also associated with quartz that commonly shows cataclasis and forms small irregular-shaped grains. The andalusite in the aureoles has a slight pinkish to greenish pleochroism not observed in the older prograde or retrograde andalusite.

## STAUROLITE

Staurolite is only preserved as sparse relics in the Early Proterozoic rocks of the central Front Range in a small area from the mountain front westward to about Central City (fig. 14). It occurs as subrounded inclusions in quartz and plagioclase or in the groundmass as eroded crystals along grain boundaries. In the Eldorado Springs area, about 2 km south of Boulder, andalusite forms overgrowths on staurolite crystals (Wells and others, 1964). In cordierite-garnet-sillimanite-biotite gneiss of the Morrison area, to the south of Golden, staurolite occurs as tiny, subrounded inclusions in quartz and plagioclase; in adjacent gedrite-garnet-biotite gneiss it occurs as singular, subrounded eroded crystals. Staurolite in thin section is bright golden yellow or less commonly cream yellow. Relic staurolite is nearly free of inclusions, but the relics observed are perhaps only inclusion-free parts of larger crystals.

## MUSCOVITE

The muscovite in the metamorphic rocks is of several generations. Primary muscovite rarely crosscuts biotite laths but occurs in small books associated with biotite and as thin laths interleaved with biotite and does not show textural evidence indicating it is a replacement mineral. Secondary muscovite predominates in the metamorphic rocks, and its flakes impart a silver-white luster to the rocks especially noticeable in the vicinity of the Idaho Springs-Ralston shear zone. Crystals of primary muscovite are the same size or smaller than those of biotite in the same rock, but some secondary muscovite forms much larger crystals. Primary muscovite is generally devoid of inclusions except for trace amounts of magnetite, zircon, and xenotime-monazite; whereas, secondary muscovite commonly is poikilitic and contains inclusions of the groundmass. The secondary muscovite forms overgrowths on biotite and magnetite and replaces and sheathes sillimanite. Two orientations of muscovite may be associated with a single biotite lath, one believed to be primary and the other secondary or retrograde. Secondary muscovite in rocks adjacent to the Idaho Springs-Ralston shear zone occurs in very large crystals replacing K-feldspar, plagioclase, and biotite. Sillimanite trains in muscovite are not uncommon, and sillimanite is both stable and unstable adjacent to muscovite. South of the shear zone the amount of both primary and secondary muscovite increases in the gneissic rocks at least as far as the Evergreen area. Braddock (1969) stated that there is primary muscovite in all biotite gneiss in the Empire quadrangle that lies just to the west of the Central City area. In the Central City area muscovite gradually disappears northward and is replaced by a finer grained muscovite-sericite in the Nederland-Ward-Gold Hill area. A late, widespread generation of muscovite-sericite replaced much of the feldspar, especially plagioclase, in the Nederland area and north to the Longs Peak-St. Vrain Batholith. In some places, the muscovite-sericite comprises as much as 45 percent of the rock; however, the overall average for biotite gneiss is several percent (tables 5 and 7-11). In the aureoles of the Laramide intrusives, plagioclase is intensely altered to sericite that locally replaces entire crystals.

## GARNET

Lenses and layers of garnet-bearing gneiss decrease in abundance and size from north to south in central Front Range biotite gneiss. In the northern part of the study area garnet-bearing rocks (pl. 1) are abundant and fairly continuous in outcrop (Gable, 1969, 1972, 1980; Gable and Madole, 1976); in the southern part only scattered discontinuous lenses are present (Sims and Gable, 1967; Gable, 1969; Sheridan and others, 1972, 1976; Taylor, 1976). Garnet-bearing rocks define a sequence of gneissic layers that extends across the Continental Divide into the Indian Peaks Wilderness area (northwest corner of map area), but faulting, folding, and rugged terrain made mapping of these layers difficult.

The garnet ranges from baseball-size porphyroblasts to small, sparse crystals that can only be identified by a hand lens. Most are anhedral, pink to red, and many are poikiloblastic, enclosing groundmass grains. Garnets formed during regional prograde metamorphism are generally zoned, and the outer zones are generally free of inclusions; however, the inner part of the crystal is generally crowded with inclusions of magnetite, quartz, and unidentified material. Garnets in gedrite-bearing gneiss and calc-silicate gneiss appear to have fewer inclusions. Garnet-bearing gneiss in aureoles adjacent to plutons of the Routt Plutonic Suite (Boulder Creek Granodiorite) have well-defined coronas of retrograde biotite, cordierite, K-feldspar, magnetite, and quartz (fig. 15). In the study area most garnets are fractured, and the fractures are locally filled with chlorite, green biotite, magnetite, quartz, and cordierite. Garnet in skarn rocks are nonpoikiloblastic, generally small, and orangish red or brownish orange. In some aureoles of the Laramide plutons regional metamorphic garnet occurs as small eroded grains; in other aureoles garnet is replaced totally by thermal cordierite, magnetite, and both brown and green biotite.

## CORDIERITE

In earlier reports on the Front Range (Gable and Sims, 1969; Gable and others, 1970) only two generations of cordierite were recognized--a regional prograde metamorphic mineral and a contact metamorphic mineral associated with emplacement of the Late Cretaceous-early Tertiary intrusives. Petrographic relationships, summarized below, suggest, however, that there were two additional generations of cordierite formed during the Proterozoic as a result of retrograde metamorphism, one associated with emplacement of the Boulder Creek batholith, the other with emplacement of the younger Longs Peak-St. Vrain batholith. The oldest cordierite, developed during major prograde regional metamorphism, is a primary constituent of the high-grade metamorphic assemblage cordierite-garnet-sillimanite-biotite ± K-feldspar ± plagioclase. The earliest retrograde cordierite formed coronas on garnet during the waning stages of regional metamorphism during emplacement of the Boulder Creek batholith. It is these two cordierites that make up the regional cordierite used by Sims and Gable (1964) and Gable and Sims (1969) to define the regional prograde metamorphism of the area.

Regional prograde cordierite occurs as poikilitic crystals containing variable amounts of inclusions of any of the following minerals: garnet, biotite, magnetite, quartz, and sillimanite. Its crystal growth is similar to that of adjacent minerals, and the crystals are aligned along the regional trend of foliation defined by the sillimanite and biotite (see fig. 15*A*). Sometime later, I believe retrograde cordierite formed coronas on garnet in cordierite-garnet-sillimanite-biotite gneiss satellitic to the Boulder Creek batholith (fig. 16). New sillimanite, K-feldspar, biotite, and quartz also formed at this time. It was Hensen (1977, p. 83) who suggested that coronas on garnet are related to retrograde metamorphism. This new cordierite deformed the rock fabric defined by biotite and sillimanite (curvature in fig. 15*A*) and displaced or destroyed the garnet, as illustrated in figure 15*A* and 15*B*. In areas where garnet was replaced (fig. 15*B*), cordierite forms imperfect coronas on garnet, and the K-feldspar occurs as vermicular growths in the cordierite. The youngest Proterozoic cordierite in the metamorphic rocks appears to be retrograde cordierite that perhaps developed due to heating by the 1.5-1.4 b.y. Berthoud Plutonic Suite intrusives. This retrograde cordierite is found south of the Longs Peak-St. Vrain batholith and is entirely different in mode of occurrence from cordierite described thus far. This youngest retrograde cordierite developed in or adjacent to biotite and sillimanite as shapeless blebs associated with quartz and magnetite. It does not contain inclusions and tends to displace the foliation. This later retrograde metamorphism probably followed emplacement of the Silver Plume Granite of the Berthoud Plutonic Suite. Cordierite also developed in aureoles of the Late Cretaceous-early Tertiary stocks (Gable and others, 1970).

## PLAGIOCLASE

Plagioclase is ubiquitous in the biotite gneisses, but the amount varies greatly even within the same gneiss layer. Gedrite-bearing biotite gneiss generally contains very little plagioclase, and cordierite-bearing gneiss typically contains very little or no plagioclase.

Plagioclase crystals generally are xenomorphic and equal in size to crystals of K-feldspar and quartz. Much of the plagioclase contains profuse opaque particles, some display normal zoning, and most plagioclase is predominantly albite or Carlsbad twinned. Myrmekite is common and is present between albite-rimmed plagioclase and K-feldspar and adjacent to perthitic feldspar or muscovite. Plagioclase is commonly altered to sericite. In the Nederland mining district plagioclase has been altered to kaolinite.

Generally, the plagioclase in biotite gneiss of the central Front Range has an average composition of oligoclase that varies between $An_{26}$ and $An_{30}$. In biotite-quartz-plagioclase-biotite gneiss, however, the plagioclase has an average composition of andesine ($An_{32}$), and in gedrite-bearing biotite gneiss it is $An_{14}$ to $An_{22}$.

Plagioclase crystals in hornblende gneiss are better developed than in biotite gneiss, the crystals are fresher looking, and the plagioclase typically is andesine $An_{33}$ to $An_{50}$. Labradorite ($An_{63}$) to bytownite ($An_{86}$) is the typical plagioclase in amphibolite associated with hornblende gneiss.

In the aureoles of the Late Cretaceous-early Tertiary stocks, twinning disappears in the plagioclase, and the crystals appear very cloudy. New plagioclase, but in smaller crystals, has profuse inclusions of sillimanite and tiny new biotite laths.

## K-FELDSPAR

In the central Front Range the K-feldspar in biotite gneiss is maximum microcline, intermediate microcline, microperthite or microcline-microperthite, and orthoclase. The K-feldspar occurs both as anhedral crystals that are of equal size to those of quartz and plagioclase, and as interstitial groundmass grains. South of the Longs Peak-St. Vrain batholith K-feldspar replaces some plagioclase and biotite as result of retrograde metamorphism. The most common inclusions in the K-feldspar are quartz, sillimanite, plagioclase (some with albitic rims), magnetite, and biotite. Rarely, monazite and apatite crystals are observed in microcline and microperthite.

Orthoclase and maximum microcline are both present in cordierite-garnet-sillimanite-biotite gneiss of the Central City area (Gable and Sims, 1969) and in scattered biotite gneiss elsewhere in the central Front Range; restrictions on distribution in Proterozoic rocks in the area are not known. Orthoclase is also present in the aureoles surrounding the central Front Range Laramide stocks (Gable and others, 1970). Microcline-microperthite is chiefly a film, or bleb perthite, but patch and vein microperthites are common in some areas. Vein microperthite appears to form mostly in sheared and deformed rocks. Microperthite accounts for nearly half of the K-feldspar in many areas, and it commonly is the chief form of K-feldspar in the metamorphic rocks in the northern part of the central Front Range.

K-feldspar is generally sparse in biotite gneiss along the mountain front from Boulder southward to about Evergreen, (the south boundary in not well defined because of sparseness of thin-section data); however, a few thin layers containing several percent of untwinned intermediate microcline can be found. In the Conifer and Pine areas, south of Evergreen, the amount of K-feldspar increases. The westward limit of the area sparse in K-feldspar is also poorly defined, but between Evergreen and Idaho Springs and Central City K-feldspar again is conspicuous in most biotite gneisses. In this area there are also a few thin layers containing several percent of untwinned intermediate microcline. Except for albitic rims on K-feldspar crystals, the K-feldspar shows the least amount of alteration of any of the major minerals in the biotite gneiss, suggesting that most K-feldspar crystallized late in prograde metamorphism. Microcline and microperthite crystals are both large and anhedral and equal in size to plagioclase or quartz, or the crystals have conformed to space available and are subordinate in size to plagioclase. The latter K-feldspar is probably the younger. Northward in the central Front Range sillimanite in K-feldspar has sharp contacts and no reaction rims nor etching, but sillimanite adjacent to K-feldspar crystals is often sheathed from the K-feldspar by quartz. In addition to partial rims of K-feldspar on sillimanite, K-feldspar may also rim garnet, and borders of K-feldspar adjacent to cordierite are sometimes fuzzy.

Front Range hornblende gneiss and amphibolite normally contain no K-feldspar, but in areas where hornblende gneiss is interlayered with calc-silicate rocks and/or biotite gneiss, some layers of hornblende gneiss have trace amounts of exsolved K-feldspar as antiperthite in plagioclase. Impure calc-silicate rocks also contain some K-feldspar (tables 16 and 17) probably due to the dissociation of muscovite and biotite to K-feldspar and diopside.

## IRON OXIDES

Iron oxides (magnetite, hematite, ilmenite) are ubiquitous in biotite gneiss of the central Front Range. A few lenses and layers, however, have iron oxides as a major mineral. One layer in the Ward-Gold Hill area contains 5 or 6 percent magnetite, and another--a thin magnetite-quartz lens--is in the Ralston Buttes area (Young, 1985). Elsewhere in the central Front Range only very thin magnetite-bearing lenses or layers are recognized and generally only by deflection of the compass needle or in thin section. In thin section magnetite is commonly poikiloblastic with inclusions of quartz, biotite, sillimanite, and spinel. Generally, the garnet-bearing rocks have the least magnetite.

Examination of polished sections using reflected light shows magnetite is dominant in the K-feldspar-bearing cordierite-biotite gneiss; ilmenite is dominant in cordierite-gedrite-biotite gneiss; and hematite accounts for about one-third of the total oxides in sillimanite-biotite gneiss. In a comparison of iron-bearing minerals in modes with chemical analyses, it is evident that although a large amount of magnetite is present in magnetite-sillimanite-biotite-gneiss and cordierite-magnetite-sillimanite-biotite-gneiss, a sizable amount of another iron oxide, presumably hematite, also is present.

## QUARTZ

Quartz in biotite gneiss composes about 20-55 percent of the rock. In the central Front Range the biotite gneisses as a whole are quartz rich, most contain at least 30 percent quartz. Quartz is generally equigranular, and the crystal boundaries are straight, sutured, or serrate. The lack of strain shadows on small, subrounded, interstitial quartz crystals suggests it is young quartz. Inclusions in quartz crystals are not as noticeable as in other major minerals in the biotite gneiss; where present, inclusions consist mostly of microcline, sillimanite, biotite, magnetite, and tiny, dark, unidentified particles. Quartz is also a major inclusion in most other minerals, including garnet, microcline, plagioclase, and andalusite.

Quartz always shows undulatory extinction except where it has been sheared and recrystallized. Then, it occurs as large strain-shadowed, elongate crystals, parallel to foliation, and as small, clear crystals. Quartz in biotite gneiss along the mountain front from Eldorado Springs on the north to the Indian Hills quadrangle on the south forms clusters of small crystals not observed elsewhere in the central Front Range. These clusters are characteristic of partial recrystallization of chert to granular quartzite (Spry, 1969, pl. VIIb). Large, equigranular quartz crystals found elsewhere in the central Front Range are characteristic of more complete metamorphic recrystallization.

## AMPHIBOLES

The amphiboles in hornblende gneiss and amphibolite consist mainly of hornblende, gedrite, and cummingtonite. Of the three, hornblende is by far the most common and occurs as crystals in the plane of foliation. Hornblende is also a common mineral in some calc-silicate rocks, but it is rare in biotite gneiss except where the gneiss grades into hornblende gneiss or amphibolite.

In thin section hornblende is seen both as euhedral and as corroded anhedral crystals. The older euhedral crystals generally are shades of brown; whereas, the anhedral crystals are shades of green. Optical and chemical data for nine green hornblendes from hornblende gneiss, amphibolite, and amphibolite layers in cordierite-bearing biotite gneiss (Gable and Smith, 1975) show that the dominant components plot between the two end-member series of tremolite-ferropargasite and pargasite ± magnesiohastingsite-ferropargasite ± hastingsite.

Gedrite and cummingtonite occur in amphibolite lenses and pods in the Central City, Morrison, and Evergreen areas (Sims and Gable, 1964). A layered metagabbro dike in the Nederland area contains both gedrite and cummingtonite (table 3), similar to lenses in the Central City area. Both gedrite and cummingtonite may be associated with hornblende, garnet, cordierite, and biotite.

In the aureoles of the Late Cretaceous-early Tertiary stocks hornblende gneiss and amphibolite, as expected, do not show the effects of thermal metamorphism as readily as does biotite gneiss. Hornblende-bearing rocks within the aureoles have a slightly hornfelsic texture and are generally recrystallized; the hornblende is in part replaced by biotite and magnetite. Pyroxene in hornblende gneiss adjacent to the stocks has hornblende overgrowths along crystal boundaries.

## PYROXENES

Both clinopyroxene and orthopyroxene are present in central Front Range metamorphic rocks; clinopyroxenes are very common, whereas orthopyroxenes are rare. Diopside is the major clinopyroxene in the central Front Range. In hornblende-bearing rocks, diopside is the same age, as well as older and younger, than hornblende. The apparently older diopside, together with trace amounts of orthopyroxene, is associated with dark-brown hornblende. These older pyroxenes are rimmed and embayed by a younger, olive- or bright-green hornblende which is, in turn, locally mantled by even younger anhedral diopside.

Orthopyroxenes occur as rare, equant to prismatic euhedral crystals but most often as small, sparse, irregular relics. Orthopyroxenes are present in hornblende gneiss (table 12) and in metamorphosed mafic lenses and dikes (tables 3 and 14). The orthopyroxenes in mafic dikes in the Central City area are aegirene-augite, but in a dike in the Nederland area they are bronzite and hypersthene. No effort was made to identify the orthopyroxenes in the metasedimentary rocks.

Pyroxene-rich rocks, some of which are called diopsidite, are found, especially near mining districts, as layers in calc-silicate gneiss and interlensed with quartzitic rocks as in the Central City and Jamestown districts. These pyroxene-rich rocks consist of 52-97 percent diopside; garnet, scapolite, sphene, hornblende, and the retrograde mineral, epidote, make up several percent of the rocks. Diopside has locally been altered to hornblende in association with calcite, magnetite, and sphene.

## SCAPOLITE

Scapolite replaces plagioclase in calc-silicate rocks of the central Front Range, but just as much scapolite is also present in rocks where plagioclase is absent. Some scapolite occurs as clear, well-formed crystals but most crystals are anhedral. Scapolite is associated with diopside, green hornblende, sphene, and in places garnet. Sphene in scapolite-bearing rocks may be profuse as small, subhedral to anhedral, elongate crystals. Inclusions in scapolite are sparse but include tiny, rounded quartz crystals and small subhedral sphene crystals. Optical data indicate calcium is about twice as abundant as sodium in scapolite (mizzonite = $Ma_{35}$-$Me_{65}$); plagioclase in these same rocks varies from $An_{25}$ to $An_{83}$.

## APATITE, ZIRCON, AND XENOTIME-MONAZITE

The most common accessory minerals in the metamorphic rocks of the study area are apatite, zircon, and xenotime-monazite, in order of their abundance. Apatite is ubiquitous in all rock types but generally only in trace amounts; it is most abundant (but still less than 0.5 percent) in biotite-quartz-plagioclase gneiss. The crystals are euhedral to anhedral and most occur as inclusions in other minerals.

The monazite in xenotime-monazite is far more abundant in the biotite gneiss than previously reported; it is the cause of much of the radiation damage in biotite and cordierite. Monazite crystals are mostly anhedral, occur as inclusions in other mineral grains, and are generally more altered than zircon. Zircon is ubiquitous in central Front Range biotite gneiss. Most zircons are very small and are multiple zoned.

### ALLANITE

Allanite in the metamorphic rocks commonly is associated with secondary epidote and forms growths at the edge of those crystals. It is most common in biotite-quartz-plagioclase gneiss, garnet-bearing biotite-gneiss, and hornblende gneiss. Allanite is always metamict and occurs as anhedral crystals.

### CORUNDUM

Corundum occurs only rarely in metamorphic rocks of the central Front Range. It is found in biotite gneiss, sillimanite-biotite gneiss, and cordierite-gedrite gneiss. The only well-developed crystals of corundum in the central Front Range are found on Santa Fe Mountain near Idaho Springs (Sheridan and others, 1976). Here, it occurs as pink to gray, mostly subhedral to anhedral grains. Elsewhere in the central Front Range, corundum is typically found as corroded grains in association with green spinel (hercynite), magnetite-ilmenite, cordierite, and/or gedrite. This latter corundum is found near Central City (Gable and Sims, 1969) and in the Ward area (table 1).

### TOURMALINE

Tourmaline is present in metamorphic rocks that crop out along the mountain front generally between Morrison and the Idaho Springs-Ralston shear zone and westward to Central City (fig. 17). It occurs as eroded and rounded porphyroblasts (fig. 6*C*), and as angular and rounded crystals which are locally elongate parallel to the foliation. The crystals are both poikiloblastic and clear. Color varies with rock type. In quartzite, tourmaline is yellow to yellowish green, in garnet-gedrite-biotite gneiss it is dark green, and in sillimanite-biotite gneiss it is olive green to grayish green. Biotite, apatite, quartz, zircon, and magnetite form the inclusions in tourmaline. Tourmaline also occurs as inclusions in biotite and andalusite, or in clusters with biotite, quartz, and rarely garnet in biotite gneiss. Many tourmaline crystals are zoned and include five or more distinct zones. Tourmaline may makeup as much as 0.5 percent of the rock. All the tourmaline-bearing rocks that were chemically analyzed have more than 10 ppm boron; samples of non-tourmaline-bearing gneiss had no boron. Although the source of the boron is not evident, it might have come from sea water during deposition of the marine parent rocks or from volcanic processes (Slack and others, 1984), and was later concentrated in marine clays.

## GEOCHEMISTRY AND PROVENANCE OF THE METAMORPHIC ROCKS

The major types of Early Proterozoic rocks of the central Front Range, biotite gneiss, hornblende gneiss and amphibolite, and calc-silicate gneiss, have been chemically analyzed (tables 20-27, 33, 34, and 37 in Appendix II) and are herein compared with similar rocks of known origin in order to better understand the effects of metamorphism on the rocks of the region and to determine their probable protoliths.

## BIOTITE GNEISS

Ten varieties of biotite gneiss (tables 1, 2, 4-11) have been distinguished by modal counts in the central Front Range. As suggested by the modes, the average chemical signatures of the biotite gneisses fall into two major groups; sillimanite-free biotite gneiss and sillimanite-biotite gneiss (fig. 18). Chemically, as bserved in tables 20-27, sillimanite-free biotite gneiss has more $SiO_2$, CaO, and $P_2O_5$ and less MgO, $Al_2O_3$, and FeO (total) than sillimanite-bearing gneiss. $K_2O/Na_2O$ ratios can be used to separate most sillimanite-biotite gneiss from sillimanite-free biotite gneiss (fig. 19). In figure 19 some samples are displaced between the two major groups of biotite gneiss: four garnet-biotite gneiss samples plot in the sillimanite-biotite area and four samples of sillimanite-biotite gneiss and one of garnet-biotite gneiss plot in the sillimanite-free biotite gneiss area. These displacements may have been caused by gradational contacts between rock units sampled, as in table 22, sample 1, or perhaps thin lenses of differing composition within the sampled layers were not detected in hand samples.

Chemical distribution of elements between the various types of central Front Range biotite gneiss that evolved under high-grade metamorphic conditions shows element compositions of specific mineral assemblages to be dominantly dependent on bulk compositions of the rock. This conclusion is best expressed in an A'FM diagram (fig. 20). Because quartz, K-feldspar, plagioclase of near-constant composition, and magnetite (also ilmenite), are common to all rock types, they need not be part of this A'FM diagram (Reinhardt, 1968; Reinhardt and Skippen, 1970; Winkler, 1979, p. 53, 232). In figure 20*A* and *B* solid curved lines separate rock types. The curved lines define the degree to which variations in composition of the ferromagnesium and alumina minerals are a function of rock composition. Sillimanite-free biotite gneiss samples with the least iron but high aluminum plot toward the magnesium corner while sillimanite-biotite gneiss samples plot on the high iron and alumina side of figure 20. Some sillimanite-biotite and most sillimanite-free biotite gneiss assemblages plot near but outside the boundaries designated by analyzed mineral pairs. This is expected since the analyzed mineral pairs only represent those assemblages that contain garnet and/or cordierite. High alumina in the rocks displaces many analyses towards the sillimanite apex of the A'FM diagram, especially analyses of sillimanite-biotite gneiss. There is, however, a general progression from sillimanite-biotite gneiss on the magnesium side of the diagram to more iron-rich garnet-sillimanite-biotite gneiss on the iron side of the diagram. Most, but not all, cordierite-bearing rocks are on the iron side of the diagram.

The quantity of major minerals and oxides in biotite gneiss south of the Idaho Springs-Ralston shear zone differs somewhat from that north of the zone (table 28; fig. 21). Some of the differences are due to differences in the gneisses in the two areas. The gneisses to the north of the shear zone are richer in cordierite, K-feldspar, magnetite, and sillimanite. In the linear diagram (fig. 21) of major oxides and some minor oxides from biotite gneiss of the central Front Range, large variations in $SiO_2$ are evident which suggests either that silica is extremely variable between gneissic layers or that the silica was mobile and this is reflected in its variability in the biotite gneiss. Four analyses of sillimanite-biotite gneiss from the Evergreen, Indian Hills, and Squaw Pass areas plot on the magnesium side of the A'FM diagram (fig. 20) in an area of more than 25 but less than 40 percent $Al_2O_3$; whereas, nearly all sillimanite-biotite gneiss samples north of the Idaho Springs-Ralston shear zone plot above 50 percent $Al_2O_3$. These data agree with an increase in modal sillimanite to the north of the Idaho Springs-Ralston shear zone. Other differences in the major minerals and oxides in biotite gneiss north and south of the shear zone are evident in table 28. Averages for the major oxides agree quite well with the mineral data for all oxides except $K_2O$. $K_2O$ is slightly greater in the samples south of the shear zone; however, K-feldspar is less, thus reflecting the greater percentage of primary muscovite south of the shear zone.

The difference in major elements between sillimanite-biotite gneiss and sillimanite-free biotite gneiss suggests that the gneisses may be of different origin. In a plot of normative K-feldspar-plagioclase-quartz, most central Front Range sillimanite-free-biotite gneisses are grouped in the rhyolite-dacite field of Streckeisen (1980). Proterozoic felsic, sillimanite-free, bedded volcanogenic rocks from the Salida area of

Colorado that are clearly transported and metamorphosed mixtures of volcaniclastic debris and nonvolcanic material also plot in the same field (Boardman and Condie, 1986) thus, the sillimanite-free biotite gneiss of the central Front Range may be in part of similar origin.

Engel and others (1974) showed that higher $K_2O/Na_2O$ ratios depict changes in lithology related to increased maturity of clastic sedimentary rocks. Using their method, the average central Front Range sillimanite-free-biotite gneiss and garnet-biotite gneiss (table 29) have ratios of 1.3 and 1.4, respectively. The ratios for a variety of Front Range sillimanite-biotite gneisses are as follows: cordierite-sillimanite-biotite gneiss = 2.7, and cordierite-garnet-sillimanite-biotite gneiss and cordierite-magnetite-sillimanite-biotite gneiss = 3.4 and 3.3, respectively. The low ratios of 1.3-1.4 for Front Range sillimanite-free biotite gneisses suggest that the original rock composition was less mature and of different origin, perhaps igneous origin, than that of the majority of biotite gneisses of the area. The more mafic garnet-cordierite-sillimanite-biotite gneisses have ratios of 2.7-3.4, and according to Engel and others (1974), the ratios are indicative of subgraywacke or argillaceous sandstone and shale protoliths. Also, plots of rubidium and zirconium analyses for central Front Range sillimanite-biotite gneiss, when averaged, plot with argillic graywacke (Engel and others, 1974, fig. 6). The averages for barium, cesium, and lead plot in the general area of shale, again suggesting the majority of sillimanite-biotite gneisses in the central Front Range represents mature clastic sedimentary rocks (Engel and others, 1974).

Changes in the major- and minor-element and rare-earth chemistry of sedimentary rocks through time have been studied by DePaolo (1981), McLennan (1982), and Taylor and McLennan (1983) to name but a few. Neodymium radioisotope dates on Front Range gneisses suggest an Early Proterozoic age of 1.8 b.y. (DePaolo, 1981). A comparison of the average chemical composition of the major element compositions of Archean and Early Proterozoic clastic sedimentary rocks (McLennan, 1982) with the average composition of Front Range biotite gneiss (table 30) shows the central Front Range biotite gneiss closely resembles the Early Proterozoic rocks but is lower in $SiO_2$ and higher in $Al_2O_3$ and total iron. These three oxides are more nearly like those of the Archean rocks. Reed and others (1987), however, found no evidence that Archean rocks contributed any sediment to the central Front Range Early Proterozoic rocks. Trends for the major and minor elements of an average shale (Krauskopf, 1967) and those for the average central Front Range biotite gneiss are similar (fig. 22; tables 31, 32). CaO, Ce, Mo, V, and $P_2O_5$ show the greatest deviation from an average shale concentration; whereas, $Al_2O_3$, MnO, Nb, and Zn show the least. This suggests that high temperatures and moderate pressures that formed the central Front Range biotite gneisses did not greatly change the overall basic major element compositions of the gneisses but did change the concentrations of some trace elements. In figure 22*B*, one, possibly two, Front Range samples plot near Archean shales. This suggests that either these two samples are in error or they are perhaps of Archean origin; however, the study by Reed and others (1987) rules out an Archean origin. Also, nearly 80 percent of the Front Range samples plot within the field of post-Archean shales of Taylor and McLennan (1983).

## CALC-SILICATE GNEISS

The calc-silicate gneiss and associated-garnet-magnetite-hornblende-quartz gneiss, present as layers or lenses in biotite gneiss, are extremely variable both chemically and mineralogically (tables 33 and 34). All are diopside or hypersthene normative, except calc-silicate gneiss interlayered with hornblende gneiss in the Gold Hill area and a gneiss in the Ward area that is olivine normative. Some are silica rich, others are high in sodium and potassium and form plagioclase and K-feldspar, and still others, such as the strongly altered skarn rocks, are rich in iron (table 34). Composition varies considerably not only within a single layer or lens but between areas (table 35), and composition is strongly influenced by fine interlayering with other rock units (fig. 23; table 35, cols. 6 and 7). Most lenses or layers are chemically diverse and do not show a consistent geochemical signature. Calc-silicate gneiss interlayered with biotite gneiss generally has low magnesium and calcium values and high aluminum values (fig. 23, area 2). This relationship is due to fine-scale interlayering of calc-silicate gneiss with aluminum-rich felsic gneiss or biotite gneiss that is low in magnesium and calcium (table 35, col. 2). Conversely, calc-silicate gneiss interlayered with or gradational into hornblende gneiss or pyroxene-rich gneiss contains greater amounts of magnesium and calcium but less aluminum (table 35, col. 6). The interaction of MgO, CaO, and $Al_2O_3$ in calc-silicate gneiss with $SiO_2$ is demonstrated by the plot of values in figure 23. Also, some calc-silicate gneiss has high titanium and potassium and moderate amounts of fluorine; however, other calc-silicate gneiss is very low in titanium and potassium.

Both the chemistry and mineral assemblages suggest that most calc-silicate gneisses were probably derived from calcic shales. By comparing the trace elements of an average Front Range calc-silicate gneiss with the trace element values of an average carbonate rock, an average deep-sea carbonate rock, and an average basalt (table 36), it is evident that the greater quantity of trace elements in the calc-silicate gneiss (table 36) must be due to the fine interlayering of calc-silicate gneiss with hornblende gneiss (table 37) and feldspar-rich gneiss. Originally mafic and felsic volcanic rocks probably were interlayered with calcic shales.

## HORNBLENDE GNEISS AND AMPHIBOLITE

The hornblende gneiss and amphibolite of the central Front Range overall exhibit little variation in aluminum, ferric iron, magnesium, manganese, and potassium (table 37) from one locality to another; whereas, ferrous iron and calcium vary greatly (fig. 24). Variations in ferrous iron generally reflect the degree of weathering and alteration of iron-bearing minerals in the rock; the high calcium, represented in modal calcite (table 37), probably reflects thin calcite-rich sedimentary layers in hornblende gneiss. The hornblende gneiss and amphibolite, when compared with averages for basalt (Vinogradov, 1962; Turekian and Wedepohl, 1964) are high in chromium, scandium, and vanadium--and in some samples cerium; however, concentrations of nickel, copper, zirconium, niobium, and generally barium are low. Titanium and phosphorus are uniformly low in hornblende gneiss and amphibolite of the central Front Range. One exception is the Clear Creek layer where hornblende gneiss is especially rich in both elements.

Mineral norms for the hornblende gneiss and amphibolite (table 37) of the central Front Range show that a majority of these rocks are rich in quartz. In general, the more massive layers contain more quartz than scattered small lenses. About one-third of the rocks sampled are olivine normative, and about two-thirds are hypersthene-diopside normative. The variation in normative minerals mostly reflects the chemical composition of the original rocks.

The average chemical composition of hornblende gneiss and amphibolite, when compared with the average composition of various tholeiitic basalts (table 38), is similar to tholeiite or Hawaiian basalt. Composition of central Front Range hornblende gneiss and amphibolite predominantly falls into the tholeiitic field of Irvine and Baragar (1971) (fig. 25*A*) and also in the tholeiitic field of Dupuy and Dostal (1984) and Floyd and Winchester (1975). Some central Front Range hornblende gneiss may, as suggested by the scatter of plots in figure 25*B*, be derived from alkalic basalt.

Floyd and Winchester (1975) have been successful in discriminating between magma types by using the trace elements Ti, P, Zr, Y, and Nb. These elements appear to remain immobile during low-grade metamorphism; however, their use in high-grade metamorphic rocks to discriminate between alkalic and tholeiitic basalt is less certain because of element mobility with increasing temperature and pressure. Studies on Front Range rocks by Gable and Sims (1969), Hedge (1972), and Olsen (1982) all do suggest limited movement of many elements in Front Range rocks during high-grade metamorphism. Boardman and Condie (1986) also suggested limited mobility in the high-grade metamorphic rocks of the Salida area, central Colorado. Since the analyzed trace elements plotted for central Front Range hornblende gneiss and amphibolite mostly mimic trends for similar rocks in the Salida area and both areas plot in the tholeiite field of Floyd and Winchester (1975), it appears that the high grade of metamorphism has not greatly affected Front Range trace elements. In determining the origins for hornblende gneiss and amphibolite, both Dupuy and Dostal (1984) and Boardman and Condie (1986) suggest crystal fractionation can be determined by plotting $Mg/(Mg+Fe^{2+})$ = [Mg] values, as in figure 26, for the major oxides and minor elements. Crystal fractionation in most central Front Range hornblende gneiss and amphibolite is illustrated by the similarity of [Mg] values and trends to those for hornblende gneiss and amphibolite from central Colorado that Boardman and Condie (1986) demonstrated formed by crystal fractionation. In both areas the trends for FeO, $P_2O_5$, and $SiO_2$ increase with the decrease in [Mg] values (fig. 26). The incompatible trace elements Ce, Y, and Zr may also suggest crystal fractionation. Boardman and Condie (1986) also found an increase in these elements with decrease in [Mg] values; central Front Range analyses follow this same pattern. And, crystal fractionation is suggested by the less mobile trace elements since they tend to preserve primary basaltic geochemical characteristics as well as determine tectonic setting (Pearce and Cann, 1973; Pearce and Norry, 1979; Sills and Tarney, 1984). The mobile trace elements (titanium, zirconium, yttrium, and niobium) in central Front Range hornblende gneiss and amphibolite also suggest fractionation did occur. An analysis of the relations between Zr and Y in rocks of the central Front Range (fig. 27), based on the work of Pearce and Norry (1979), shows that the Proterozoic mafic rocks--hornblende gneiss and amphibolite but especially amphibolite of the central Front Range--originated in an island arc, as previously proposed by Hills and Houston (1979) and Reed and others (1987). The scatter of points in figure 27 could be due to contamination by metasedimentary units; or as indicated by Pearce and Norry (1979), there may be point scatter even for more recent volcanic rocks.

## MINOR ELEMENTS

Central Front Range Early Proterozoic metamorphic rocks are rich in many of the minor elements, and their abundance and distribution vary with locality and rock type (figs. 28-30). Certain minor elements (fig. 28) are consistently more abundant than crustal averages tabulated by Vinogradov (1962). Element abundances in central Front Range biotite gneiss (fig. 29), hornblende gneiss and amphibolite, and calc-silicate gneiss (fig. 30) show a greater concentration of minor elements in areas containing mining districts. Elements occurring in greater than crustal abundances in biotite gneiss are cerium, chromium, cobalt, fluorine, gallium, lanthanum, lead, molybdenum, scandium, tin, yttrium, and zirconium (fig. 28; table 31). In addition, hornblende gneiss, amphibolite, and calc-silicate gneiss all have substantially more chromium, copper, cobalt, fluorite, nickel, vanadium, and zinc (fig. 29; table 39) than in crustal averages by Vinogradov (1962). The rocks of Central City, Gold Hill, Nederland, Tungsten, and Ward areas not only have a wider range of minor elements, but the elements are in greater abundance than in other areas of the central Front Range (table 40). It is possible some of this abundance is due to the higher concentration of thin, discontinuous and unmappable calcic and mafic layers in the schist and gneiss sequences in these areas. Differences in quantity and distribution of minor elements between the northern and southern parts of the central Front Range are also due to differences in composition of the gneisses (fig. 28). In the northern area hornblende gneiss, amphibolite, and some calc-silicate gneiss are generally higher in fluorine, nickel, rubidium, strontium, and vanadium (fig. 28).

Uranium and thorium abundances in central Front Range metamorphic rocks are high (Phair and Gottfried, 1964). Their study shows that the averages for these elements in biotite gneiss and schist are uranium, 4.7 ppm, and thorium, 18.8 ppm; and in hornblende gneiss and amphibolite, uranium, 4.7 ppm and thorium, 10.6 ppm. The continental crustal average for uranium is 2.8 ppm and for thorium 10 ppm (Heier and Rogers, 1963). These high figures for the central Front Range reflect the presence of xenotime and monazite in many of the metamorphic rocks, especially the biotite gneisses.

## ORE MINERALS IN METAMORPHIC ROCKS

Geochemical studies of the metamorphic rocks of the central Front Range also give clues to the distribution and abundance of various elements (table 40) with respect to Precambrian ore deposits. Secondary benefits from the geochemical study include determination of the abundance of ore minerals in metamorphic rocks and their distribution, and whether the metamorphic rocks are in part the source of Precambrian ore deposits. The countless prospect pits dotting the mining areas are located generally in or adjacent to calc-silicates, hornblende gneiss, amphibolite, and other mafic Precambrian rocks suggesting some mobility of the ore minerals. Deposits are found not only along faults and at the junction of faults and shears, but at the contacts of calcic, mafic, and granitic rocks, within granitic rocks, and also in the metamorphic rocks. Their presence within the metamorphic rocks suggests that those rocks were a source for some ore deposits. Melting of the country rock during the Proterozoic is attested to by prolific migmatization due to high thermal gradients associated with Precambrian plutonism, initially at 1.7-1.65 b.y., and again during the Middle Proterozoic at about 1.5-1.4 b.y. Because of the greater than average crustal abundance of many ore minerals in metamorphic rocks of the Front Range, it is probable that some ore minerals would be locally concentrated in economic deposits. Certainly some of the ore minerals were mobile during heating of the country rock, but central Front Range studies by Gable and Sims (1969), Hedge (1972), and Olsen (1982) all suggest limited movement of elements from their source areas. On the basis of field observations of small prospect pits and somewhat larger prospects in the central Front Range that show pyrite, galena, monazite, sphalerite, magnetite, fluorite, copper, and massive sulfide deposits of Proterozoic age, it is probable that the deposits were derived from metamorphosed igneous and sedimentary rocks, and are largely in place. Examples are the massive sulfide deposit at the F.M.D. mine in Jefferson County, where pyrite and chalcopyrite are intimately intergrown with hornblende, biotite, and labradorite in an amphibolite schist, and in the Malachite and Liberty lodes near Evergreen (Lindgren, 1908). Johnson (1984) made a similar interpretation for small nonproductive sulfide deposits near Black Hawk, and I came to a similar conclusion for deposits at the Fairday mine on Overland Mountain west of Ward. Young and Sims (1961) reached a similar interpretation for the xenotime-monazite deposits near Central City.

### PROVENANCE SUMMARY

The major Early Proterozoic metamorphic rocks of the central Front Range represent two major protoliths. The biotite gneiss and calc-silicate gneiss are primarily of sedimentary origin; however, the feldspar-rich gneiss and the hornblende gneiss and amphibolite are largely of igneous origin. When analyses of the major rock types (except feldspar-rich gneiss) are plotted on a Niggli $c$-100 $mg$ diagram (Leake, 1964) (fig. 31), the probable protoliths of the rocks are well demonstrated.

Sillimanite-biotite gneiss predominantly plots in the typical pelite and semi-pelite field (fig. 31). Variations in chemical composition of the gneiss due to compositional differences in layers is expressed by plots outside the pelite field. These out of field plots suggest felsic and mafic layers in the gneiss. Sillimanite-free biotite gneiss, because it contains more calcium than sillimanite-biotite gneiss, plots on the acidic side of the igneous trend as it should if it is of igneous origin. A mixed origin, partly sedimentary but predominantly igneous, is suggested for sillimanite-free biotite gneiss. Calc-silicate gneiss and pyroxene-bearing gneiss, as suggested by chemical data and field observation, had as their protoliths mixtures of pelitic limestone and pelitic dolomite. Plots of all amphibolite and most hornblende gneiss spread along the basic portion of the igneous trend, represented by diorite, except for a few hornblende gneisses that plot in the pelitic-limestone field. The plot of hornblende gneiss in the pelitic-limestone field suggests that some hornblende gneiss is of sedimentary origin. Protoliths interpreted from figure 31 are similar to those suggested by chemical data and field observation. The quartzite and quartz gneiss and schist of the Ralston Buttes area had a different origin unrelated to the graywacke-shale and bedded volcanogenic series proposed for most central Front Range metamorphic rocks.

## METAMORPHISM AND PARAGENESIS

Pelitic rocks and certain mineral assemblages provide invaluable information on metamorphism associated with multiphase, multi-component chemical systems. Cordierite in cordierite-biotite gneiss, for example, is an indicator of grade of metamorphism but only if associated with certain critical minerals. In many places in the central Front Range cordierite-bearing biotite gneiss is interlayered with cordierite-free biotite gneiss, owing to variations in bulk composition. The cordierite-bearing layers suggest temperatures and pressures of metamorphism for a given area.

The central Front Range metamorphic rocks, as stated earlier, have been subjected to a number of metamorphic events. Gable and Sims (1969) described the Early Proterozoic regional metamorphism, and Gable and others (1970) outlined the thermal effects caused by the Late Cretaceous-early Tertiary stocks, but little has been done to identify the metamorphic effects of other known thermal events in the area, especially the thermal effects caused by emplacement of the 1.5-1.4 b.y. Silver Plume Granite. A study by Sheridan and others (1976) in the Evergreen-Squaw Pass area suggested an origin for the sillimanite gneiss units similar to those of Gable and Sims (1969) and to those of this report. Wells and others (1964), in mapping the Coal Creek area southwest of Eldorado Springs, discovered staurolite, andalusite, and sillimanite in the sillimanite gneiss but did not attempt to define a metamorphic zone or zones. In the northern Front Range, W.A. Braddock and some of his students at the University of Colorado have mapped mineral occurrences that define an intermediate-grade biotite zone on the east that grades westward into a high-grade migmatitic cordierite-garnet-sillimanite-biotite gneiss zone (La Fountain, 1975; Braddock and Cole, 1979; Nesse, 1984). Condie and Martell (1983) concurred that the grade of metamorphism in the northern Front Range increases regularly in a westerly direction. It is herein proposed that metamorphism in the central Front Range also increases in grade westward.

Plutonism, mineralization, and hydrothermal alteration have partially masked the dominant prograde metamorphism in the central Front Range, making it difficult to define metamorphic zones. Metamorphism produced two, and in places three, generations of andalusite, biotite, muscovite, and K-feldspar. Rock fabrics have been warped, crosscut, and in general altered several times (Moench and others, 1962; Sims and Gable, 1964; Braddock, 1969; Cole, 1977).

Regional metamorphism appears to have taken place over a period of time during the Early Proterozoic, resulting in the metamorphic zoning observed today with the lowest grade of metamorphism on the east and the highest on the west. In the central Front Range the easternmost zone represents a medium to medium-high grade, low-pressure, metamorphic facies characterized by the assemblage: plagioclase-quartz-sillimanite-biotite ± cordierite ± staurolite ± andalusite ± garnet. This zone is bordered on the west by a poorly defined middle, or transition, zone represented by the assemblage: muscovite-K-feldspar (microperthite)-sillimanite-biotite ± andalusite. In this zone staurolite crystals are corroded and occur as inclusions in andalusite or as separate corroded grains interstitial to larger crystals in the gneiss. Staurolite was obviously unstable during metamorphism, and its breakdown signified the beginning of intermediate-grade amphibolite-facies metamorphism. This zone is transitional westward into a high-temperature low-pressure facies characterized by cordierite-garnet-K-feldspar (microcline)-quartz-sillimanite-biotite ± plagioclase (fig. 32). Because metamorphic zonal areas were largely determined on the basis of thin-section data, all zonal boundaries in figure 32 are approximate. More extensive, detailed work in the field and laboratory would be required to determine exact metamorphic boundaries.

In the central Front Range, the transitional upper amphibolite-granulite grade of regional metamorphism, as defined by Currie (1971) and Winkler (1979), represents the last of at least two prograde metamorphic cycles. The earlier cycle is marked by relict features that include sillimanite streamers in biotite and garnet. These sillimanite streamers have a different orientation and a greater severity of folding than the surrounding rock. Also, inclusions of fresh-looking cordierite at the center of clear garnet crystals in the Gold Hill area are ascribed to the earlier cycle of prograde metamorphism. This fresh-looking cordierite also encloses oriented, acicular, unaltered sillimanite. In contrast, younger sillimanite that surrounds the garnet crystals is considerably altered and cuts across many crystal boundaries. Structures and mineral associations attributed to the earlier cycle suggest that during that cycle, temperature and pressure were similar to those that prevailed during the later major high-grade regional metamorphic event. In the central Front Range the metamorphic zones appear to be bent or perhaps cut off by the Boulder Creek batholith. West of the Continental Divide rocks representing the highest grade of metamorphism give way to muscovite-cordierite-garnet-sillimanite-biotite gneiss, indicating a zone of lower grade metamorphism may be found west of the divide, but the configuration of this zone is unknown. Schroeder (1984), however, interpreted the muscovite in this biotite gneiss to be retrograde, and most of it is, but I found unaltered muscovite and biotite laths interleaved, which may suggest that some muscovite is primary.

The east to west metamorphic zoning in the central Front Range is also present beneath the sedimentary cover to the east of the mountain front. Bore holes into the basement reveal greenschist-facies rocks (Tweto, 1987). These greenschist-facies rocks apparently grade westward, south of the Boulder Creek batholith, into the andalusite-sillimanite metamorphic zone, the lowest grade zone exposed in the central Front Range.

The mineral paragenesis plagioclase-quartz-sillimanite-biotite ± cordierite ± staurolite ± andalusite ± garnet characterizes the easternmost metamorphic zone in the central Front Range along the mountain front. Major parageneses for this zone are

biotite-cordierite-plagioclase-quartz-sillimanite
andalusite-biotite-cordierite-magnetite-quartz-sillimanite
andalusite-biotite-garnet-quartz-sillimanite
andalusite-biotite-muscovite-magnetite-quartz
magnetite-plagioclase-quartz

In this zone the K-feldspar is generally microperthite, is rarely grid-twinned microcline, and occurs only in local patches. Within the zone, muscovite and K-feldspar are unstable; about half of the muscovite-quartz associations are unstable, and muscovite-sillimanite is both stable and unstable. The mineral relationships are undoubtedly related to the reaction: 1 muscovite + 1 quartz ⇔ 1 orthoclase + 1 sillimanite; this reaction signifies the transition to the high-grade amphibolite facies of metamorphism to the west.

To the west the rocks in the sillimanite-muscovite-microperthite-microcline-transition zone (fig. 32) contain both stable and unstable assemblages of muscovite-microcline and muscovite-sillimanite-quartz. The pairs K-feldspar-sillimanite and quartz-sillimanite are stable, but in places trace amounts of sillimanite are sheathed by quartz, indicating local unstable conditions. Major parageneses for this zone are

biotite-microcline-plagioclase-quartz-sillimanite ± muscovite
biotite-microcline-magnetite-sillimanite ± muscovite

The amount of microcline increases somewhat to the west and north in the transition zone, and the increase in microcline and reciprocal decrease in muscovite suggest that temperatures increased to the west and north. The stable assemblage of sillimanite-muscovite-microcline was first recognized in this zone by Braddock (1969) in the Empire area.

The sillimanite-microcline zone, the highest prograde metamorphism in the area, extends from Central City northward to at least the south border of the Longs Peak-St. Vrain Batholith (fig. 32). The zone is represented by the stable assemblage of cordierite-garnet-K-feldspar (microcline)-sillimanite-biotite ± plagioclase. This assemblage represents a transition between upper amphibolite-facies and granulite-facies metamorphism. Currie (1971) and Winkler (1979) called this transitional facies the hornblende-granulite facies. Small to moderate increases in K-feldspar, sillimanite, and magnetite are due to the breakdown of biotite, plagioclase, and quartz. Hypersthene, representative of granulite facies, is rare in the central Front Range (table 31); however, north of the Longs Peak-St. Vrain Batholith, in the northern Front Range, it occurs in a local granulite facies (Cole, 1977).

Sillimanite of this zone in places is sheathed by quartz, but in general the sillimanite is in equilibrium with both quartz and K-feldspar. Muscovite is not a primary mineral in this facies except in rare patches. The patches exist because of small variations in temperature and pressure in fold terranes, where pressure-temperature paths can be complex and can vary widely between anticlines and synclines (Chamberlin and Karabinos, 1987). The complex fold patterns in the central Front Range metamorphic rocks suggest that folding might have locally influenced variations in pressure and temperature.

Evidence of the oldest retrograde metamorphism identified in the central Front Range is in rocks to the west of the Boulder Creek batholith. It is believed that the batholith was emplaced late in the period of major regional metamorphism (1.7 b.y.), but until this study, no thermal effects had been documented. I interpret cordierite coronas on garnet, bent biotite laths that surround these coronas, quartz sheathes on sillimanite, new orthoclase, and secondary cordierite as evidence of this retrograde metamorphism, but the evidence is not unequivocal.

Distribution coefficients for magnesium and iron in cordierite and garnet in Front Range metamorphic rocks, tabulated in table 12 of Gable and Sims (1969), are high according to Hensen (1977); he interpreted the high values to be the result of retrograde metamorphism. Holdaway and Lee (1977, table 6), however, showed distribution coefficients for high-grade pelitic rocks for both cordierite-biotite and cordierite-garnet pairs that match the Front Range values, but they ascribed them to prograde metamorphism. The distribution of cordierite-garnet coronas is across the foliation in cordierite-garnet-sillimanite-biotite gneiss in the northern part of the central Front Range and in cordierite-garnet gneiss on the west side of the Continental Divide in the Strawberry Lake area adjacent to the Boulder Creek batholith. This suggests that Hensen (1977) may be correct, and the cordierite-garnet coronas are due to retrograde metamorphism related to emplacement of the Boulder Creek batholith.

Mineral ages for rocks metamorphosed during the 1.7 b.y. period of metamorphism were all reset by the 1.5-1.4 b.y. thermal event (Pearson and others, 1966; Peterman and others, 1968). This event included emplacement of the Silver Plume Granite of the Berthoud Plutonic Suite. The area of this later retrograde metamorphism, investigated in thin-section studies, extends across the study area for at least 20 km south of the Longs Peak-St. Vrain granitic rocks into an area of numerous plutons of the same age (fig. 11) near the Mt. Evans batholith. The minor retrograde metamorphism associated with emplacement of the Silver Plume Granite produced the following, poorly developed assemblage: andalusite-biotite-quartz-magnetite $\pm$ cordierite $\pm$ muscovite. The growth of andalusite in and adjacent to biotite occurs by the reaction biotite $\Leftrightarrow$ andalusite $\pm$ magnetite. This retrograde assemblage is sometimes found adjacent to retrograde cordierite or muscovite. Sparse migmatites are present in metamorphic rocks adjacent to some of the Berthoud Plutonic Suite plutons and are best developed adjacent to the south margin of the Longs Peak-St. Vrain batholith and adjacent to plutons of Silver Plume Granite in the Pine-Bailey area. In the Tarryall region, just south of the central Front Range area, Hawley and Wobus (1977, p. B23) described migmatites of Silver Plume age and attributed the local deformation, recrystallization, and retrograde of the layered gneisses to emplacement of the Silver Plume Granite.

The youngest retrograde metamorphism recorded in the metamorphic rocks of the study area occurred during emplacement of the Late Cretaceous-early Tertiary intrusives (fig. 2). Besides the mineral changes in the contact aureoles of the stocks, mentioned earlier, widespread retrograde metamorphism in the country rock is expressed by the occurrence of pinite, sericite, and chlorite as alteration products of cordierite, plagioclase, and biotite, respectively. Sericite is ubiquitous, and the amount of sericite in plagioclase increases northward in the central Front Range. The amount of sericite is greatest next to the large Laramide-age intrusives in the northern area; however, the other retrograde minerals, chlorite and pinite, occur far from those intrusives, thus ruling out the intrusives as the only cause for the development of these retrograde minerals. Chlorite and pinite, as well as sericite, are profuse in the mining districts of the area, which suggests that hydrothermal alteration associated with emplacement of the ore deposits is also a factor in their formation.

## PHYSICAL CONDITIONS OF METAMORPHISM

The occurrence of andalusite in the metamorphic rocks along the mountain front in the central Front Range implies medium-grade metamorphism during which pressures were no greater than 3.5 kb, and, according to Turner (1981, p. 152), also suggests that metamorphism occurred at a depth of less than

10 km. The presence of untwinned K-feldspar (microperthite or simple-twinned microcline) suggests a moderate temperature of 450°C (Ribbe, 1983, p. 21-55). At this temperature few or no migmatites form.

Olsen (1982) has suggested that migmatites form in a transition zone between medium-grade and high-grade metamorphism. This zone is represented by the mineral assemblage of sillimanite-muscovite-microperthite-microcline and forms at about 4.0 ± 1 kb and 660°C to 700°C. Mineralogy in the central Front Range suggests that the migmatites formed at the lower end of the temperature range, for mafic selvages still contain considerable quartz that would have completely entered the melt at about 675°C and 5 kb (Winkler, 1979). Front Range biotites contributed the major part of the potassium to the leucosome (Olsen, 1982), therefore, water had to have been abundant locally, for biotite melts with difficulty in the absence of water.

The highest grade of prograde metamorphism, characterized by sillimanite-microcline, produced the assemblage of biotite-cordierite-garnet-K-feldspar-quartz-sillimanite ± plagioclase. Migmatite is also found in this metamorphic zone. This assemblage suggests a minimal temperature of 660°C at 3.4 kb (Winkler, 1979). Lee and Holdaway (1977) suggested that the assemblage crystallized at a temperature of about 690°C, at a pressure of 4.3 kb, and at a ratio of water pressure to total pressure of about 0.5. Etheridge and others (1983) suggested that fluids generated during high-grade metamorphism may be melt dominated; if so, in the central Front Range the circulation of fluids may reflect restriction by impermeable, thin schist layers, as suggested by the presence of corundum in isolated layers.

## EARLY PROTEROZOIC PALEOGEOGRAPHY OF NORTHERN COLORADO

Just north of the Wyoming border a major shear zone, the Cheyenne belt, separates the Archean terrane of Wyoming from the Early Proterozoic terrane of Colorado. There have been numerous, and sometimes conflicting, models to explain the tectonic relationship between these two terranes and the origin of the Early Proterozoic rocks south of the shear zone. Hills and Houston (1979), Condie (1982, 1986), and Reed and others (1987) all suggested that the Early Proterozoic rocks of the Front Range are the products of arc magmatism and sedimentation in an east-trending arc-related basin along a convergent margin south of the Archean terrane of Wyoming. In the northern Front Range of Colorado arkosic wackes or subgraywackes west of the Precambrian-Paleozoic contact grade westward into pelitic rocks (Braddock and Cole, 1979); a similar east to west fining of the Proterozoic sedimentary rocks occurred in the central Front Range. In the central Front Range the original composition and distribution of Early Proterozoic sedimentary rocks, now represented in part along the eastern front of the range by marble and calc-silicate rocks, suggest they were deposited in a subaqueous environment. Interlayered with the calcium-rich rocks are various biotite gneisses that were originally clastic sedimentary rocks. Compositional variation in the biotite gneisses is evident both in a north to south and east to west direction. This major basin of deposition also contained many layers of felsic and mafic rocks of probable volcanic origin that are now represented by felsic gneiss and hornblende gneiss and amphibolite, respectively.

Variations in rock types biotite gneiss from north to south in the central Front Range suggest that the main basin of Proterozoic deposition may have been upwarped along the present Idaho Springs-Ralston shear zone so as to form a smaller basin on the south side. The two basins appear to have converged to the west into a larger, arc-related basin south of the Archean terrane. Chemically, the exposed biotite gneisses reflect variations in the original sedimentary rocks, from sandy shale on the east to mature clay shale on the west. Rocks of coarser sedimentary parentage lie under the sedimentary cover of the High Plains of Colorado to the east of the central Front Range and are only known from the study of core data (Tweto, 1987). The source area for some Proterozoic rocks, especially the younger Early Proterozoic rocks of the Coal Creek syncline area, hinted at by Condie and others (1983) and more strongly suggested by Sims and Peterman (1986), was probably to the east.

# REGIONAL STRUCTURE

The geologic setting for the Early Proterozoic is believed to have been a west-trending, arc-related basin south of the Archean terrane of Wyoming. In the central Front Range area this basin appears to have been locally divided into two separate basins in the vicinity of the present Idaho Springs-Ralston shear zone. The southern basin was filled by volcanic deposits interlayered with limestones, shales, and some quartzose sedimentary rocks; mature shales and fewer volcanics were deposited in the northern basin.

The regional structures in the Proterozoic metamorphic rocks of the central Front Range represent two periods of folding of Early Proterozoic age and a later period of Middle Proterozoic age. The structures, especially fold axes, were determined from compositional layering, mineral lineations, and trends of foliation. The structures generally follow what is believed to be the original layering of the rocks.

The axes of the oldest folds (Period I and Ia folds) trend west and northwest to north (fig. 33). The structures were refolded later in the Early Proterozoic (Period II folds) about axes that trend mainly north and northeast. The youngest folding (Period III folds) in the area is recognized by poorly developed northeast-trending folds. The oldest folds are the most widespread; however, in the Central City and Empire areas,the Period I folds are almost completely masked by Period II folds (Moench and others, 1962; Sims and Gable, 1964; Braddock, 1969; and Taylor, 1976). South of Clear Creek, however, Period I folds (Sheridan and others, 1968, 1972; Sheridan and Marsh, 1976), are very evident and appear to be less complex. The earliest period of folding is believed to have closely followed the end of sedimentation and was coeval with regional metamorphism. Structures related to Period II deformation are spatially and temporally related to Routt Suite plutonism. These Period II folds may not be much younger than the folds of Period I. The youngest period of folding, Period III, and accompanying retrograde metamorphism are attributed to emplacement of the Silver Plume Granite of the Berthoud Plutonic Suite during the Middle Proterozoic.

Period I folds in gneiss adjacent to the Boulder Creek batholith were modified by the forcible emplacement of the batholith (Gable, 1969, 1980; Taylor, 1976), producing a series of warped Period I anticlines and synclines, as in the Ward and Gold Hill areas and also in the Black Hawk area (fig. 33). Southwest of Gold Hill the Period I west-northwest fold axes were later refolded along north-northwest trends before Period II folding. These secondary folds are referred to as Period Ia folds. The Period Ia folds are very tight which suggests a space problem created by the intrusion of the Boulder Creek batholith and its satellitic plutons.

Period II folding followed intrusion of the Boulder Creek batholith, as evidenced by folding, or at the least warping, that produced the Scar Top anticline within the southern part of the Boulder Creek batholith (Wells, 1967) and the Rowena syncline within the northern part of the batholith (Gable, 1980). In the Indian Peaks area, in the northwest part of the study area (fig. 33), northeast-trending fold axes, mapped by Gable and Madole (1976) and Pearson (1980), are probably related to Period II deformation; much of the Indian Peaks area, however, has only been mapped in reconnaissance, and the structure probably is more complex than shown. The map pattern (pl. 1) of the garnet-bearing biotite gneiss unit (Xgnc) also suggests complex folding in the Indian Peaks Wilderness area. The Coney Lakes synform, a Period II fold, which lies east of the Continental Divide near the north edge of the study area, is present in garnet-sillimanite-biotite gneiss inliers in Silver Plume Granite (Gable and Madole, 1976). These inliers have exactly the same trend as the surrounding country rock, suggesting that the Silver Plume passively intruded this area (Gable and Madole, 1976). I believe that the axis of the Caribou antiform, a Period II fold located north of Nederland (fig. 33), projects southward along the Laramide Front Range arch to the Loch Lomond antiform north of Empire; the arch area was the locus for Late Cretaceous-early Tertiary intrusives.

Along the mountain front from South Turkey Creek to south of Kassler (fig. 33), fold axes in Precambrian gneiss have been mapped in reconnaissance only (Peterson, 1964). The north-northeast and northwest trends probably reflect folding related at least to Period I, and possibly to Period II, folding, but more detailed mapping is needed to work out the structure.

The youngest Proterozoic deformation (Period III) of Middle Proterozoic age, associated with the Idaho Springs-Ralston shear zone and emplacement of the Silver Plume Granite at about 1.5-1.4 b.y., is reflected in folding and cataclastic shear.

## SUMMARY

In Early Precambrian time the broad anticlinal uplift of the central Front Range was part of a west-trending, arc-related basin that existed south of the Archean terrane of Wyoming. The Early Proterozoic igneous and metamorphic rocks were originally part of a sedimentary and igneous basinal sequence consisting of graywacke, shale, and sandstone and minor amounts of limestone and conglomerate interlayered with basaltic flows and felsic to mafic tuffs. This sedimentary and igneous sequence was subjected to high temperatures and moderate pressures during regional metamorphism (1.7-1.65 b.y.) that produced a variety of schists and gneisses in the amphibolite-granulite facies. This facies is recognized by the diagnostic mineral assemblage cordierite-garnet-sillimanite-biotite ± K-feldspar ± plagioclase. The mafic rocks, mostly basaltic flows, produced the assemblage hornblende-plagioclase-quartz ± clinopyroxene ± orthopyroxene. The major prograde metamorphic event resulted in metamorphic zoning in the central Front Range where the zone of lowest grade metamorphism is along the east side of the study area and the highest zone is on the west: the two zones are separated by a belt of transitional metamorphic grade. Metamorphism resulting from emplacement of the Mt. Evans batholith produced retrograde metamorphism that is mostly definable by thin-section studies. A third, less pervasive metamorphic event was associated with Late Cretaceous-early Tertiary plutonism.

Structural features from three periods of folding, two of Early Proterozoic age and one of Middle Proterozoic age, controlled the later emplacement of Late Cretaceous-early Tertiary stocks in the Front Range mineral belt. The structural relations of the quartzite and mica schist in the small synclines at the northeast end of the Idaho Springs-Ralston shear zone near the mountain front to adjacent sequences of biotite gneiss, hornblende gneiss, and amphibolite strongly suggest that the quartzite and mica schist are younger.

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## DESCRIPTION OF MAP UNITS

### SURFICIAL DEPOSITS

Qa **Alluvium, colluvium, and glacial deposits (Holocene and late Pleistocene)**

QTg **Gravels (Quaternary and Tertiary)**—Rounded to subangular pebbles, cobbles, and boulders derived from metamorphic and igneous rocks largely to the west of the map area. Patterned area consists of debris derived almost entirely from Proterozoic rocks and found on higher slopes above modern drainage channels

### EARLY TERTIARY AND LATE CRETACEOUS INTRUSIVE ROCKS

TKi **Monzonite, granodiorite, and syenite**—May include minor amounts of mafic rocks, such as pyroxenite

### SEDIMENTARY ROCKS

PIPf **Fountain Formation (Permian and Pennsylvanian)**—Map unit locally includes Lykins Formation (Triassic and Permian) and Lyons Sandstone (Permian).—Fountain Formation, predominantly arkosic conglomerate and moderately coarse-grained sandstone; Lykins Formation, red and light-green calcareous sandstone; Lyons Sandstone, red and pink fine- to very fine grained sandstone

### PROTEROZOIC INTRUSIVE ROCKS

Ypg **Pikes Peak Granite (Middle Proterozoic)**—Biotite granite and biotite-hornblende granite, minor quartz syenite, fayalite granite, riebeckite granite, and locally granodiorite and quartz monzonite. Rb-Sr age about 1,040 m.y. (Hedge, 1970)

**Silver Plume Granite (or Quartz Monzonite) of the Berthoud Plutonic Suite (Middle Proterozoic)**

Ysp Quartz monzonite and monzogranite facies—Predominantly massive gray to buff, fine- to medium-grained quartz monzonite or monzogranite displaying aligned tabular feldspar crystals and aligned biotite laths especially along borders of plutons. U-Pb zircon age 1,400 m.y. (Aleinikoff and others, 1990)

Yspm Monzodiorite to granodiorite facies—Medium- to coarse-grained, grayish-white and black, foliated monzodiorite to granodiorite. Occurs locally in Mt. Evans batholith. Contains 6-8 percent magnetite. U-Pb zircon age of 1,443 m.y. (Aleinikoff and others, 1990)

Yspb Inclusions—Profuse inclusions mostly of biotite gneiss in Silver Plume Granite

Xqm **Quartz monzonite (Early Proterozoic)**—Light gray to light tan, leucocratic, and fine to medium grained. Includes Twin Spruce Quartz Monzonite of the Eldorado Springs area. Field evidence suggests Twin Spruce is in part younger and also the same age as the Boulder Creek Granodiorite. Patterned where unit contains numerous biotite gneiss inclusions

Xgg **Granodiorite (Early Proterozoic)**—Gray to pinkish-gray, medium- to coarse-grained gneissic granodiorite; weathers a darker pinkish gray. Occurs locally at Mt. Morrison and in Clear Creek and Turkey Creek Canyons. Isotopically fits the 1,700 m.y. isochron of the Boulder Creek Granodiorite (C.E. Hedge, oral comm., 1976?). Field evidence suggests this granodiorite is both same age and younger than Boulder Creek Granodiorite

Xgd **Boulder Creek Granodiorite and associated rocks of the Routt Plutonic Suite (Early Proterozoic)**—Mottled grayish-white and black, medium- to very coarse grained, locally porphyritic, predominantly granodiorite but includes lenses and layers of gabbro, hornblende diorite, hornblendite, and quartz diorite. Rb-Sr determinations suggest the Boulder Creek is about 1,700 m.y. old (Peterman and others, 1968; Reed and others, 1987). Unit Xqm in and adjacent to the Boulder Creek batholith is included in unit Xgd

Xg **Gabbro and related rocks (Early Proterozoic)**—Dark-gray to pinkish- gray, black, and white, massive, coarse- to very coarse grained rock ranging in composition from metagabbro to quartz diorite; contains intermediate plagioclase and orthopyroxene and clinopyroxene

Xqhd **Hornblende diorite, quartz-bearing hornblende diorite, quartz diorite, and hornblendite (Early Proterozoic)**—Gray to black, medium- to fine-grained, gray to black hornblende-bearing rocks. Occurs in small plutons, lenses, pods, and dikes

## EARLY PROTROZOIC METAMORPHIC ROCKS

Xam **Amphibolite (Early Proterozoic)**—Dark-greenish-gray to black, fine- to medium-grained, nonlayered to poorly layered, weak to strongly foliated rock, composed mostly of hornblende and plagioclase

## EARLY PROTEROZOIC METASEDIMENTARY AND METAVOLCANIC ROCKS

Xq **Quartzite and quartz gneiss**—Quartzite is white, gray, and pinkish or purplish gray, medium to coarse grained and locally conglomeratic. Interlayered with quartz-mica schist and some calc-silicate gneiss lenses. Quartzite along Coal Creek and in Eldorado Springs area is interlayered with conglomeratic quartzite. At some localities foliated quartz gneiss is conspicuously layered and contains variable amounts of garnet, magnetite-ilmenite, and epidote

Xqs **Quartz-biotite-muscovite schist**—Silver-gray to dark-gray fine- to medium-grained micaceous schist, locally containing porphyroblasts of andalusite, cordierite, and garnet and small amounts of staurolite and sillimanite. Mapped along mountain front in Ralston Buttes area

Xf **Feldspar-rich gneiss**—Light-gray, leucocratic, fine-to medium-grained, microcline-plagioclase-quartz-biotite gneiss. Conspicuously foliated; granitic in appearance. Locally garnetiferous and ubitiquously interlayered with conformable thin to thick layers and lenses of hornblende gneiss, amphibolite, biotite gneiss, and in some places calc-silicate rock

Xfh **Interlayered feldspar-rich gneiss and hornblende gneiss**—Feldspar-rich gneiss, may contain hornblende and is generally darker than feldspar-rich gneiss unit (Xf). Interlayered hornblende gneiss is black, white, and dark gray or greenish gray and similar in composition to hornblende gneiss in hornblende gneiss unit (Xgnh). Layers and lenses of biotite gneiss, amphibolite, calc-silicate rock, and biotite-quartz-plagioclase gneiss make up 10-30 percent of unit

Xgnh **Hornblende gneiss and amphibolite**—Black, black and white, and dark gray or greenish gray, fine to medium grained, and layered; has weak to strong foliation. Consists of hornblende-plagioclase-quartz gneiss or hornblende-clinopyroxene-quartz-feldspar gneiss, in places interlayered with amphibolite, calc-silicate gneiss, biotite-quartz-plagioclase gneiss, and minor quartzite

Xhcs **Interlayered hornblende gneiss, calc-silicate gneiss, and amphibolite**—Black and white, light gray, greenish gray, and yellowish green, fine to medium grained, layered; has moderate to good compositional layering and moderate to weak foliation. More leucocratic than hornblende gneiss (Xgnh) because individual gneiss layers are thicker and contain more felsic-, calcic-, and quartz-bearing layers. Contains minor cordierite-biotite gneiss and biotite-quartz-plagioclase gneiss

Xgnb **Biotite gneiss**—Dark-gray, fine- to medium-grained, foliated, biotite-quartz-plagioclase gneiss; in places garnetiferous and microcline-bearing and interlayered with hornblende gneiss, calc-silicate gneiss, and sillimanite-biotite-quartz gneiss. Patterned areas contain profuse lenses and layers of granite gneiss

Xma **Biotite gneiss and amphibolite**—Gray, fine- to medium-grained biotite-quartz-plagioclase gneiss interlayered and intergraded with amphibolite that in places forms profuse thin lenses and layers. Also contains lenses and layers of hornblende-biotite-plagioclase gneiss, calc-silicate gneiss, quartzite, and profuse lenses and layers of granite gneiss and pegmatite

Xmb **Biotite gneiss**—Interlayered and intergraded biotite-quartz-plagioclase gneiss and sillimanite-biotite-quartz-plagioclase gneiss; has profuse lenses and layers of granitic gneiss and pegmatite, and at some localities small lenses and layers of calc-silicate gneiss, amphibolite, and quartzite. Contains much less amphibole than in biotite gneiss and amphibolite unit (Xma)

Xgng **Garnet-biotite gneiss**—Occurs as individual layers that grade into and are interlayered with minor units of biotite-quartz-plagioclase gneiss, garnet-sillimanite-biotite gneiss, and cordierite-garnet-sillimanite-biotite gneiss

Xgnq **Quartz-plagioclase gneiss**—Leucocratic, poorly foliated, and contains thin layers of biotite gneiss, feldspar-rich gneiss, quartzite, hornblende gneiss, and amphibolite. Only mapped along mountain front south of Morrison

Xgnca **Cordierite-garnet-gedrite-biotite gneiss**—Dark gray to black, medium to very coarse grained, foliated to massive. Interlayered with thinner layers of cordierite-biotite gneiss, garnet-biotite gneiss, and cordierite-garnet-sillimanite-biotite gneiss. K-feldspar is not present or is rare in these rocks. A dotted pattern differentiates these rocks from cordierite-garnet-sillimanite-biotite gneiss (Xgnc)

Xgns **Sillimanite-biotite gneiss**—Banded light gray, very dark gray, or black; at some localities interlayered with biotite-quartz-plagioclase gneiss and layers and lenses of amphibolite, biotite gneiss, calc-silicate gneiss, and garnet-biotite gneiss. South of the Idaho Springs-Ralston shear zone primary muscovite and trace amounts of cordierite found in unit. Pattern shows area that contains profuse pods and lenses of Silver Plume Granite (Ysp)

Xgnc **Cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar ± plagioclase**—Generally gray to very dark-gray, fine to medium-grained, and foliated. Foliation or layering disrupted by pegmatite, garnet, fibrolitic sillimanite, and clusters of cordierite and biotite. May be finely interlayered with one or more of the following gneisses: garnet-sillimanite-biotite, cordierite-biotite, garnet-biotite, cordierite-garnet-biotite, cordierite-sillimanite-biotite, magnetite-sillimanite-biotite, and cordierite-magnetite-sillimanite-biotite

Xgmc **Cordierite-magnetite-sillimanite-biotite gneiss and minor magnetite-sillimanite-biotite gneiss**—Light gray to nearly black, fine to medium grained, compositionally layered. Layers sometimes discontinuous due to stringers and clots of pegmatite, and knots of cordierite, sillimanite, biotite, and magnetite. Both rock types gradational into cordierite-garnet-sillimanite-biotite gneiss (Xgnc) and sillimanite-biotite gneiss (Xgns)

Xcb **Cordierite-sillimanite-biotite gneiss**—Light-gray, medium-grained, foliated, biotite gneiss. Mapped only in Evergreen-Squaw Pass area

Xgncs **Calc-silicate gneiss**—Variable gray, green, white, or black, fine to coarse grained. Color depends on the type and quantity of minerals present, such as hornblende, diopside, biotite, calcic-plagioclase, scapolite, and quartz. Foliation poor but compositional layering good

Xr **Rutile-bearing, sillimanite-quartz gneiss and biotite-quartz gneiss**—Light gray, fine to medium grained, and commonly interlayered. Occurs as thin lenses in the Evergreen-Squaw Pass area

Xrsq **Sillimanite-quartz gneiss containing accessory rutile lenses**—Light gray to gray, fine to medium grained, and foliated. Occurs only in the Evergreen and Squaw Pass quadrangles as lenses 15 cm to 30 m wide; most are of limited extent but one extends for 6 km

Xqf **Augen gneiss**—Fine-grained, sheared gneiss containing small, pink feldspar augen in a well-foliated biotitic matrix. Mapped only in Ralston Buttes area

# CORRELATION OF MAP UNITS

| | | |
|---|---|---|
| Qa | Holocene and late Pleistocene | QUATERNARY |
| QTg | | QUATERNARY AND TERTIARY |

INTRUSIVE ROCKS

| | | |
|---|---|---|
| TKi | Early Tertiary and Late Cretaceous | TERTIARY AND CRETACEOUS |

SEDIMENTARY ROCKS

| | | |
|---|---|---|
| PIPf | | PERMIAN AND PENNSYLVANIAN |

Unconformity

INTRUSIVE ROCKS

| | | | | | |
|---|---|---|---|---|---|
| Ypg | | | | | MIDDLE PROTEROZOIC |
| Ysp | Yspm | Yspb | | | |
| Xqm | Xgg | Xgd | Xg | Xqhd | EARLY PROTEROZOIC |

METAMORPHIC ROCKS

| |
|---|
| Xam |

METASEDIMENTARY AND METAVOLCANIC ROCKS

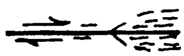
| | | |
|---|---|---|
| Xq | Xqs | |
| Xf | Xfh | |
| Xgnh | Xhcs | |
| Xgnb | Xma | Xmb |
| Xgng | Xgnq | |
| Xgnca | | |
| Xgns | Xgnc | Xgmc |
| Xcb | Xgncs | |
| Xr | Xrsq | Xqf |

Interlayered lithologic units; no stratigraphic order implied

EARLY PROTEROZOIC

# MAP SYMBOLS

**Contact**—Approximately located, dotted where concealed; queried where inferred



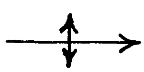
**Fault or fracture zone**—Dashed where approximately located; dotted where concealed; queried where uncertain. Arrows show apparent direction of relative movement. Pattern indicates broad zone of brecciation

**Fault zone**—Shown where map unit is fractured and not identifiable

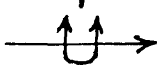
**Zone of closely spaced shears**

**Boundary of Idaho Springs-Ralston shear zone**

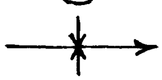
**Folds**—Showing approximate trace of axial plane and direction of plunge. Dotted where concealed; queried where inferred



**Antiform**

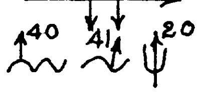


**Overturned antiform**



**Synform**

**Overturned synform**




**Small-scale linear and planar features**

**Bearing and plunge of axis of minor fold**—Symbols show plan view of minor folds

**Strike and dip of foliation**


**Inclined**

**Vertical**


**Bearing and plunge of lineation**—Lineations defined by aligned minerals, mineral streaks, and fold axes or intersection of planar elements. Symbol may be combined with foliation symbol

# SOURCES OF GEOLOGIC DATA

(Index map shown on Plate 2)

1. Pearson, 1980
2. Pearson, 1980
3. Pearson, 1980
4. Wrucke and Wilson, 1967
5. Gable, 1980
6. Gable and Madole, 1976
7. Pearson, 1980
8. Schroeder, 1995
9. Young, 1991
10. Gable, 1969
11. Gable, 1972
12. Wells, 1967
13. Van Horn, 1972
14. Sheridan, and others, 1967
15. Taylor, 1976
16. Sims and Gable, 1967
17. Braddock, 1969
18. Moench, and others, 1962
    Moench, 1964
    Hawley and Moore, 1967
19. Sheridan and Marsh, 1976
20. Sheridan, Reed, and Bryant, 1972
21. Gable, 1968
22. Bryant, and others, 1973
23. Bryant, 1974a
24. Bryant, 1976
25. Bryant, 1974b
26. Peterson, 1964
27. Scott, 1963

Figure 1

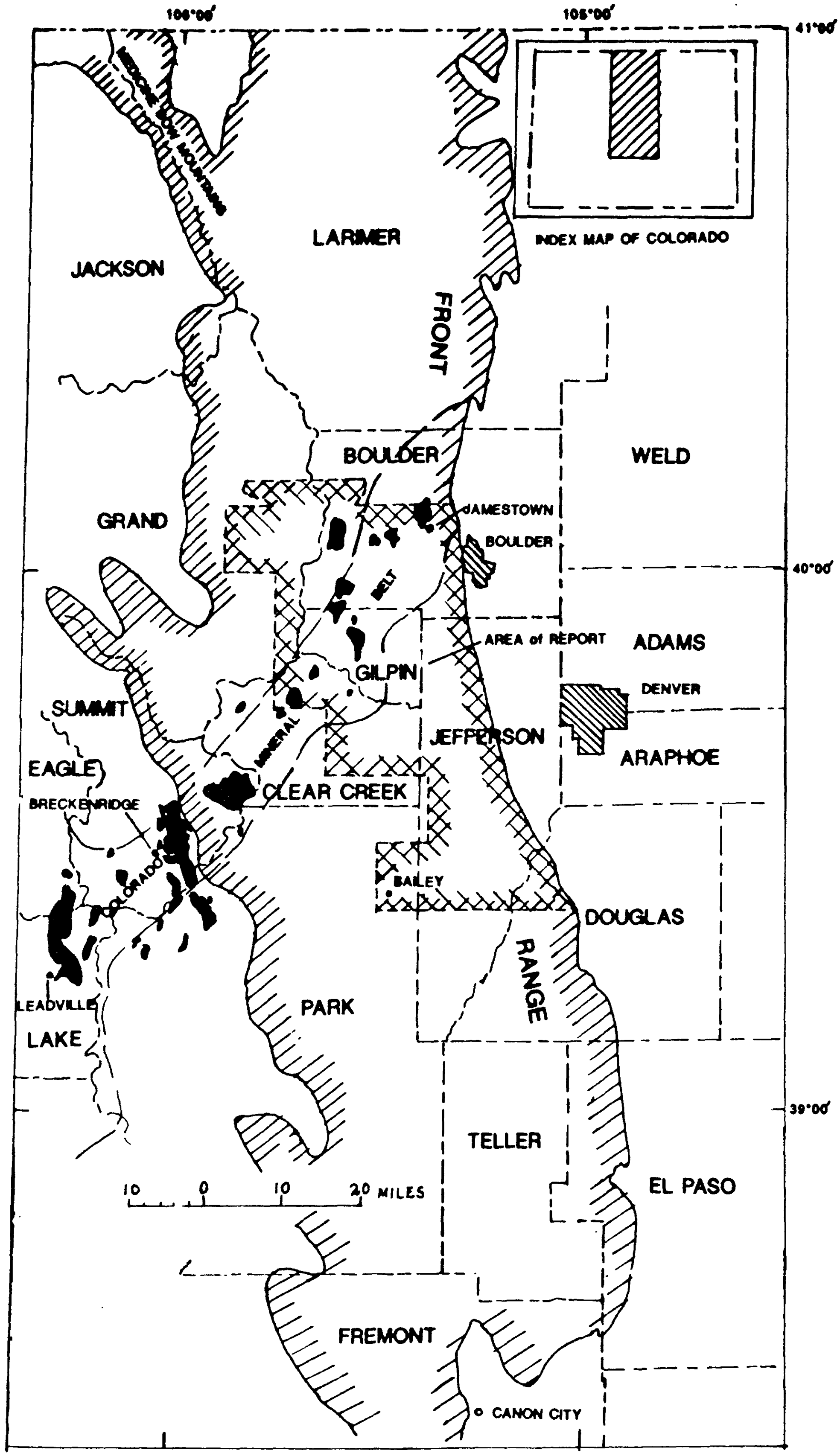



Figure 1. Index map of the Front Range, Colorado, showing area of this report (shaded) in relation to the Colorado Mineral Belt, and Laramide intrusive rocks (black) (modified from Lovering and Goddard, 1950)

Figure

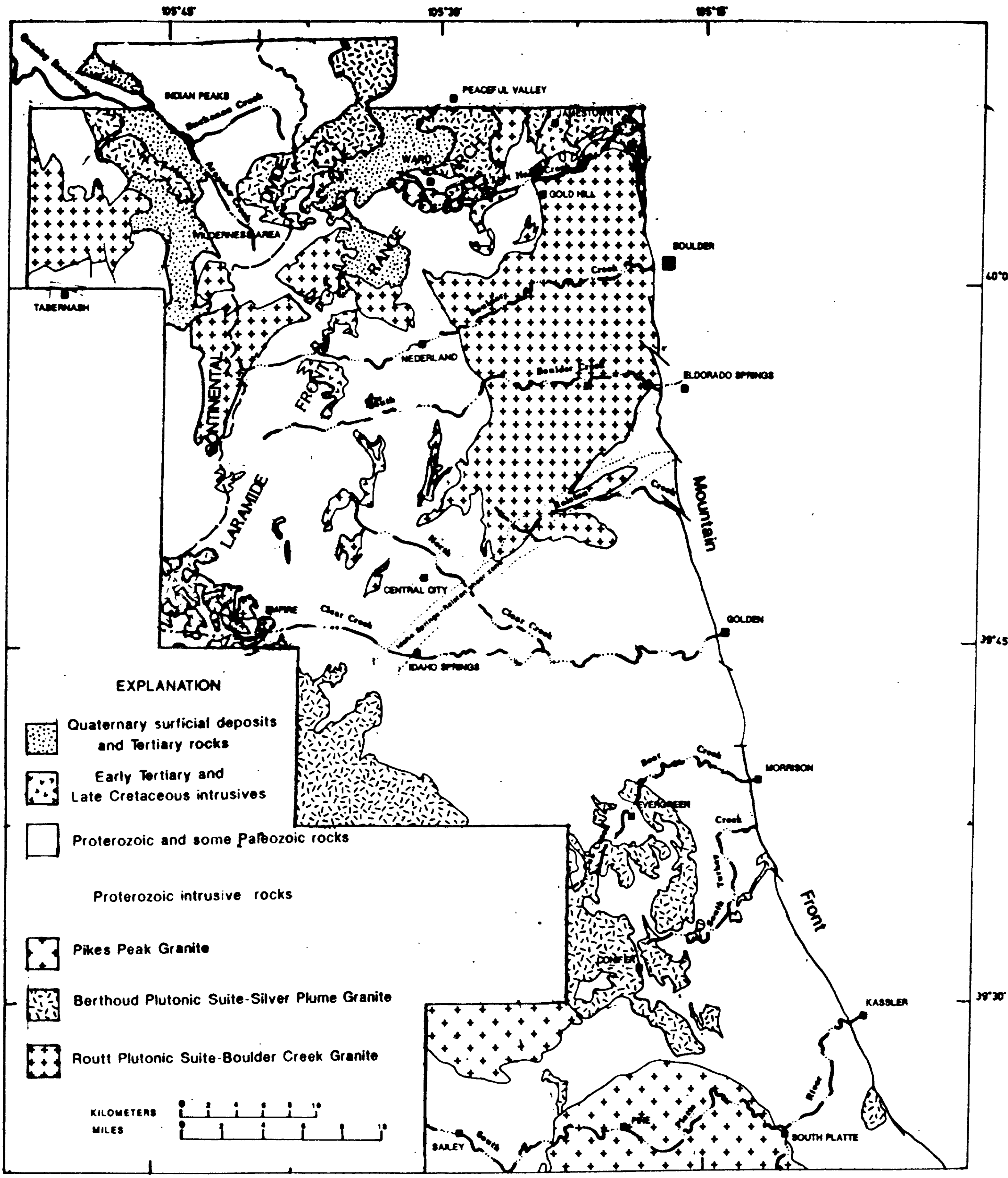



Figure 2. Generalized map showing the major Proterozoic intrusive rocks, Proterozoic metamorphic rocks, Late Cretaceous-early Tertiary intrusive rocks, and selected areas of Tertiary rocks and Quaternary surficial deposits

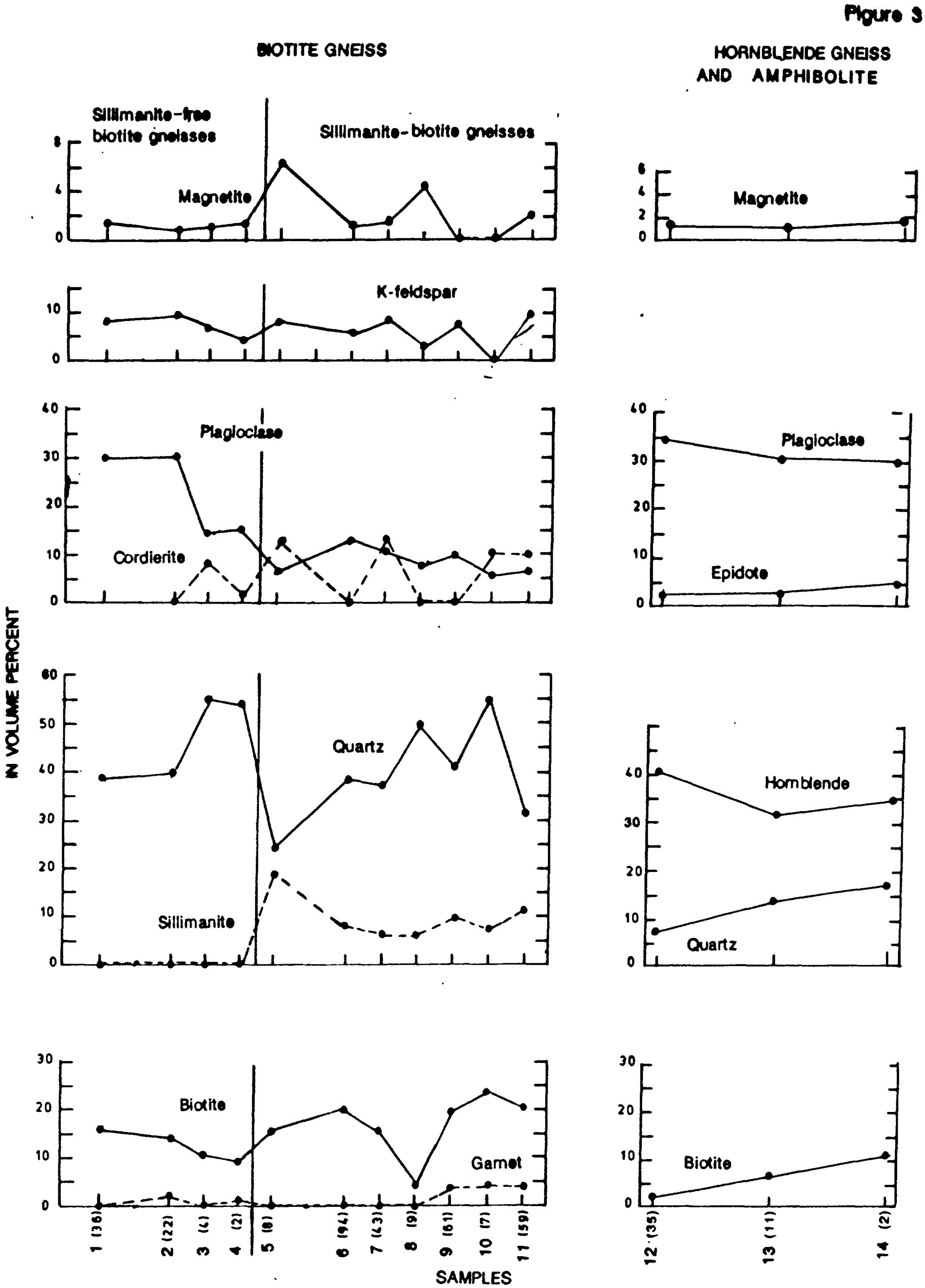



Figure 3.--Summary of modal analyses of selected minerals in biotite gneiss, hornblende gneiss, and, amphibolite, central Front Range, Colo. Number of modes represented = 500; solid and dashed lines connect dots representing a single mineral. 1, biotite-quartz-plagioclase gneiss; 2, garnet-biotite gneiss; 3, cordierite-biotite gneiss; 4, cordierite-garnet-biotite gneiss; 5, cordierite-magnetite-sillimanite-biotite gneiss; 6, sillimanite-biotite gneiss; 7, cordierite-sillimanite-biotite gneiss; 8, magnetite-biotite gneiss; 9, garnet-sillimanite-biotite gneiss; 10, cordierite-garnet-sillimanite-biotite gneiss; 11, cordierite-K-feldspar-garnet-sillimanite-biotite gneiss; 12, hornblende gneiss; 13, interlayered hornblende gneiss and biotite gneiss; 14, amphibolite lens in biotite gneiss. Numbers of modes are listed in parentheses

Figure 4

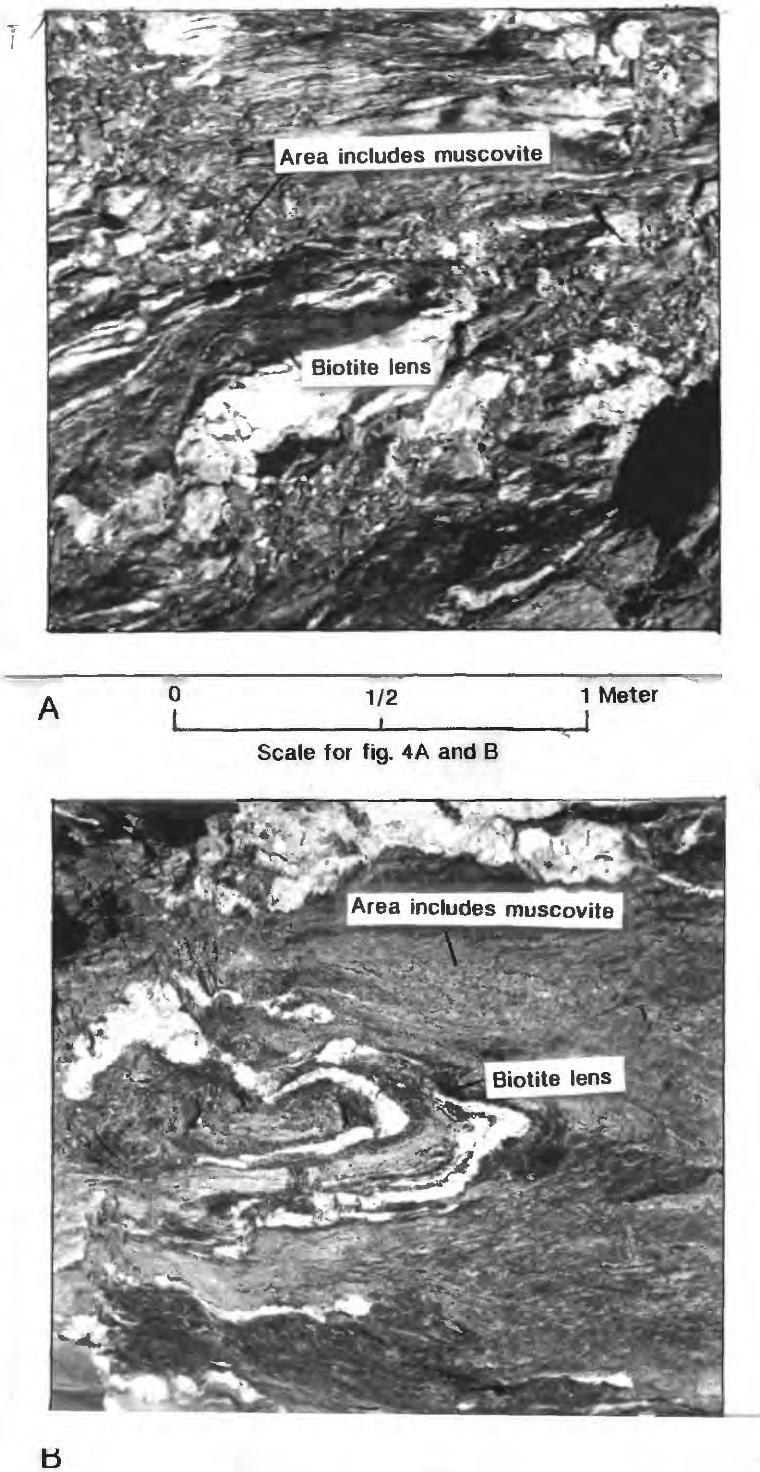
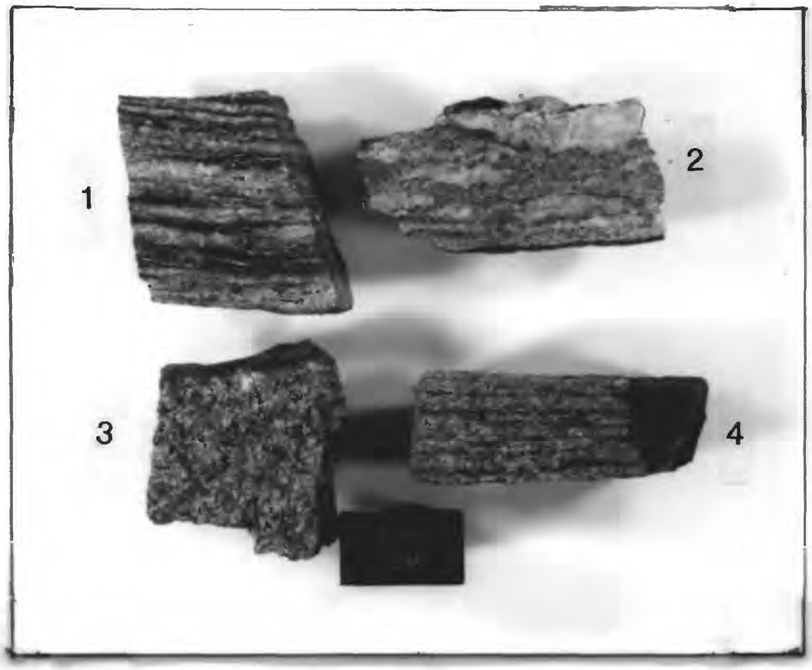



Figure 4.--Sillimanite-biotite gneiss (Xgns) with profuse secondary muscovite. From outcrops in Golden Gate Canyon.

A. Migmatitic schistose gneiss

B. Folded migmatitic schistose gneiss; biotite selvages along of nose of fold near center of photograph suggest migmatite locally derived

Figure 5




A

Figure 5.--Sillimanite-biotite gneiss from areas of high-grade and medium-high-grade metamorphism (sample localities shown on plate 2).

*A*, Well-foliated, slightly to strongly migmatitic sillimanite-biotite gneiss, from area of high-grade metamorphism.

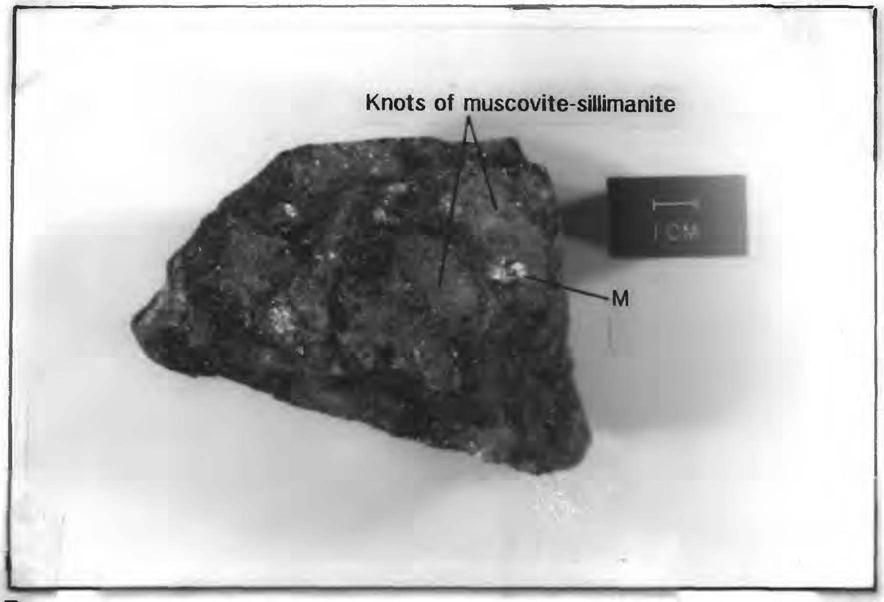
A-1, Typical banded gneiss showing good compositional banding of light and dark layers; Ward area, sample W265-71, locality 113

A-2, Quartz lenses in weakly foliated biotite gneiss; Nederland area, sample N-34, locality 252

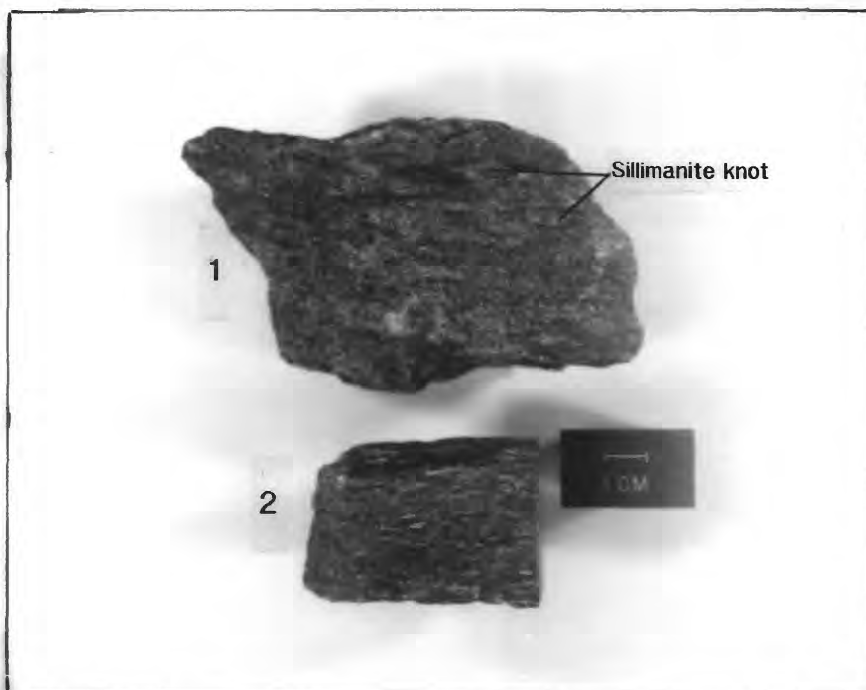
A-3, Weakly foliated gneiss; Gold Hill area, sample, GH32-72, locality 65

A-4, Fine-grained, layered, or banded gneiss; Nederland area, sample N378-75, locality 207

Figure 5B and C




B




C

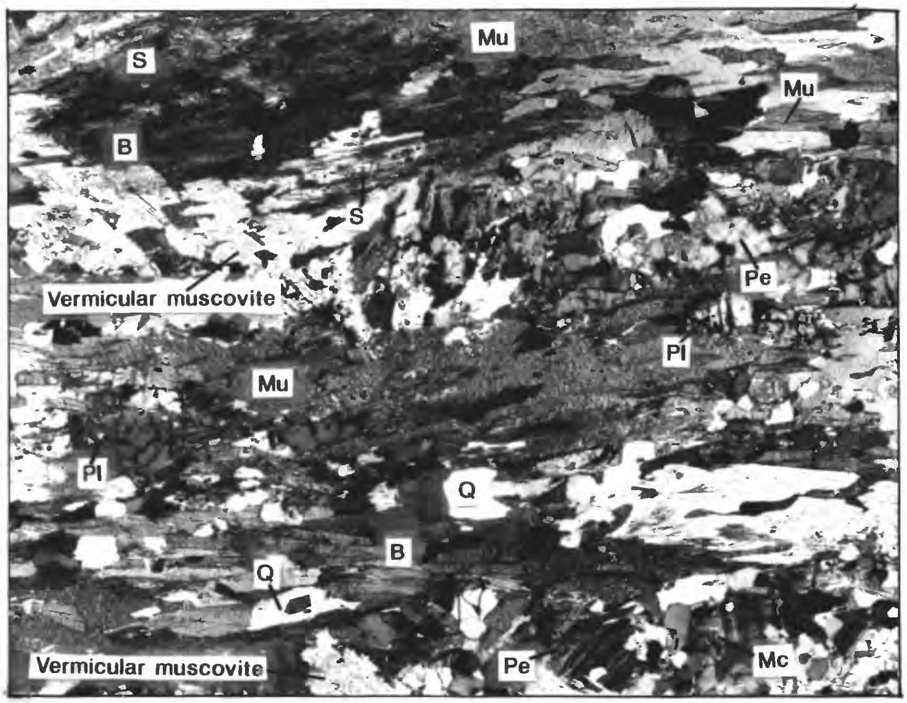
B, Weakly foliated muscovite-bearing schist in medium- to medium-high-grade regionally metamorphosed rocks. Knots of muscovite-sillimanite on foliation plane suggest relic clay clasts in graywacke; M, muscovite. Indian Hills area, sample IH2-80, locality 316

C, Muscovite-sillimanite-biotite gneiss, same grade of metamorphism as in B.

C-1, Weakly foliated, muscovite-bearing schistose gneiss, containing leucocratic lenses that define the foliation; Ralston Buttes area, sample RB5-80, locality 355

C-2, Finer, more even grained muscovite-bearing schistose gneiss than in C-1; Indian Hills area, IH-2-80, locality 316

Figure 6

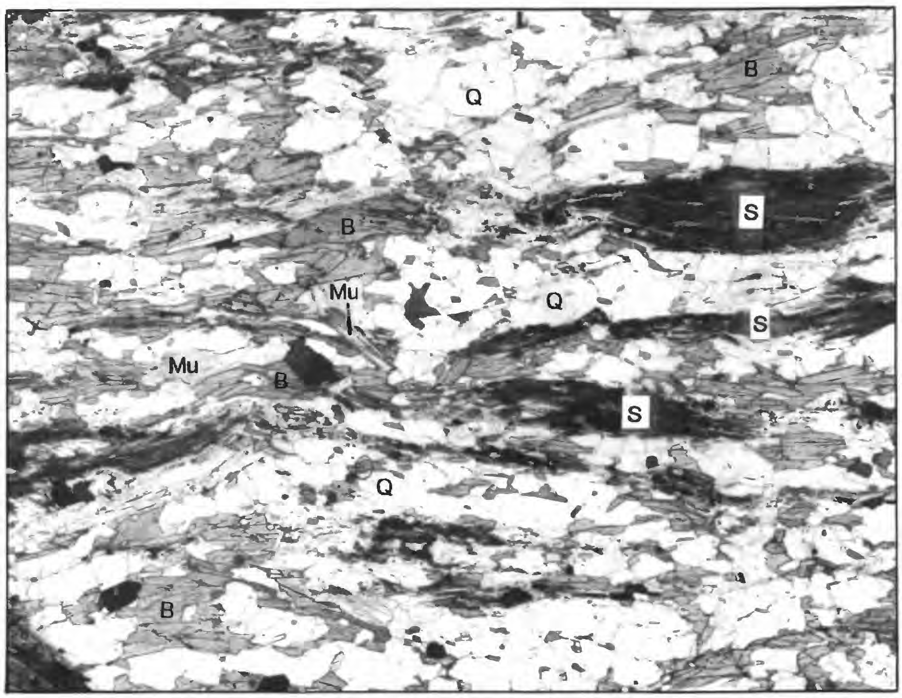



A

Figure 6.--Photomicrographs of sillimanite-biotite gneiss and schist. Shows textures in medium- to high-grade muscovite-bearing sillimanite-biotite gneiss and schist. Symbols: B, biotite; Mc, microcline; Mt, magnetite; Mu, muscovite; Pl, plagioclase; Pe, microperthite; Q, quartz; S, sillimanite; T, tourmaline; PA, primary andalusite; SA, secondary andalusite. See plate 2 for location of samples.

*A*, Fine- to medium-grained muscovite-sillimanite-K-feldspar-biotite gneiss. Secondary muscovite aligned along foliation of biotite, and secondary muscovite forms vermicular growths; crossed-nicols, 15x; Squaw Pass area, sample SP3-80, locality 272

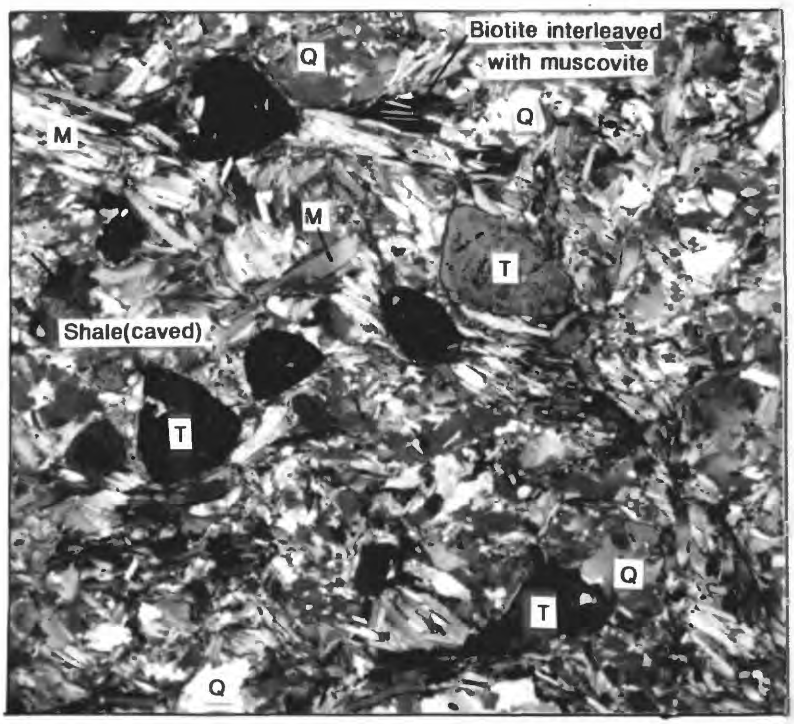
Figure 6B




B

*B*, Primary muscovite in muscovite-sillimanite-biotite schist. Plane light, 15x; Ralston Buttes area, sample RB5-80, locality 355

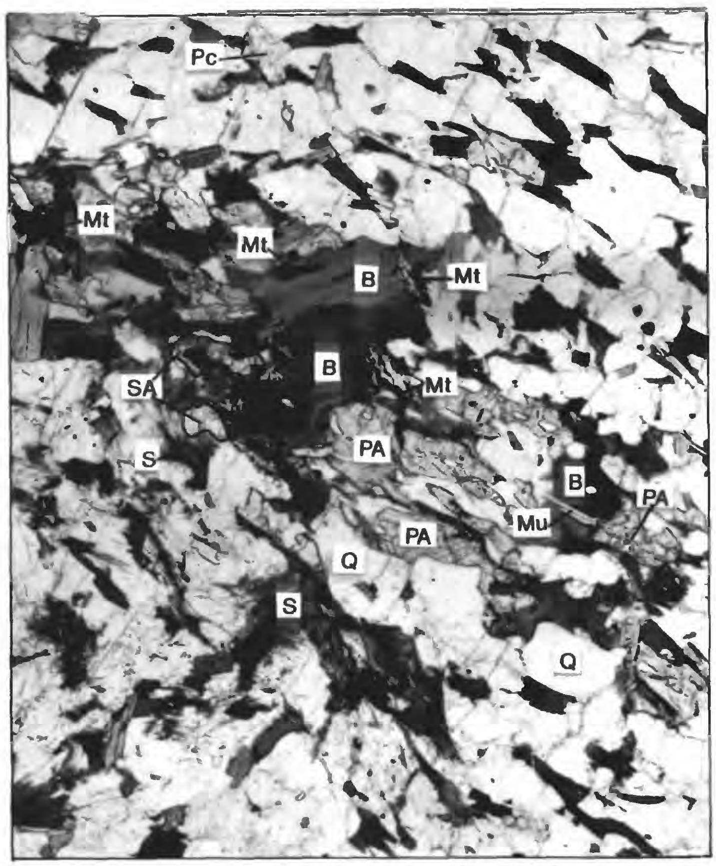
Figure 6C




C

*C*, Muscovite-sillimanite-biotite gneiss. Crossed nicols, 15x; Black Hawk area, sample J-463, locality 298

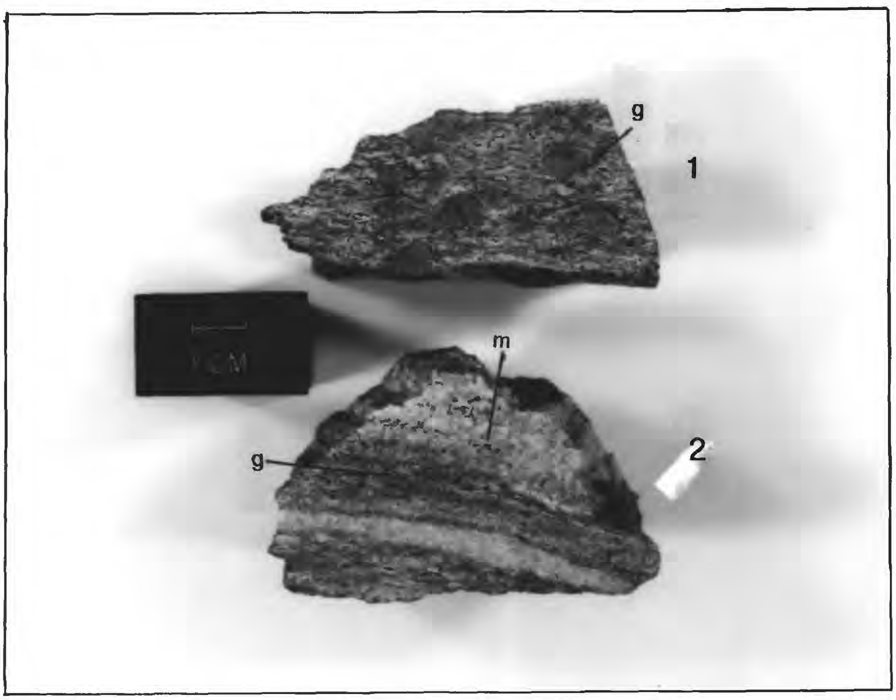
Figure 6D




D

*D*, Quartz-rich andalusite-muscovite-sillimanite-biotite gneiss showing two generations of andalusite. Plane light, 40x; Ralston Buttes area, sample RB2-80, locality 352

Figure 7




A

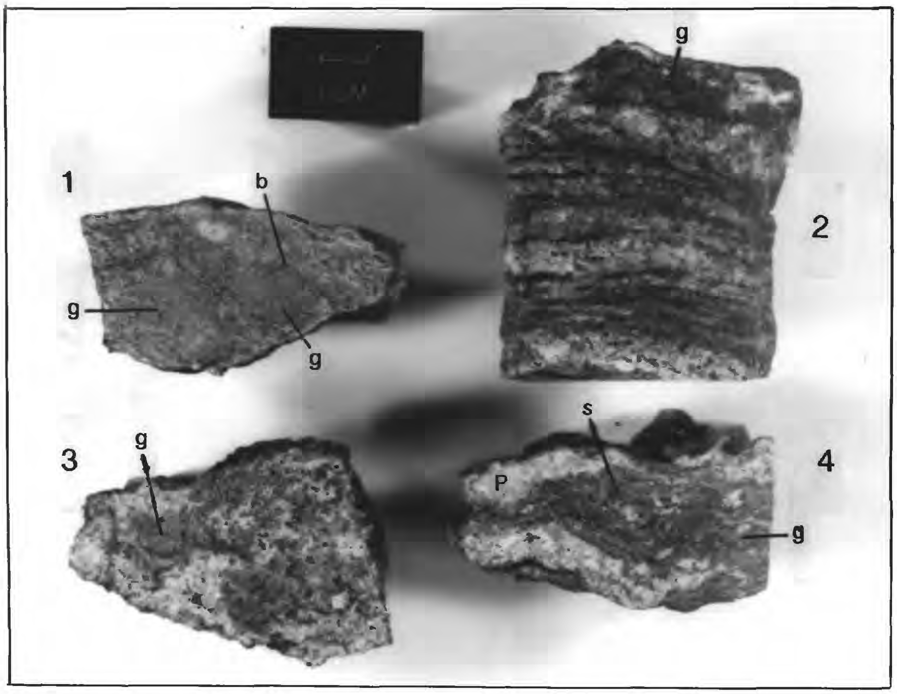
Figure 7.--Biotite gneiss showing deformed foliation and lack of foliation typical of high-grade metamorphism. Symbols: g, garnet; m, magnetite; b, biotite; P, pegmatite; s, sillimanite. See plate 2 for location of samples.

A, Garnet-sillimanite-biotite gneiss

A-1, Garnets distort foliation; Nederland area, sample N144-65, locality 191

A-2, Same area as A-1 but shows good foliation and migmatite

FIGURE 7B




B

B, Cordierite-garnet-sillimanite-biotite gneiss

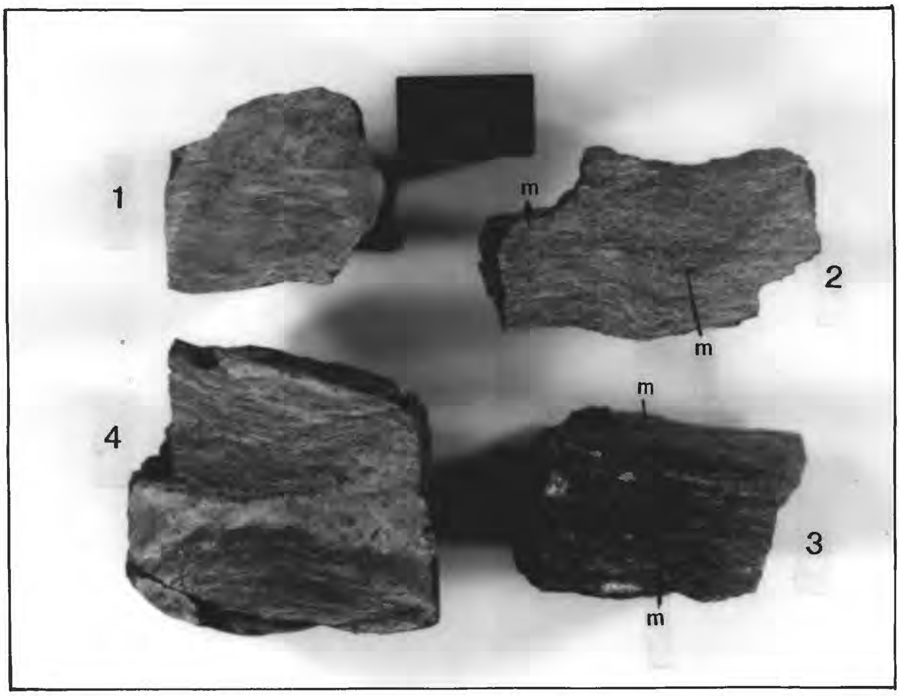
B-1, Retrograde after high-grade metamorphism; Central City area, sample JG-38b, locality 345

B-2, Migmatitic, poorly foliated gneiss; Ward area, sample W30-73, locality 14

B-3, Deformed gneiss, Gold Hill area, sample GH-177-74, locality 44

B-4, Pegmatitic and highly distorted schistose gneiss, East Portal area, sample EP-1, locality 324

Figure 7C




C

C, Cordierite-magnetite-sillimanite-biotite gneiss

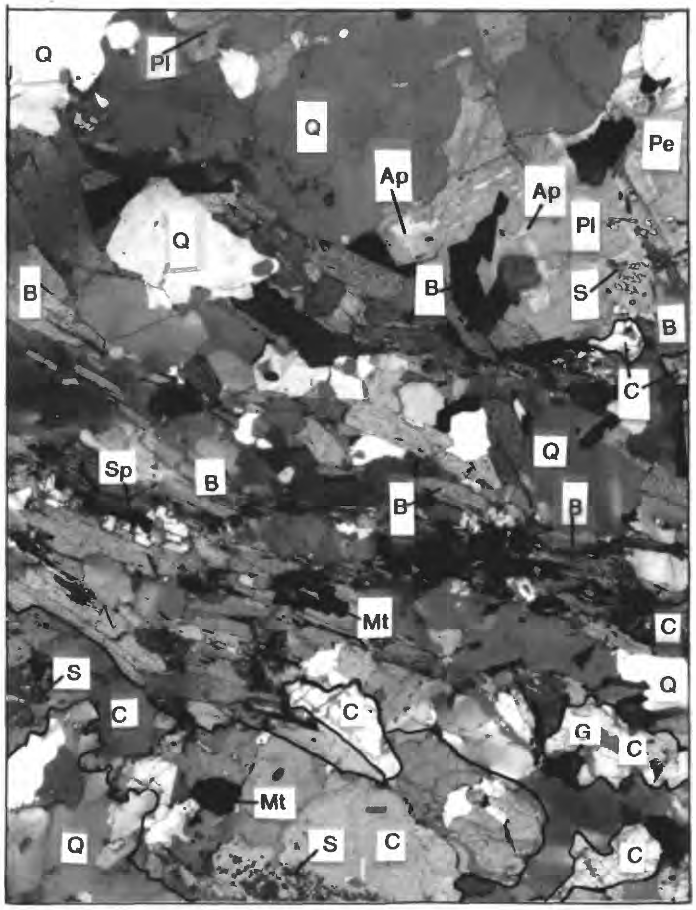
C-1, Thermally metamorphosed gneiss; Ward area, sample W58-73, locality 82

C-2, Thinly layered and weakly schistose gneiss; Ward area, sample W92a-71, locality 94

C-3, Another view of C-2 showing tiny black blebs of magnetite; rock contains 6 percent magnetite

C4, Migmatitic gneiss; Ward area, sample W258B-71, locality 110

Figure 8

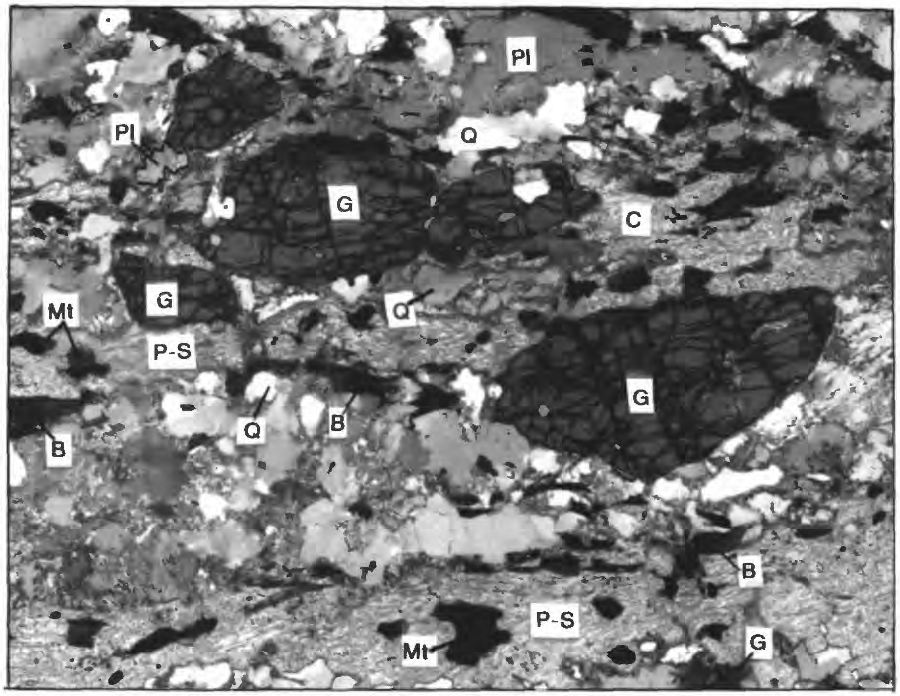



A

Figure 8.--Photomicrographs of high-grade regionally metamorphosed cordierite-bearing biotite gneiss. Symbols: A, andalusite; B, biotite; C, cordierite; G, garnet; Mt, magnetite; Pl, plagioclase; P-S, pinnite-sericite replacing cordierite and sillimanite; Q, quartz; Pe, perthite; S, sillimanite; Sp, spinel; Ap, apatite; Mc, microcline. See plate 2 for location of samples.

A, Cordierite-garnet-sillimanite-biotite gneiss. Crossed nicols, 15x; Monarch Lake area, sample ML-1, locality 299

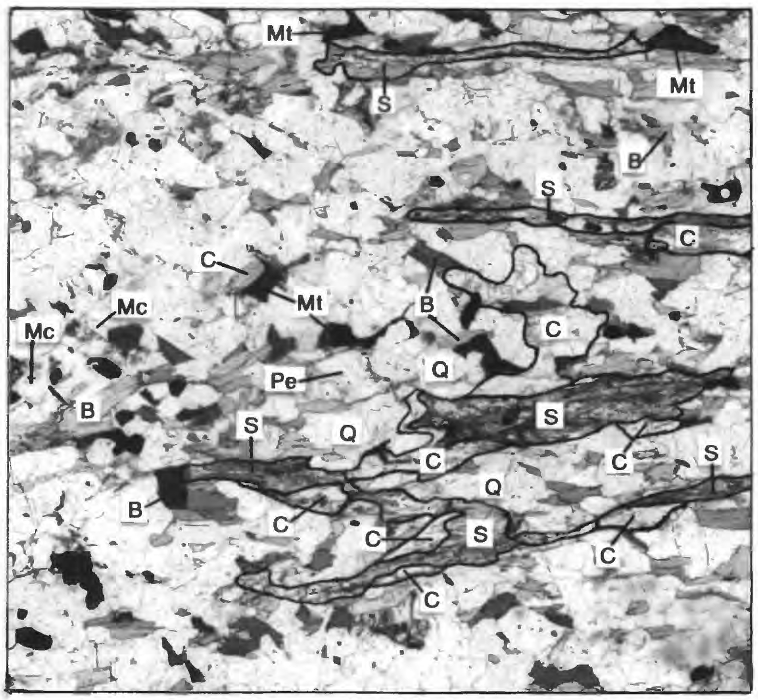
Figure 8B




B

B, Altered and partially recrystallized cordierite-garnet-sillimanite-biotite gneiss from vicinity of Late Cretaceous-early Tertiary intrusive. Crossed nicols, 15x; Ward area, sample W30-73, locality 80, 81

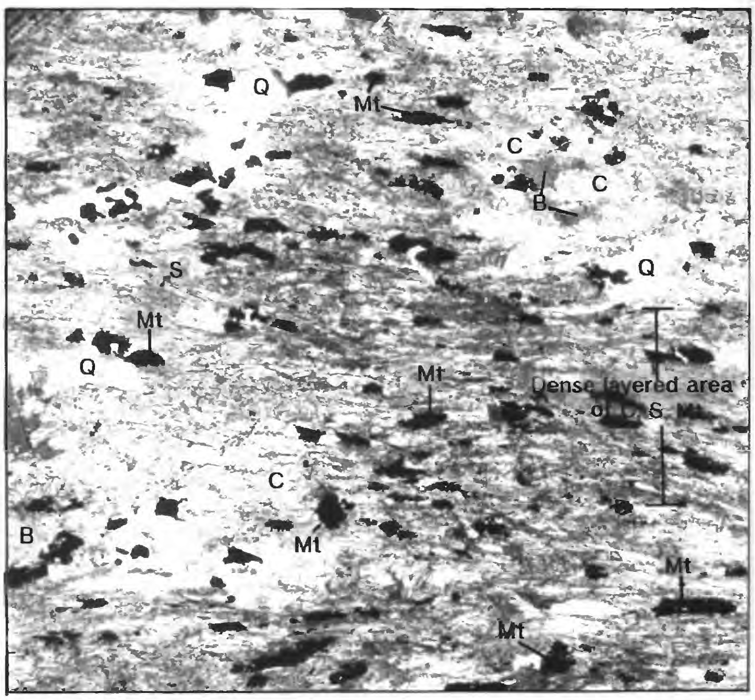
Figure 8C




C

C, Cordierite-sillimanite-biotite gneiss, cordierite sheathes knots and streamers of sillimanite. Plane light, 15x; Ward area, sample W22-72, locality 85

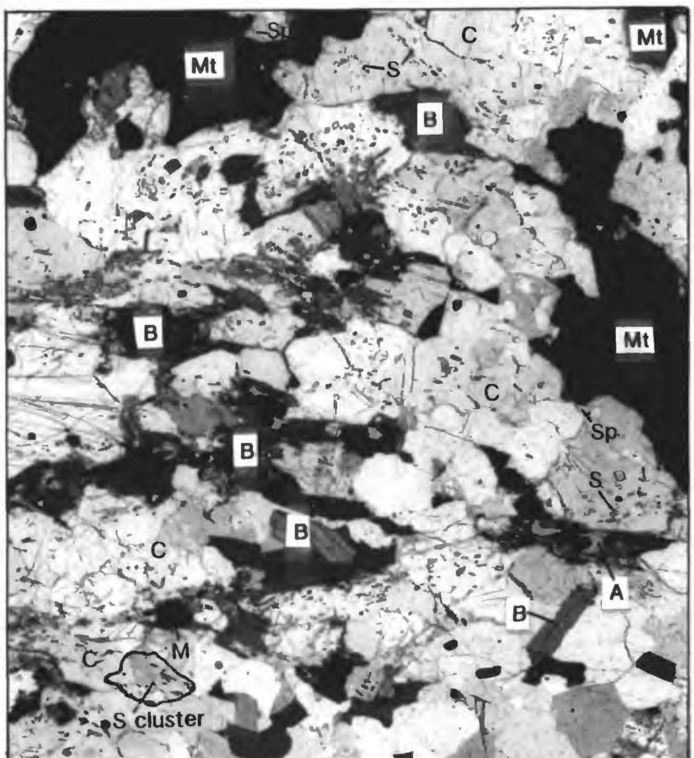
Figure 8D




D

D, Fine- to medium-grained magnetite-cordierite-sillimanite-biotite schistose gneiss with 6 percent magnetite. Plane light, 15x; Gold Hill area, sample GH268-74, locality 47

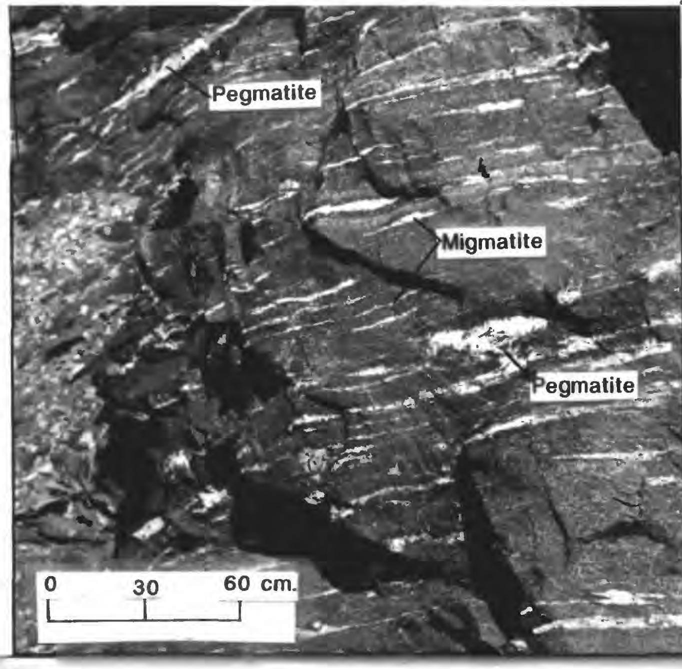
Figure 8E




E

E, Retrograde coarse-grained magnetite-cordierite-sillimanite-biotite gneiss; local reaction zones between cordierite and magnetite of green spinel (hercynite); andalusite growths along grain boundaries of biotite; new slender sillimanite and stumpy, relict sillimanite crystals preserved within younger mosaic of cordierite grains. Plane light, 15x; Gold Hill area, sample GH-32, locality 65

Figure 9




A

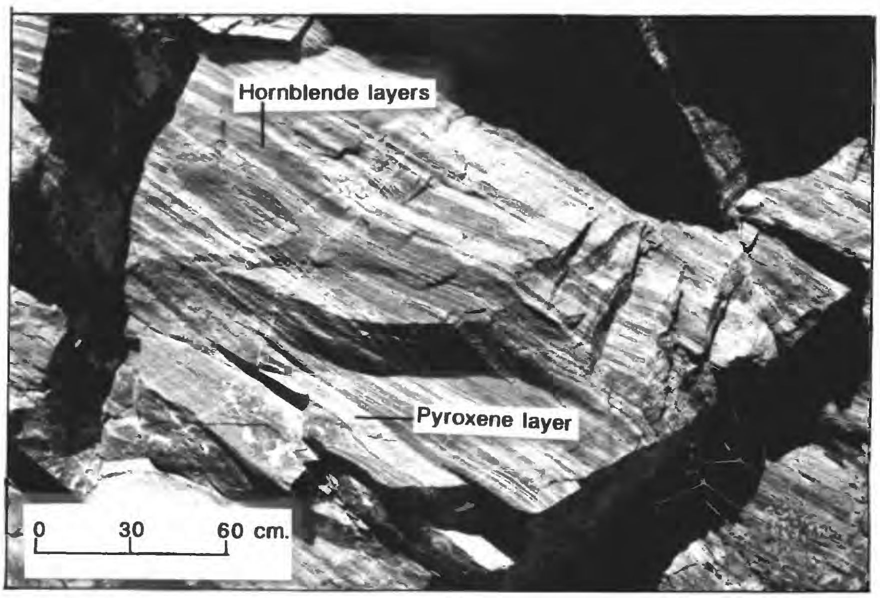

B

Figure 9.--Hornblende gneiss and amphibolite in Clear Creek Canyon.
A, Hornblende gneiss in road cut at junction of Clear Creek and North Clear Creek. Migmatite lenses average about 2-6 cm thick and 30-50 cm in length. Pegmatite, coarser grained and may cut trend of foliation
B, Interlensing of massive amphibolite (Xam) and foliated hornblende gneiss (Xgnh) in road cut along Clear Creek east of Idaho Springs

Figure 9C and D

C

C, Isoclinal fold in hornblende gneiss showing compositional bands. Dark bands are hornblende-rich and light bands are pyroxene-rich. Plants 40 cm in length indicate scale




D

D, Fine- to coarse-layered hornblende-rich gneiss interlayered with pyroxene-rich gneiss

Figure 10

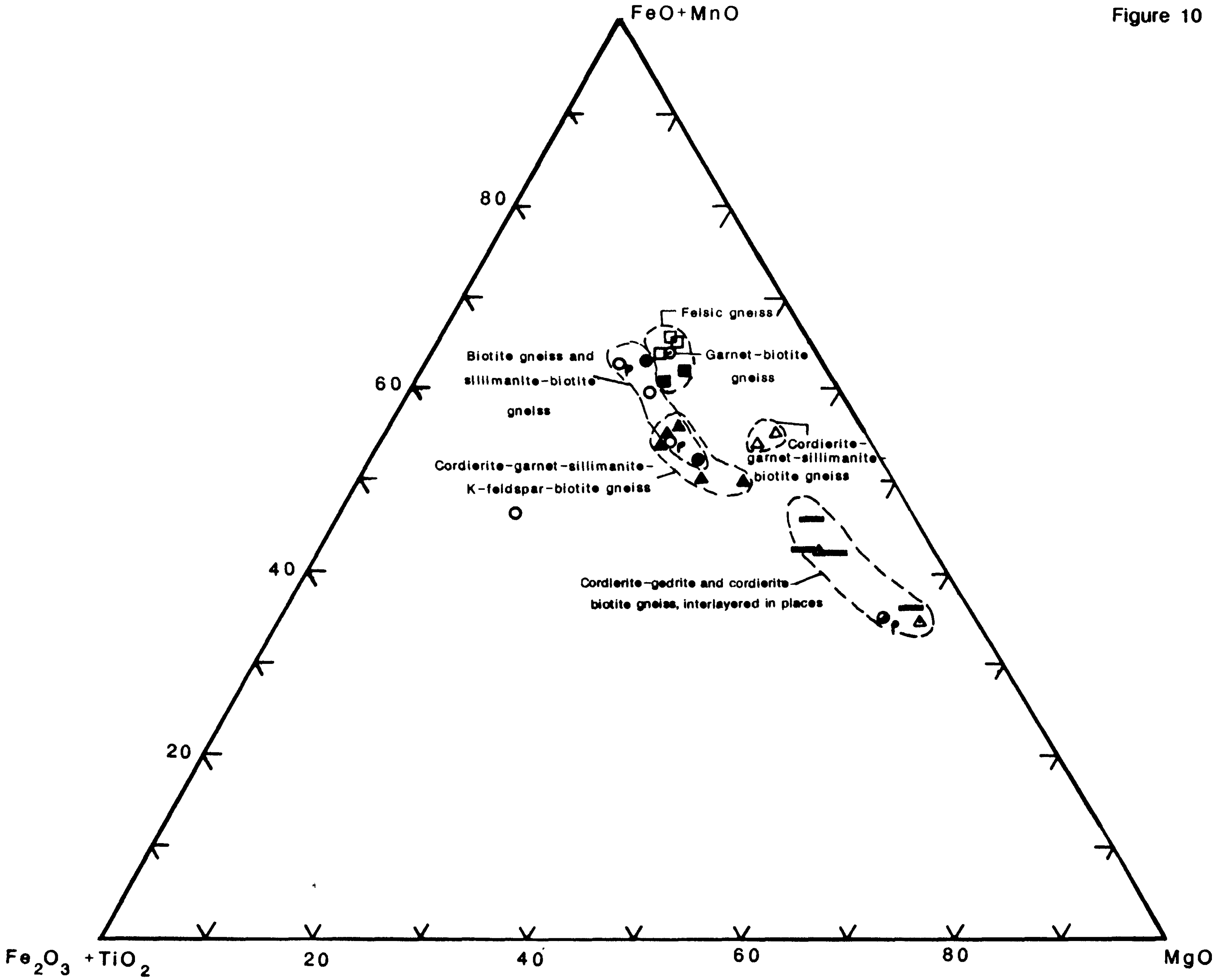



Figure 10.—A plot of biotite compositions according to rock type: □, feldspar-rich gneiss; ■, hornblende-bearing felsic gneiss; ●, biotite gneiss; ○, sillimanite-biotite gneiss; ○p, pegmatite; ●p," pegmatite in gedrite-bearing rocks; △, cordierite-garnet-sillimanite-biotite gneiss; ▲, cordierite-garnet-K-feldspar-sillimanite-biotite gneiss; ◬, cordierite-biotite gneiss interlayered with cordierite-gedrite-biotite gneiss; ▬, cordierite-gedrite-biotite gneiss. Dashed line encloses gneisses with same mineral assemblage

Figure 11

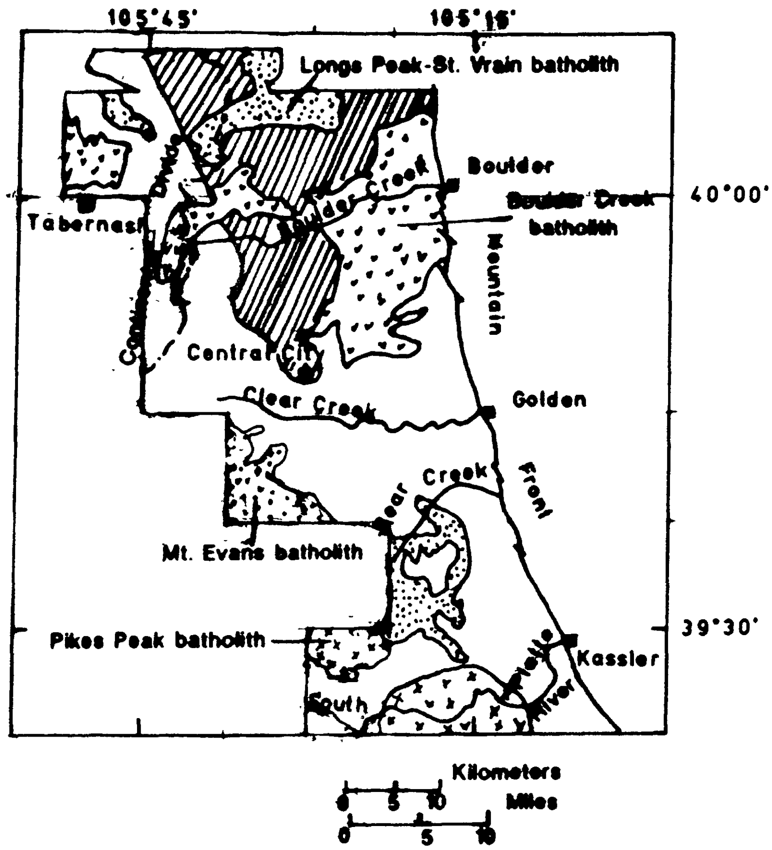



Figure 11.--Distribution of retrograde andalusite (hachured area) in biotite gneiss, central Front Range, Colo. Nonpatterned area, Proterozoic metamorphic rocks. [v v] Granitic rocks 1.7-1.65 b.y.; [dotted] Granitic rocks 1.5-1.4 b.y.; [x x] Granitic rocks 1.0 b.y.

Figure 12

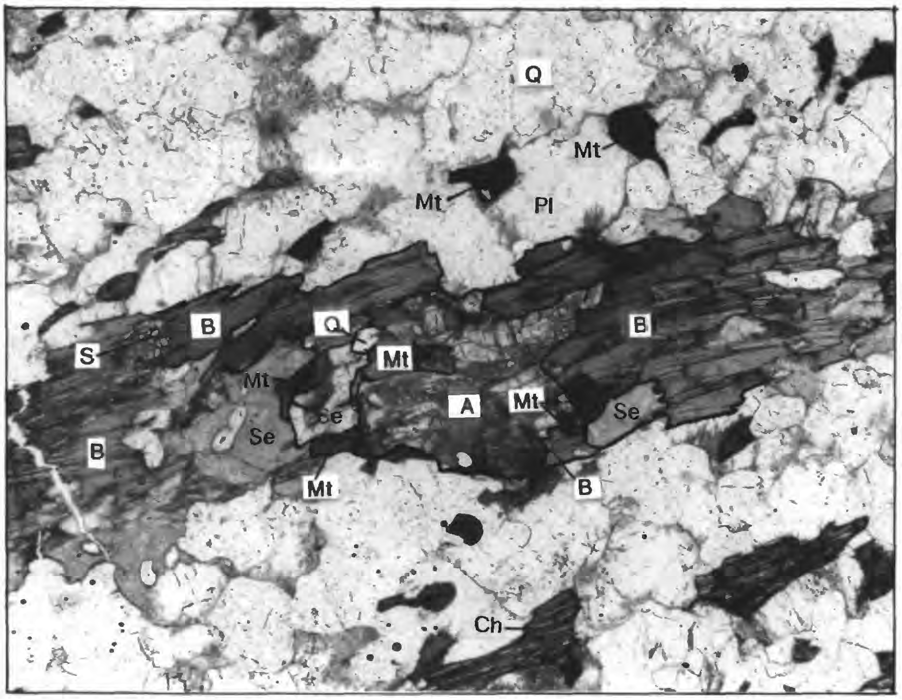
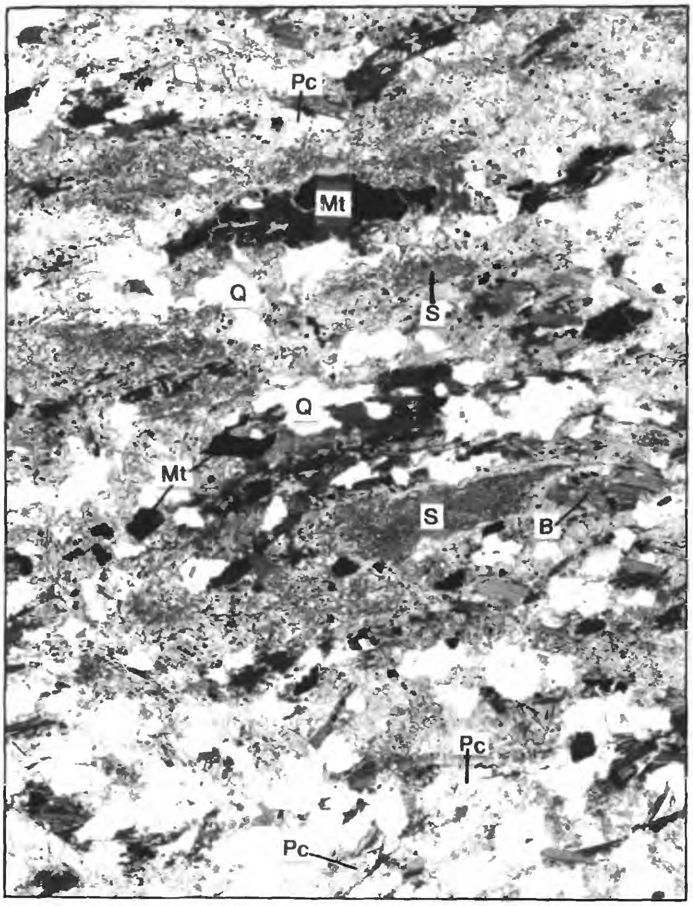



Figure 12.--Photomicrograph of sillimanite-biotite gneiss that has been slightly sheared and recrystallized. Retrograde andalusite growth on biotite believed due to heating associated with emplacement of the nearby Silver Plume Granite, Ward area. Crossed nicols, 40x; sample W265-71. Symbols: A, andalusite; B, biotite; Ch, chlorite; Mt, magnetite; Pl, plagioclase; Q, quartz; S, sillimanite; Se, sericite after cordierite. See plate 2 for location of sample

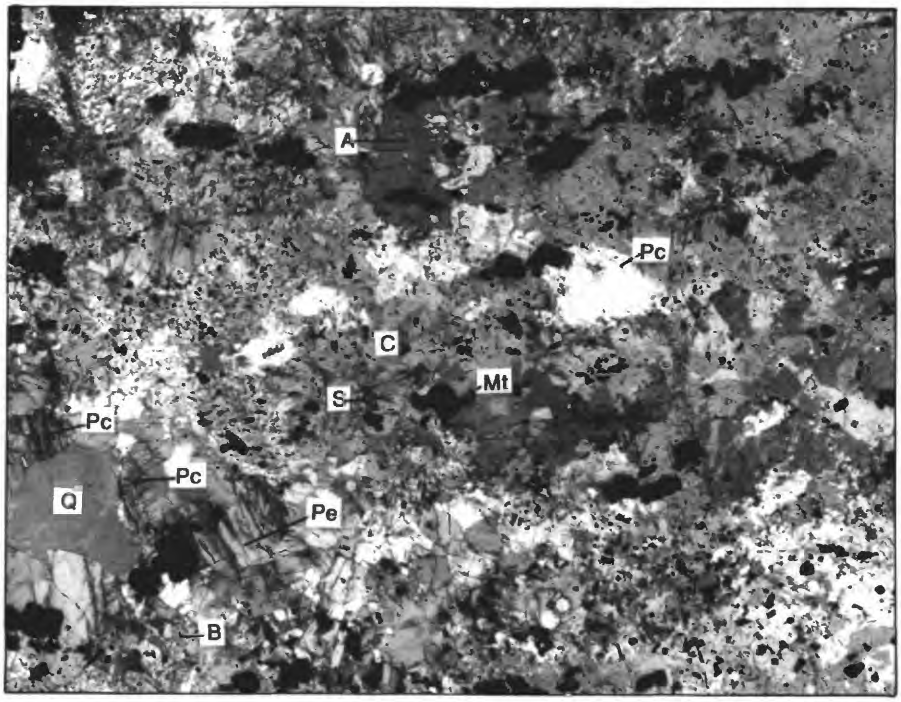
FIGURE 13




A

Figure 13.--Photomicrographs of thermally altered biotite gneiss. Symbols: A, thermal andalusite; B, biotite; C, cordierite no distinct grain boundaries and extremely poikiloblastic with inclusions of magnetite, andalusite, and sillimanite; G, garnet; Mt, magnetite; Pc, plagioclase; Pe, perthite; Q, quartz; S, sillimanite. See plate 2 for location of samples.
A, Recrystallized poorly foliated andalusite-bearing (andalusite not visible)-cordierite-magnetite-sillimanite-biotite gneiss from thermal aureole of Laramide stock. Crossed nicols, 15x; sample N104a-64, locality 214

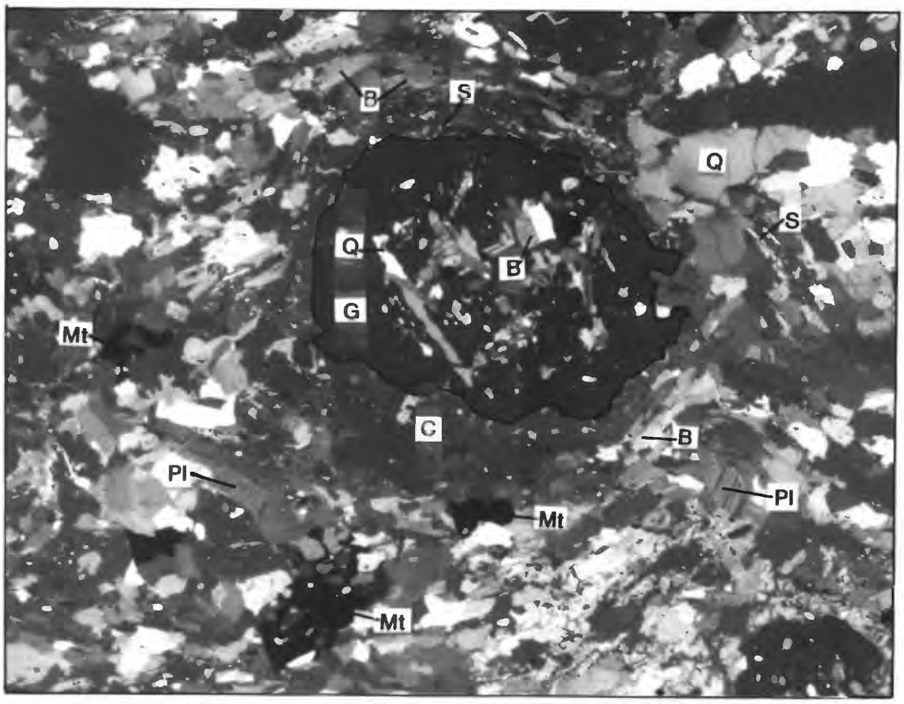
Figure 13B




B

B, Recrystallized andalusite-bearing cordierite-magnetite-biotite gneiss from thermal aureole of Caribou stock, northwest of Nederland, showing new randomly oriented crystals. Crossed nicols, 15x; sample N236-65, locality 226

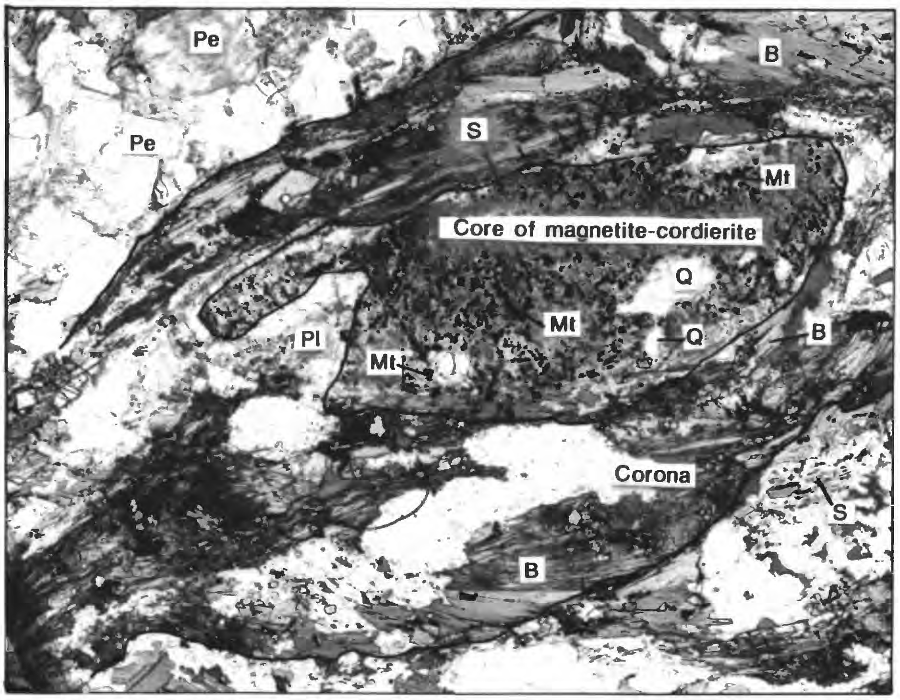
Figure 13C




C

C, Cordierite corona on garnet in cordierite-garnet-K-feldspar-sillimanite-biotite gneiss west of Boulder Creek Batholith. Crossed nicols, 15x; Central City area, sample JG-12A, locality not identified on plate 2

Figure 13D




D

D, Corona destroyed by thermal heating adjacent to a Laramide intrusive. Garnet at core of crystal now filled by cordierite-magnetite. The original cracks in garnet now filled by tiny magnetite grains. Plane light, 15x; sample N87-64, locality 213

**Figure 14**

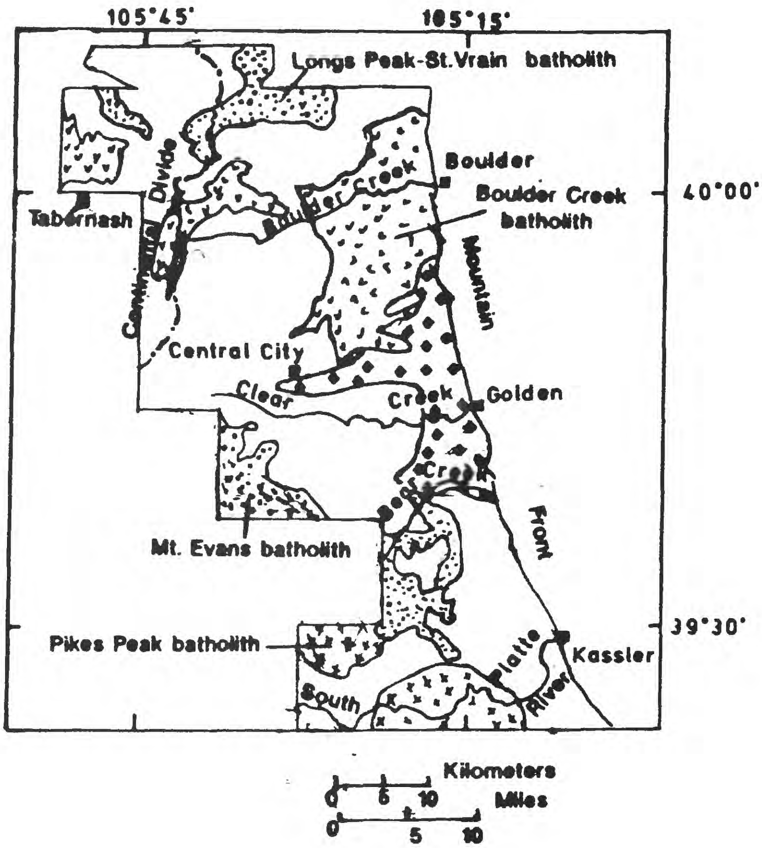
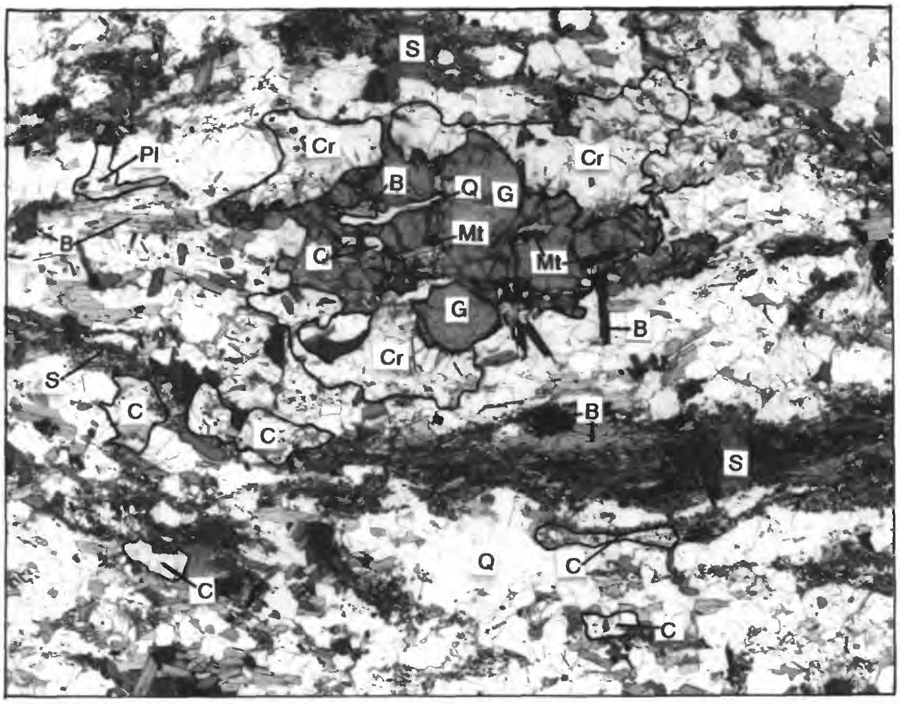



Figure 14.--Distribution of staurolite-bearing biotite gneiss, central Front Range, Colo. Nonpatterned area, undifferentiated metamorphic rocks: Staurolite-bearing metamorphic rocks; Granitic rocks 1.7-1.65 b.y.; Granitic rocks 1.5-1.4 b.y.; Granitic rocks 1.0 b.y.

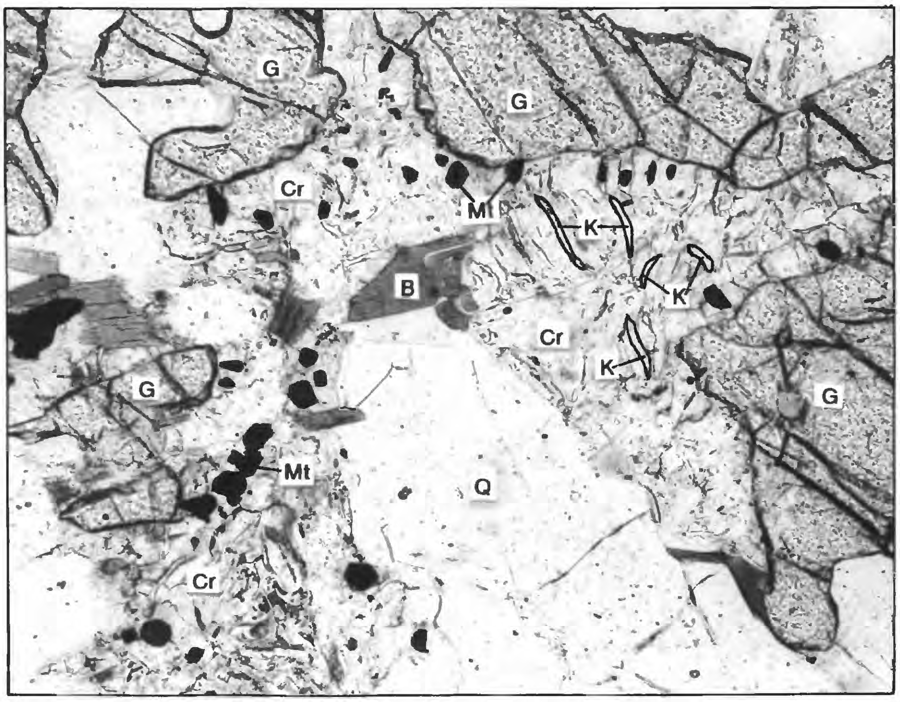
Figure 15




A

Figure 15.--Photomicrographs of several regionally metamorphosed cordierite-garnet-K-feldspar-sillimanite-biotite gneiss showing minor retrograde metamorphism. Symbols: B, biotite; C, cordierite; Cr, retrograde cordierite; G, garnet; K, K-feldspar vermicular intergrowths; Mc, microcline; Mt, magnetite; Pl, plagioclase; Q, quartz, S, sillimanite.
A, Cordierite, scattered and profuse in thin section. Plane light, 15x; Gold Hill area, sample GH12-74

Figure 15B




B

B, Similar gneiss as in A. Magnified 100x, plane light, Central City area, sample D-417. Garnet and locally biotite replaced by cordierite, magnetite, and K-feldspar

Figure 16

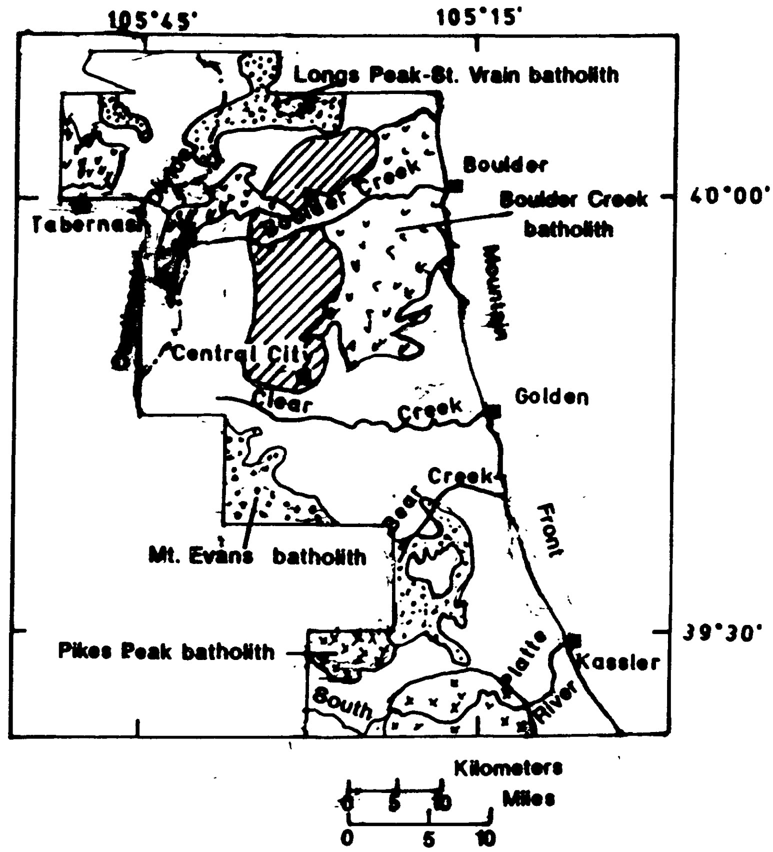



Figure 16.--Distribution (hachured area) of retrograde cordierite coronas on garnet in biotite gneiss, central Front Range, Colo. Nonpatterned area, metamorphic rocks; Granitic rocks, 1.7-1.65 b.y.; Granitic rocks, 1.5-1.4 b.y.; Granitic rocks, 1.0 b.y.

Figure 17

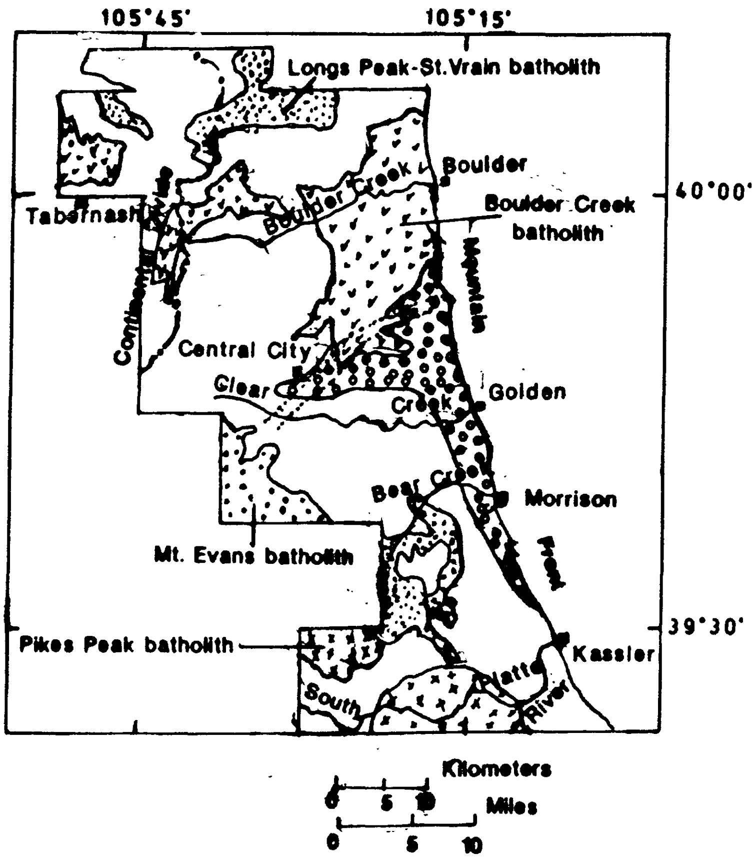



Figure 17.--Distribution ( ) of Proterozoic tourmaline-bearing biotite gneiss in the central Front Range, Colo. Nonpatterned area, metamorphic rocks; Granitic rocks, 1.7-1.65 b.y.; Granitic rocks, 1.5-1.4 b.y.; Granitic rocks, 1.0 b.y.

Figure 18.--Variations in oxide composition of various sillimanite-biotite gneisses and sillimanite-free biotite gneisses.:
1, Biotite-quartz-plagioclase gneiss
2, Garnet-biotite gneiss
3, Cordierite-garnet-biotite gneiss
4, Sillimanite-biotite gneiss
5, Magnetite-sillimanite-biotite gneiss
6, Garnet-sillimanite-biotite gneiss
7, Cordierite-magnetite-sillimanite-biotite gneiss
8, Cordierite-sillimanite biotite gneiss
9, Cordierite-garnet-sillimanite-biotite gneiss
10, Cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar

Figure 18

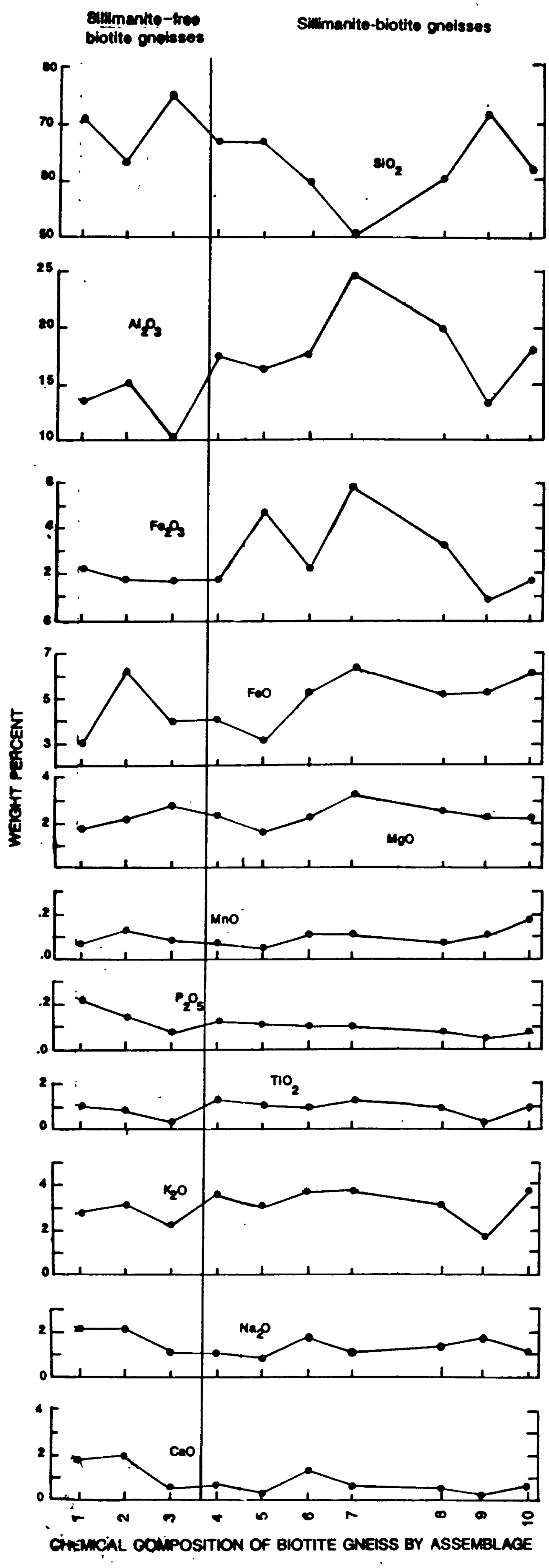

Sillimanite-free biotite gneisses
Sillimanite-biotite gneisses
SiO2
Al2O3
Fe2O3
FeO
MgO
MnO
P2O5
TiO2
K2O
Na2O
CaO
WEIGHT PERCENT
CHEMICAL COMPOSITION OF BIOTITE GNEISS BY ASSEMBLAGE

Figure 19

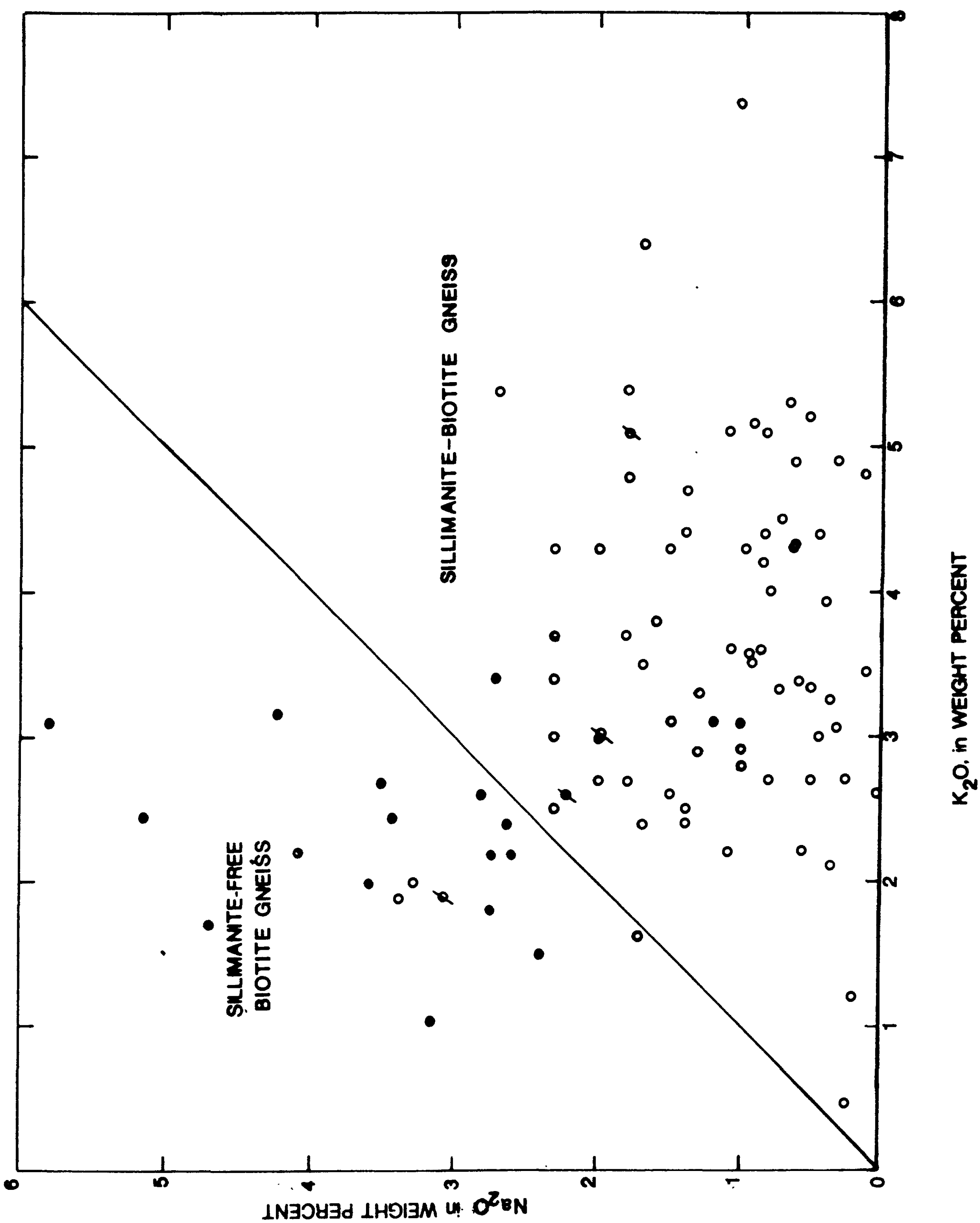



Figure 19.--K2O/Na2O ratios from analyses of sillimanite-free biotite gneiss (table 20), sillimanite-biotite gneiss (tables 21, 23-26) and garnet-biotite gneiss (table 22), central Front Range, Colo. Symbols: ●, sillimanite-free biotite gneiss; o, sillimanite-biotite gneiss; ø, garnet-biotite gneiss. Additional ratios from Gable and Sims (1969, fig. 4*F*).

Figure 20 A

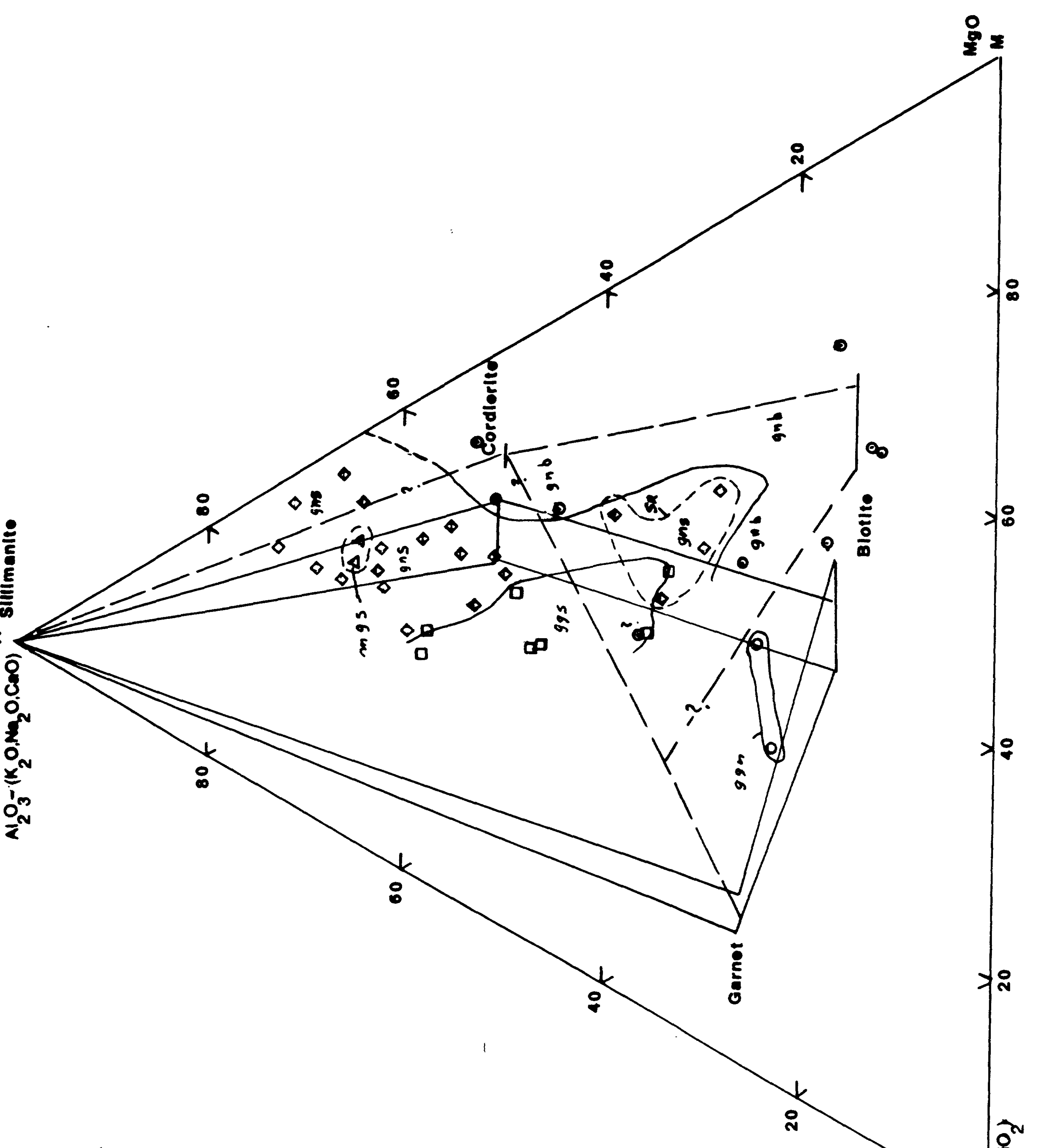


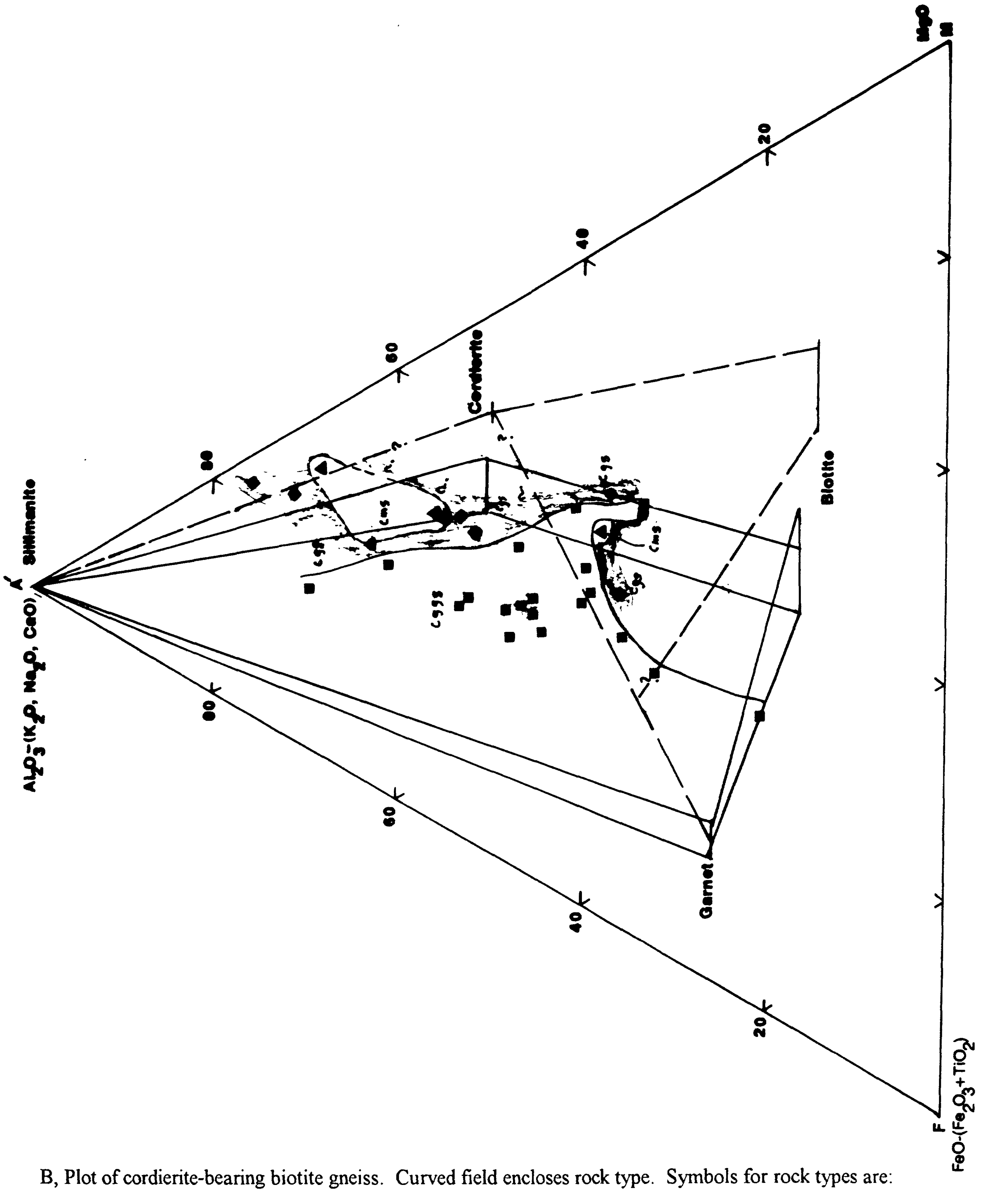

Figure 20.--A'FM diagrams of rock compositions (in mole percent) for biotite gneiss from high-grade metamorphic rocks, central Front Range, Colo. Tie lines for mineral pairs of K-feldspar-bearing biotite gneiss in Central City and Nederland areas (Gable and Sims, 1969, fig. 3). K-feldspar, plagioclase, quartz, and magnetite common to all assemblages.

A, Plot of cordierite-free biotite gneiss. Curved field encloses rock type. Symbols for rock types are:

gnb, sillimanite-free biotite gneiss
ggn, garnet-biotite gneiss
gns, sillimanite-biotite gneiss
ggs, garnet-sillimanite-biotite gneiss ± K-feldspar
mgs, magnetite-sillimanite-biotite gneiss

Dashed field represents sillimanite-biotite gneiss s mples from south of Idaho Springs-Ralston shear zone

Figure 20 B




B, Plot of cordierite-bearing biotite gneiss. Curved field encloses rock type. Symbols for rock types are:

cgs, cordierite-sillimanite-biotite gneiss

cggs, cordierite-garnet-sillimanite-biotite gneiss ± K-feldspar

cms, cordierite-magnetite-sillimanite-biotite gneiss

**Figure 21**

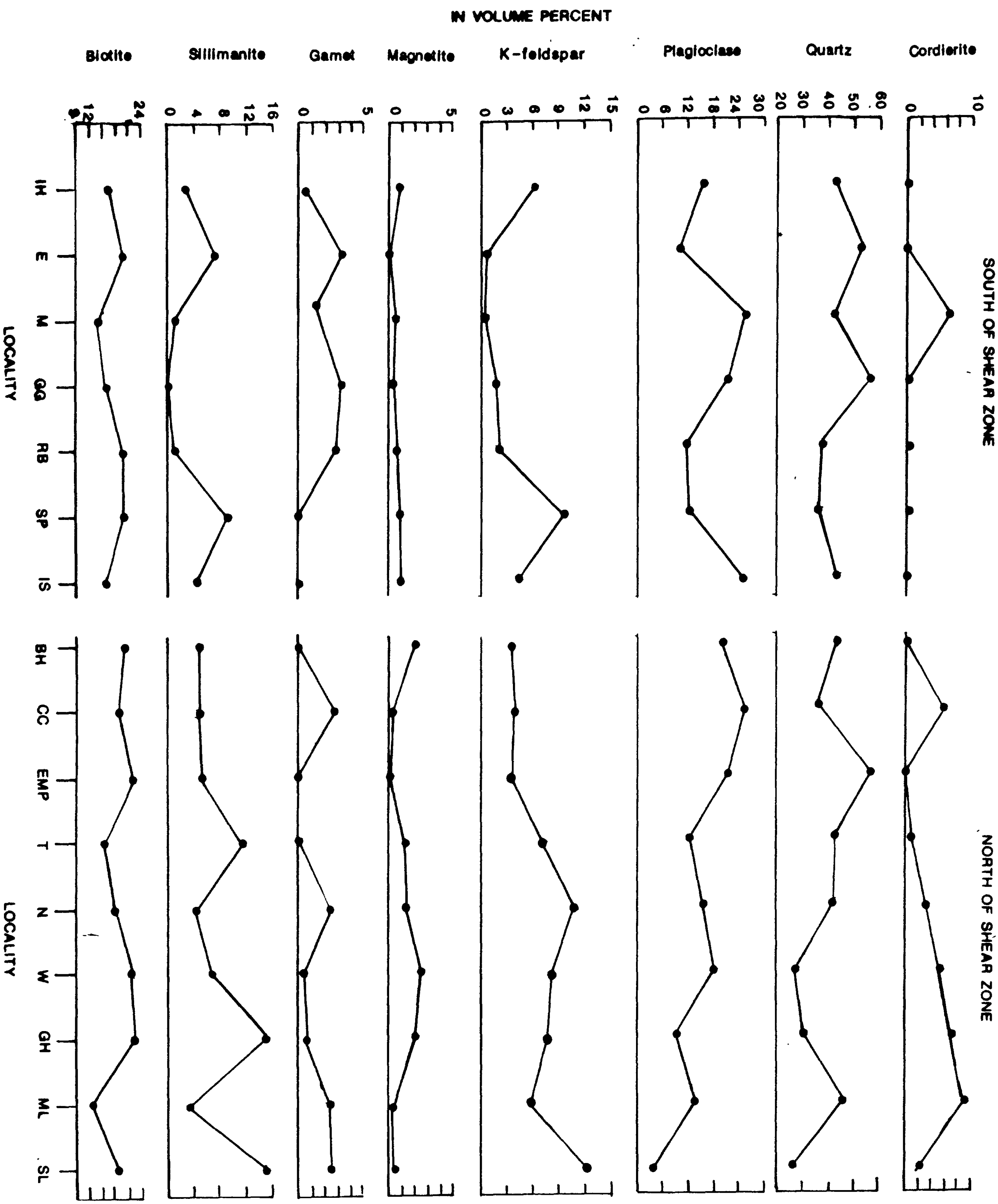



Figure 21.—Average major mineral composition of biotite gneiss south and north of the Idaho Springs-Ralston shear zone. Localities are: IH, Indian Hills; E, Evergreen; M, Morrison; GG, Golden Gate; RB, Ralston Buttes; SP, Squaw Pass; IS, Idaho Springs; BH, Black Hawk; CC, Central City; EMP, Empire; T, Tungsten; N, Nederland; W, Ward; GH, Gold Hill; ML, Monarch Lake; SL, Strawberry Lake.

Figure 22 A

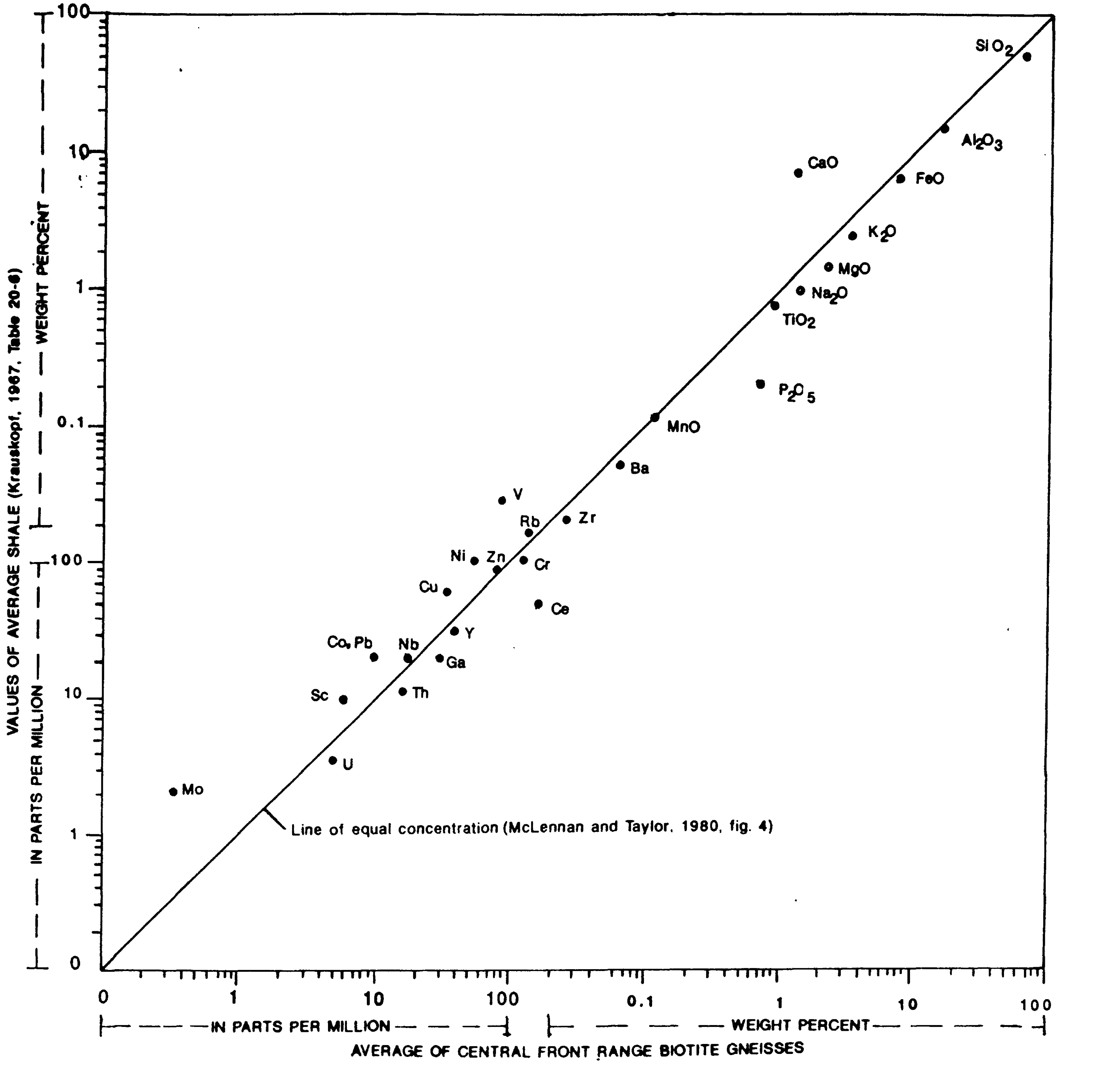
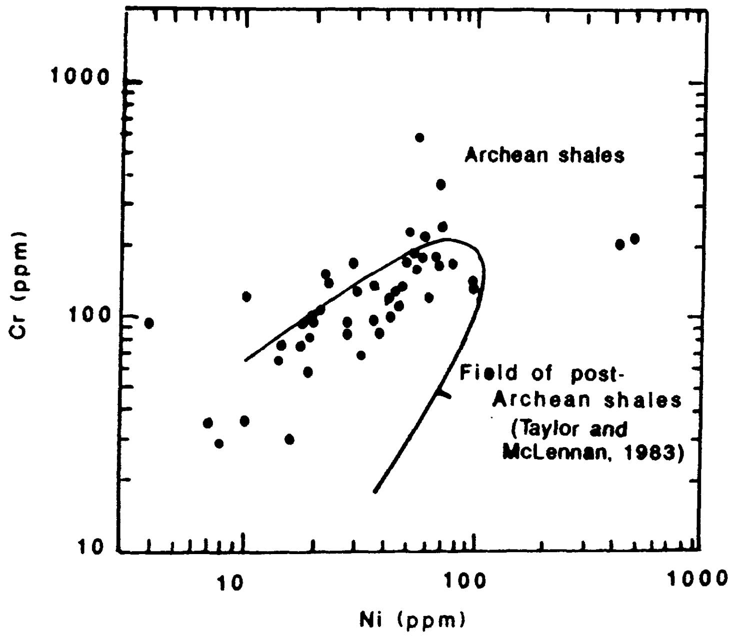



Figure 22.—Major oxides and minor elements in biotite gneiss, central Front Range, Colo., compared with average shale, and Archean shale.
*A*, Averages for major and minor elements in Front Range biotite gneiss (96 analyses) compared to elements in average shale

FIGURE 22 B




*B*, Plot of Cr versus Ni for central Front Range biotite gneiss (46 samples) compared to field of post-Archean shales

FIGURE 23

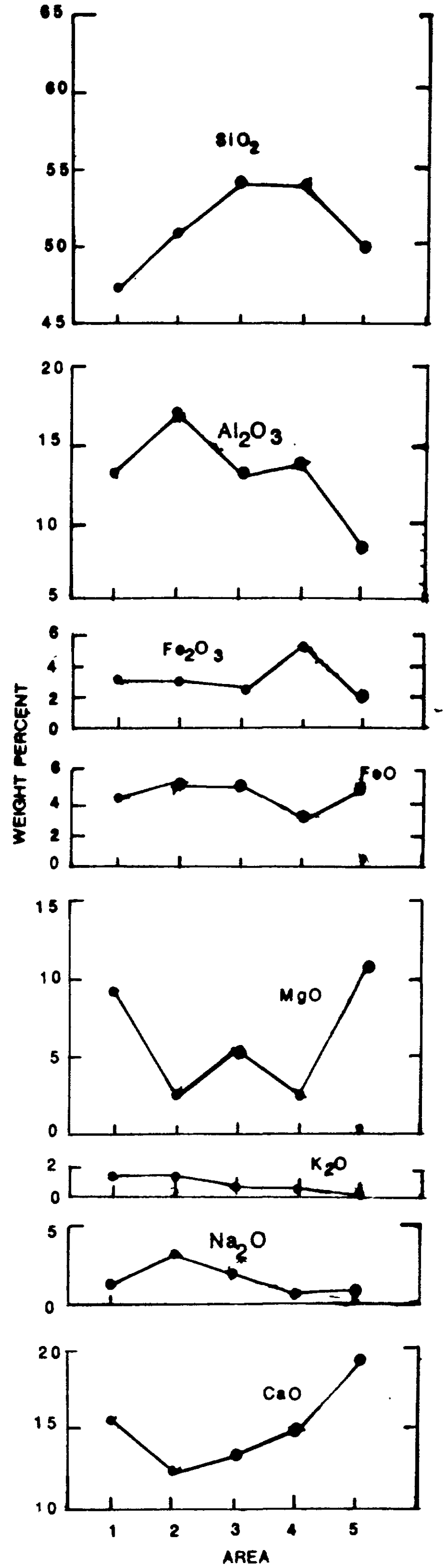



Figure 23.--Differences by area, for averaged select major oxides in calc-silicate gneiss due to interlayering with other gneisses, central Front Range, Colo. Sample areas are the following:

1, Ward area, interlayered with hornblende gneiss and cordierite-garnet-sillimanite-biotite gneiss (table 35, col. 4)

2, Idaho Springs area, interlayered with sillimanite-biotite gneiss (table 35, col. 5)

3, Gold Hill area, interlayered with hornblende gneiss (table 35, col. 6)

4, Nederland area, Phoenix layer, interlayered with and adjacent to hornblende gneiss and amphibolite (table 35, col. 1)

5, Gold Hill area, lenses interlayered with pyroxene-rich gneiss (table 35, col. 7)

FIGURE 24

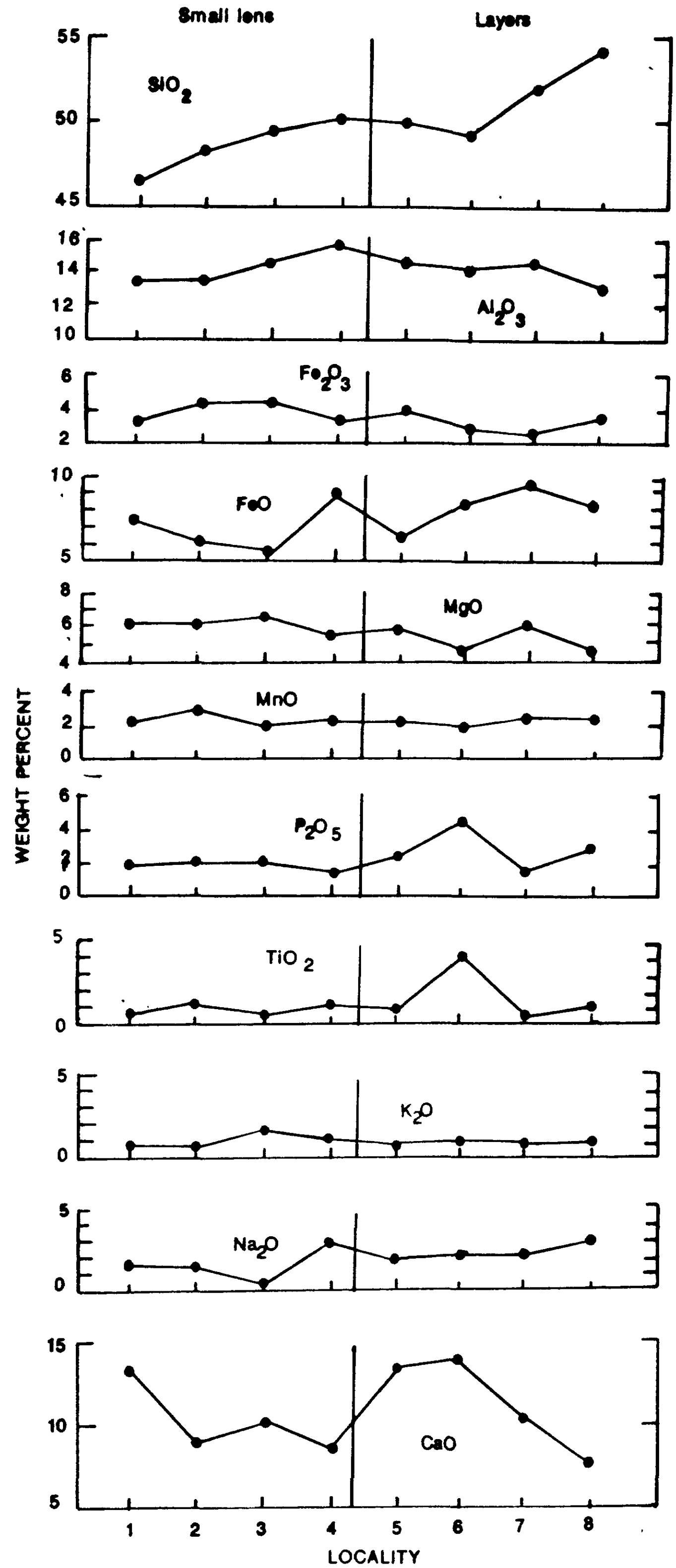



Figure 24.—Average value of major oxides in hornblende gneiss and amphibolite, by area, central Front Range, Colo. Sample localities are as follows: 1, Small lenses in Nederland area, not including the Phoenix layer; 2, Small lenses, Morrison area; 3, Lenses, Ward area; 4, Small lenses, Central City area; 5, Phoenix layer, Nederland area; 6, Clear Creek layer, Clear Creek Canyon; 7, Morrison layers; 8, Golden Gate layers, Golden Gate Canyon. Analyses from table 37.

Figure 25 A

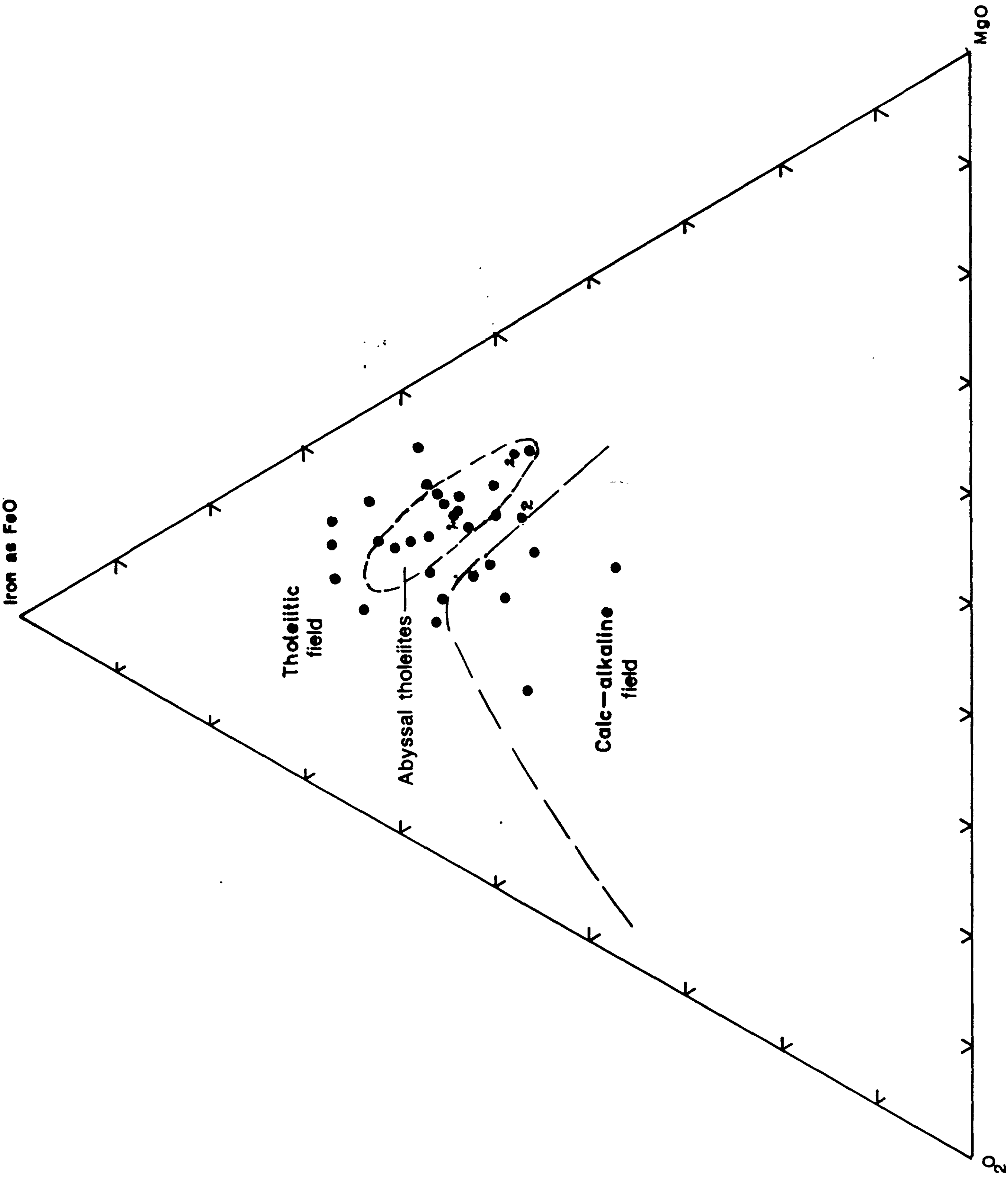
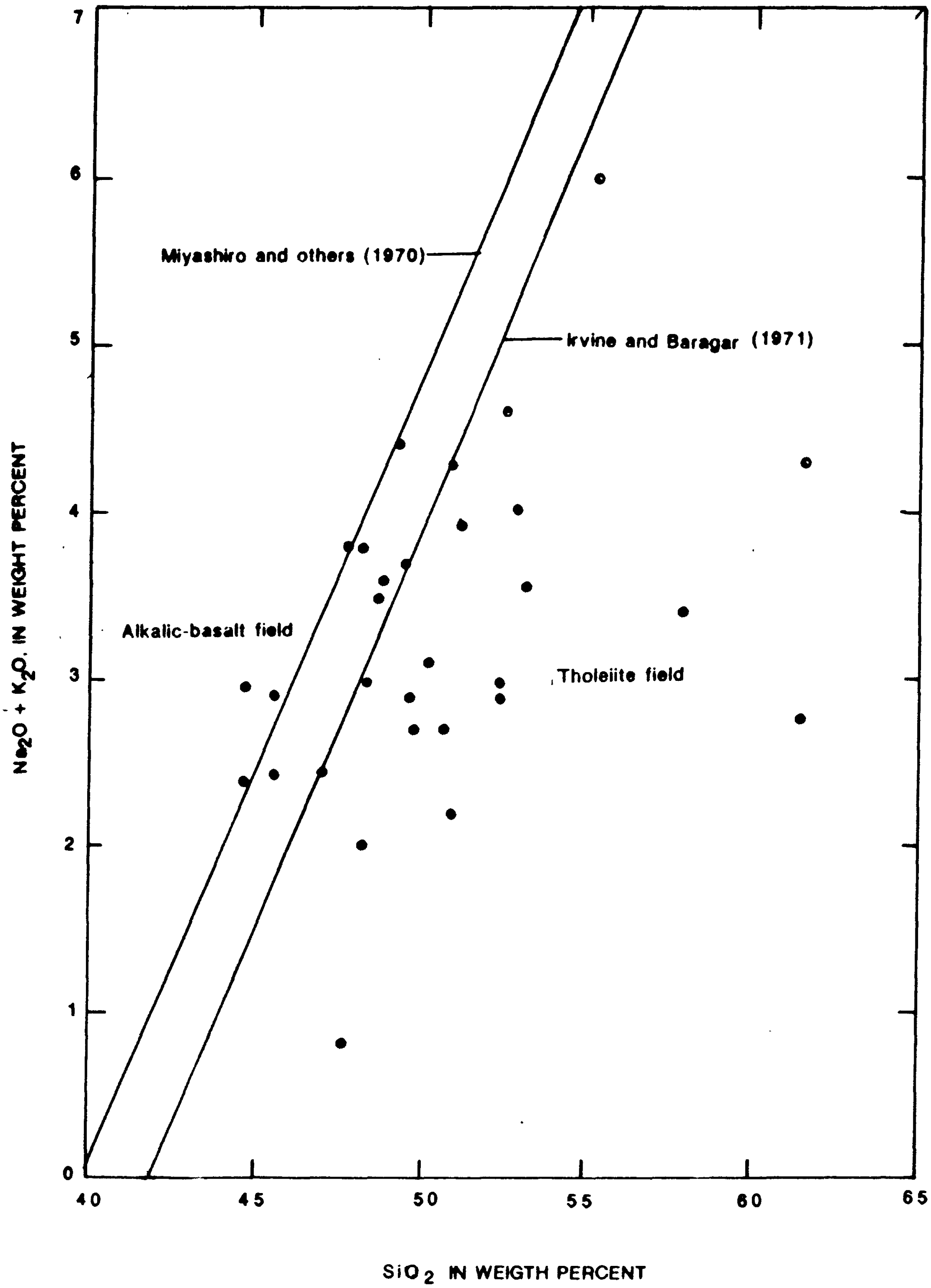



Figure 25.--Distribution diagrams for hornblende gneiss and amphibolite, central Front Range, Colo. Data from table 37 and from Gable and Sims (1969, table 2); 33 analyses.
A, A'FM diagram for hornblende gneiss and amphibolite (in mole percent). Boundary between tholeiitic basalt and calc-alkaline rocks from Irvine and Barager (1971). Area of abyssal tholeiites from Miyashiro and others (1970). No analyses of 4.0 percent or more $Fe_2O_3$ were used

Figure 25 B




B, Alkali-silica diagram for hornblende gneiss and amphibolite, central Front Range; diagram from Irvine and Barager (1971)

Figure 26.--Major oxides and trace elements for hornblende gneiss and amphibolite, central Front Range, Colo., plotted against [Mg], where [Mg] = Mg/(Mg+$Fe^{2+}$) atomic ratio assuming $Fe^{3+}/Fe^{2+}$ = 0.15, from Dupuy and Dostal (1984). *A*, Major oxides; *B*, Trace elements. Solid line represents visual average of Front Range plots. Dashed line represent $TiO_2$ and $P_2O_5$ in basalt and tholeiite from Dupuy and Dostal (1984).

MAJOR OXIDES

Figure 26 A

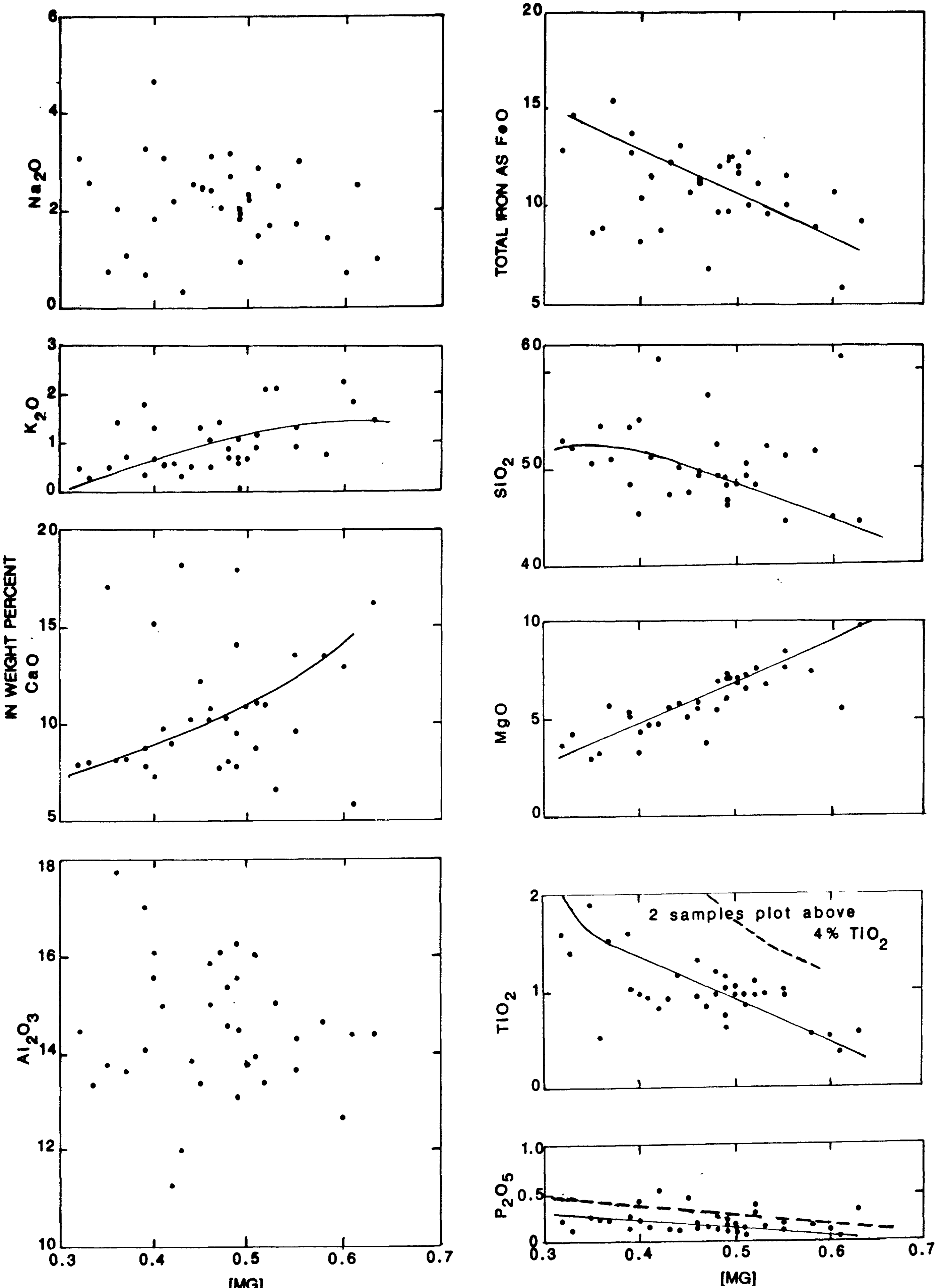


Figure 26 B

TRACE ELEMENTS

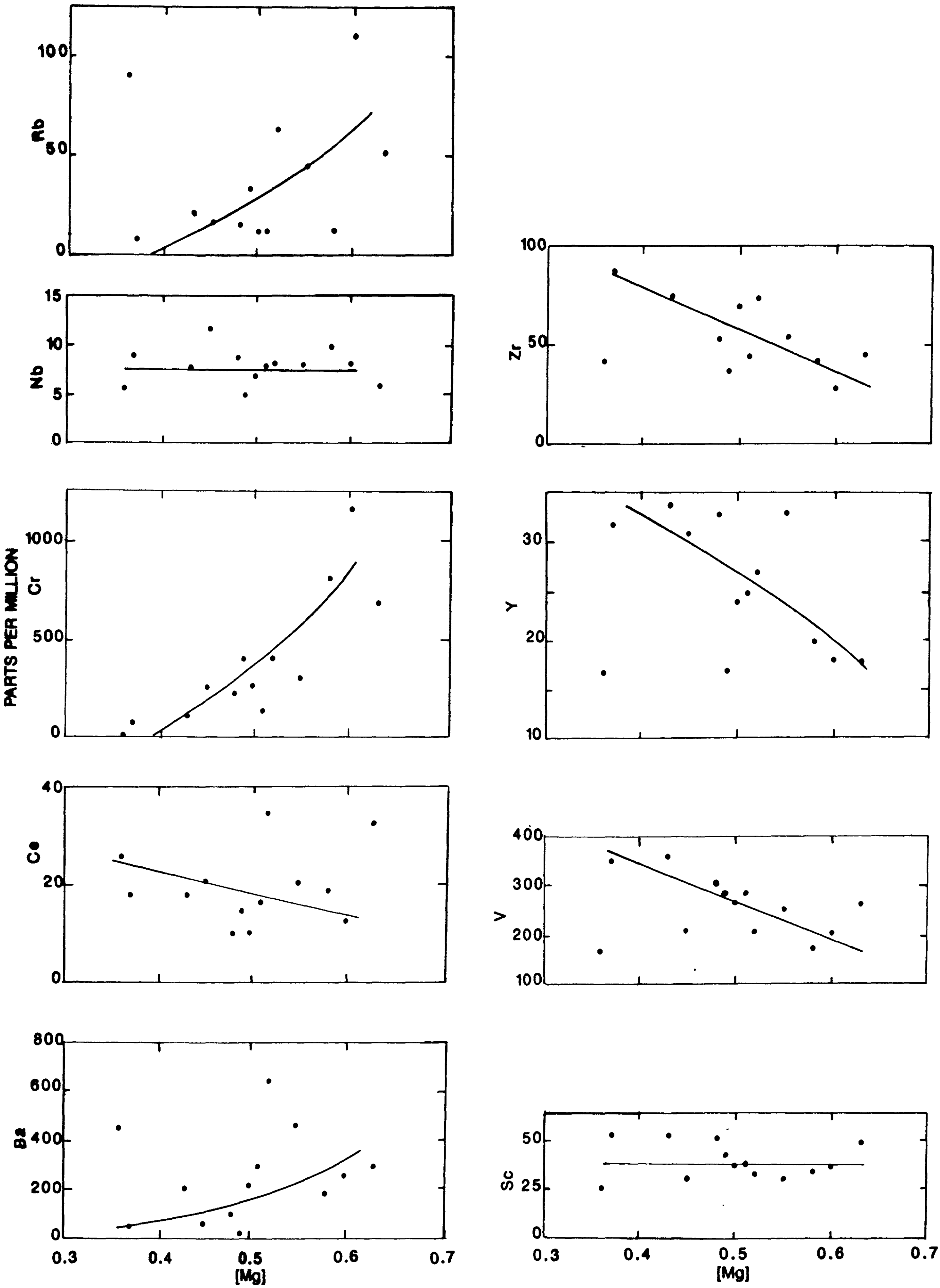


Figure 27

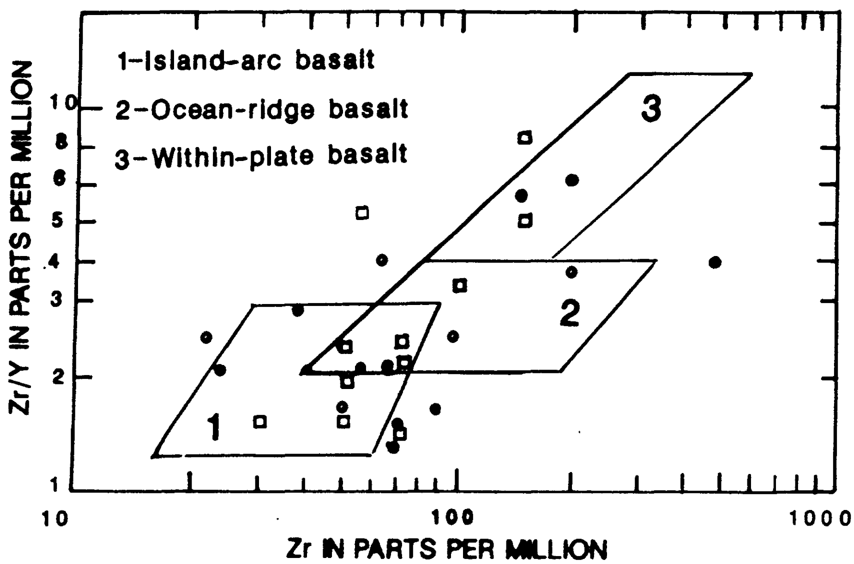



Figure 27.--Zr/Y-Zr plot of hornblende gneiss and amphibolite, central Front Range. Solid circles, lenses and small bodies; open squares, layers. Field of basalt compositions from Pearce and Norry (1979).

Figure 28

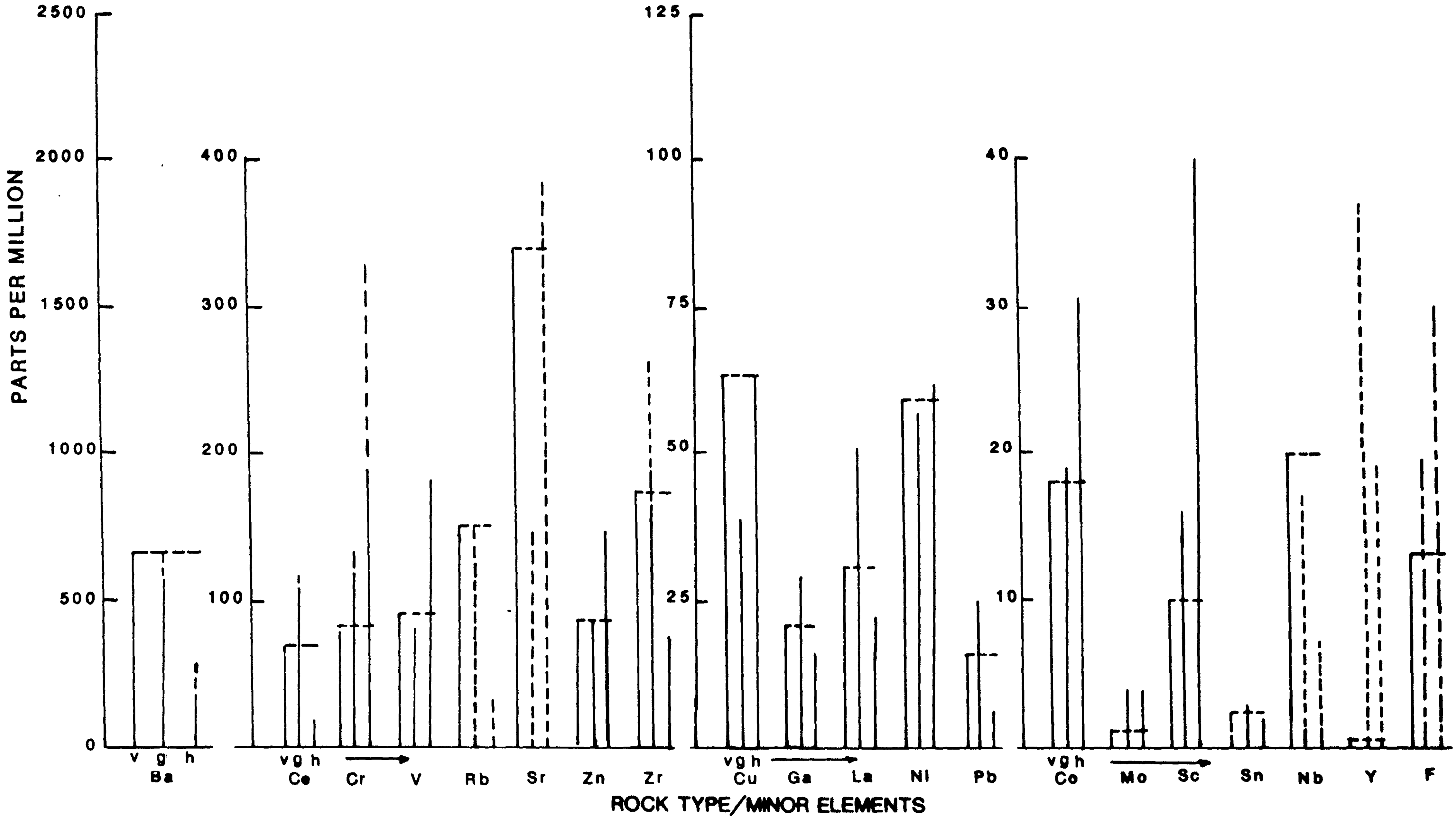



Figure 28.--A comparison of amounts of minor elements in the Early Proterozoic metamorphic rocks, central Front Range, Colorado, with crustal averages calculated by Vinogradov (1962). Symbols: v, Vinogradov; g, biotite gneiss (98 samples); h, hornblende gneiss, amphibolite, and calc-silicate gneiss (52 samples); dashed horizontal line, average of Vinogradov; solid vertical line, semiquantative analyses; short-dashed vertical line, X-ray diffraction analyses; long- and short-dashed vertical line, rapid-rock analyses.

Figure 29.--Minor elements in biotite gneiss, by area, central Front Range, Colo. Areas arranged with the southern area at the top. Analyses for F by rapid-rock analysis; Ba, Ce, Cr, Rb, Sr, V, Y, and Zr by optical and X-ray spectrography (XRF); Be, Co, Cu, Ga, La, Mo, Ni, Pb, and Zn by emission spectrography. Data compiled from tables 1-11 and 31.

Figure 29

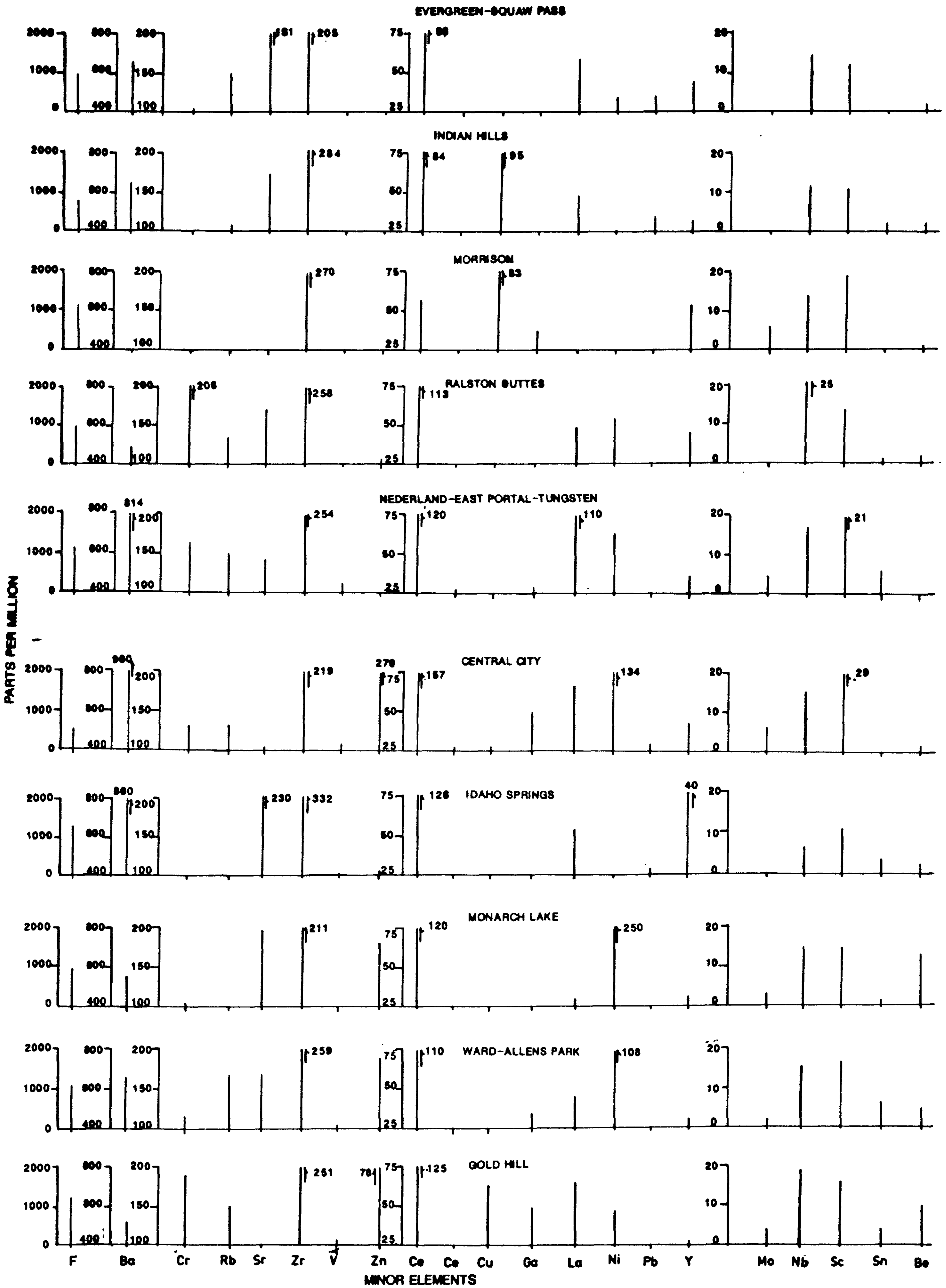

EVERGREEN-SQUAW PASS
INDIAN HILLS
MORRISON
RALSTON BUTTES
NEDERLAND-EAST PORTAL-TUNGSTEN
CENTRAL CITY
IDAHO SPRINGS
MONARCH LAKE
WARD-ALLENS PARK
GOLD HILL
PARTS PER MILLION
F
Ba
Cr
Rb
Sr
Zr
V
Zn
Ce
Co
Cu
Ga
La
Ni
Pb
Y
Mo
Nb
Sc
Sn
Be
MINOR ELEMENTS

Figure 30.--Amounts of minor elements in hornblende gneiss and amphibolite, and calc-silicate gneiss, by area, central Front Range, Colo. Areas arranged with the southern area at the top. Solid line, hornblende gneiss and amphibolite; dashed line, calc-silicate gneiss. Analyses of Ba, Ce, Cr, Nb, Rb, Sc, Sr, V, and Zr, by optical and X-ray spectrography (XRF); F, rapid-rock analysis; and Co, Cu, La, Ni, and Pb by emission spectrography. Data compiled from tables 33, 37, and 39.

Figure 30

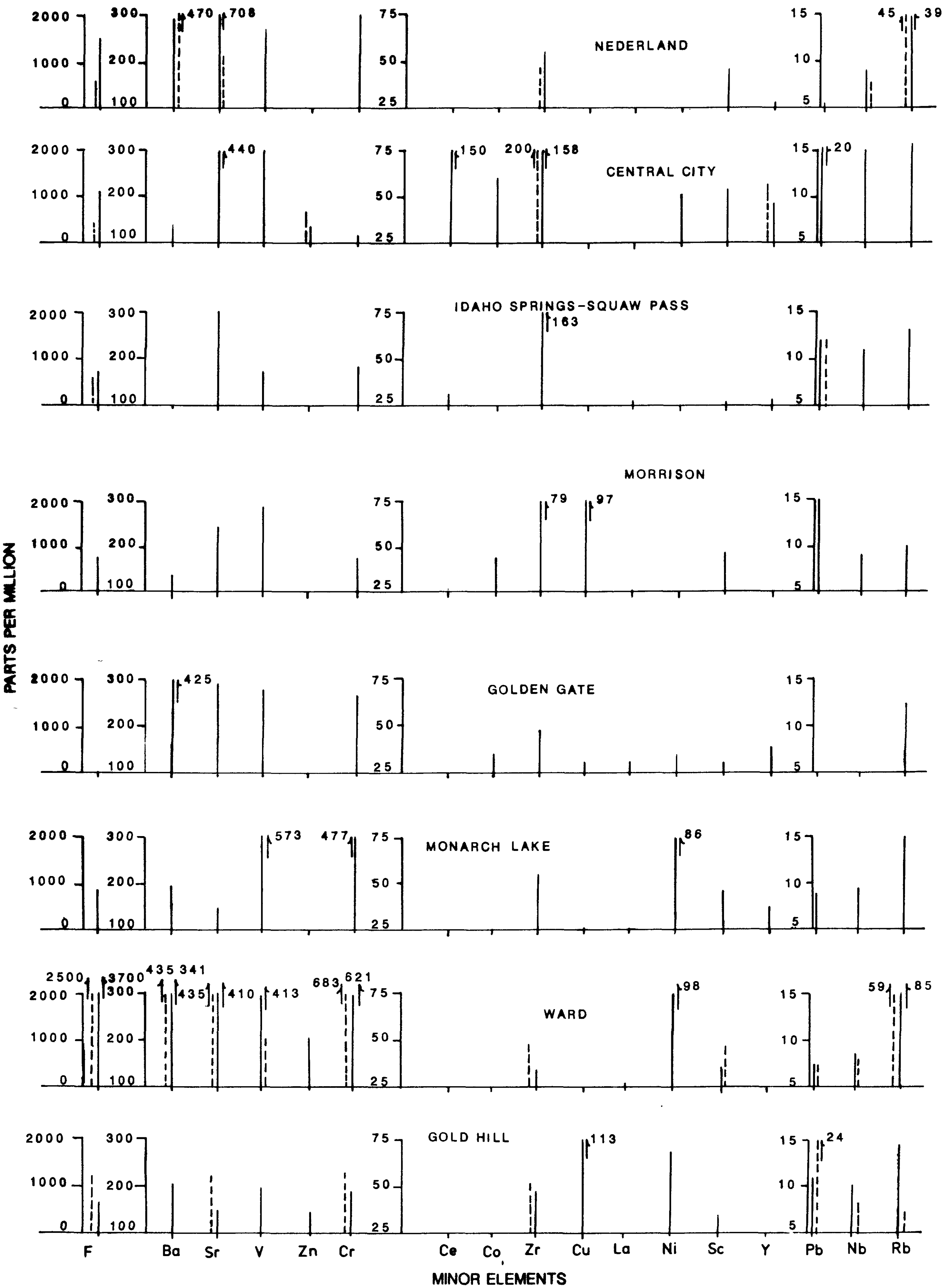

NEDERLAND
CENTRAL CITY
IDAHO SPRINGS-SQUAW PASS
MORRISON
GOLDEN GATE
MONARCH LAKE
WARD
GOLD HILL
PARTS PER MILLION
F
Ba
Sr
V
Zn
Cr
Ce
Co
Zr
Cu
La
Ni
Sc
Y
Pb
Nb
Rb
MINOR ELEMENTS

Figure 31

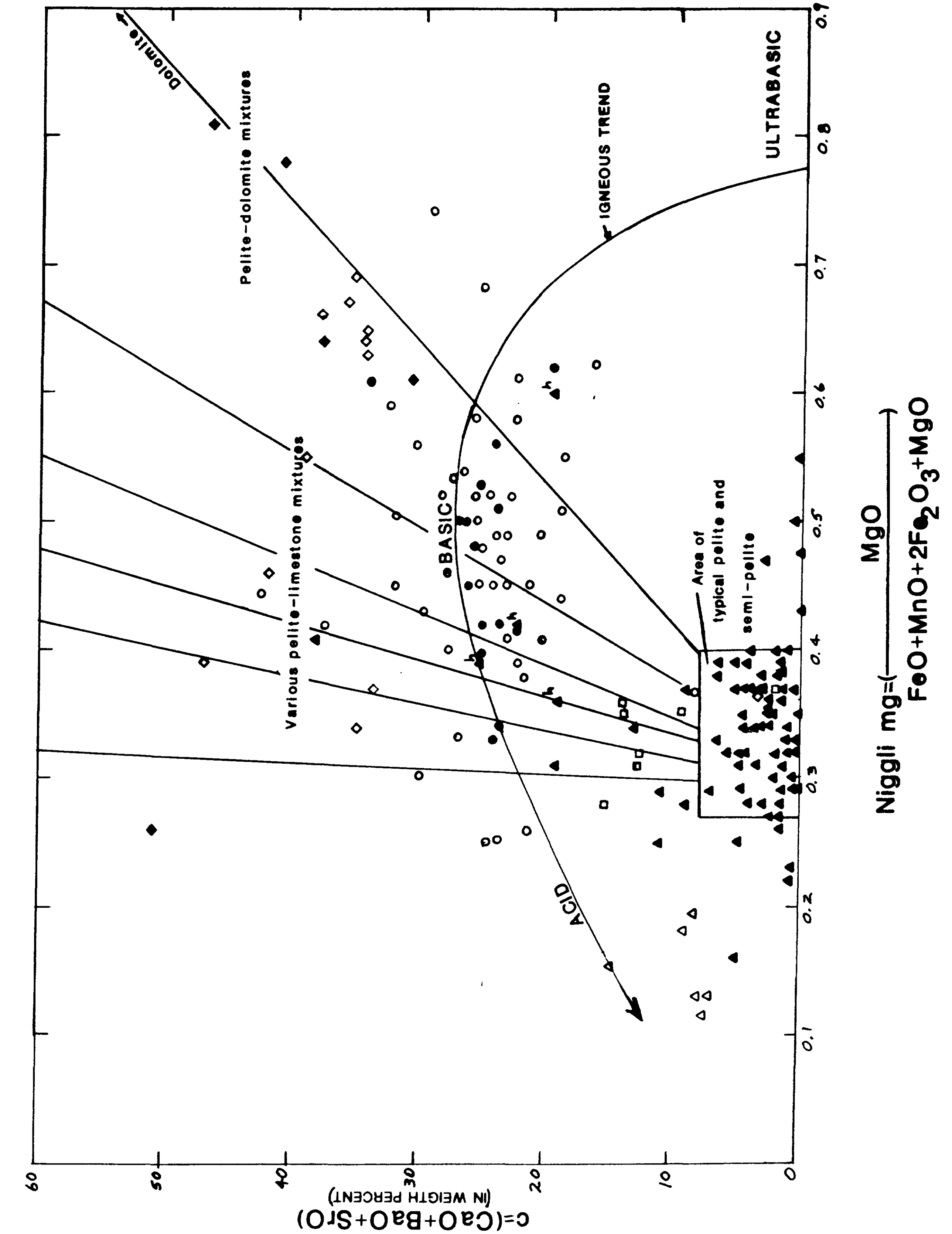



Figure 31.--Niggli- *mg* against *c* diagram after Leake (1964, fig. 1). Plots of central Front Range metamorphic rocks are compared to the igneous trend and field for various sedimentary rocks and rock mixtures. Open circles, hornblende gneiss; filled circles, amphibolite; open diamonds, calc-silicates; filled diamonds, pyroxene-bearing gneiss; open triangle, garnet-magnetite-hornblende-quartz gneiss; filled triangle, sillimanite-biotite gneisses; open squares, biotite-quartz-plagioclase gneiss; filled triangle with "h," varieties of cordierite-magnetite-garnet gneiss containing hornblende.

Figure 32

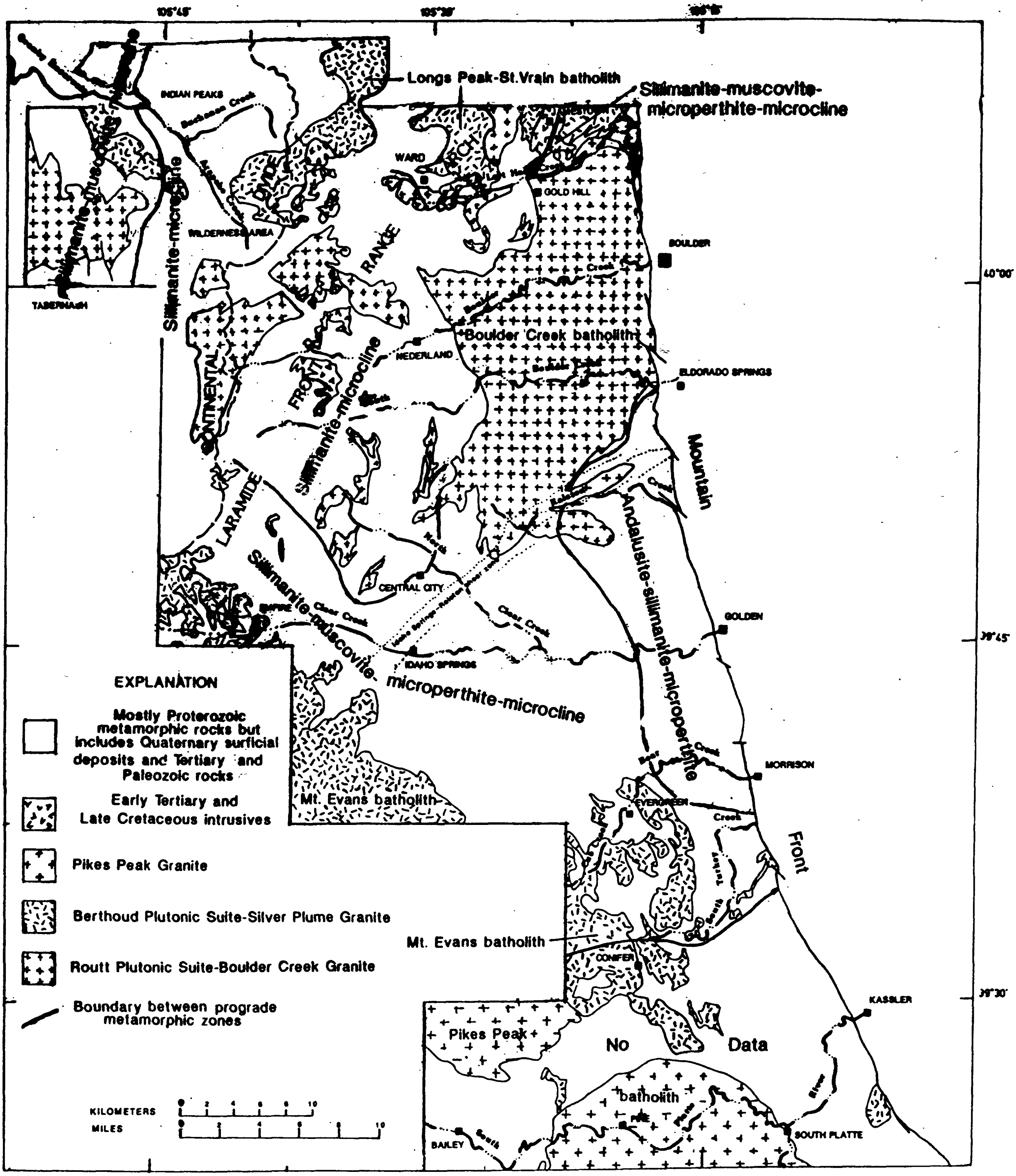



Figure 32.--Prograde metamorphic zones in the central Front Range, Colorado.

**Figure 33**

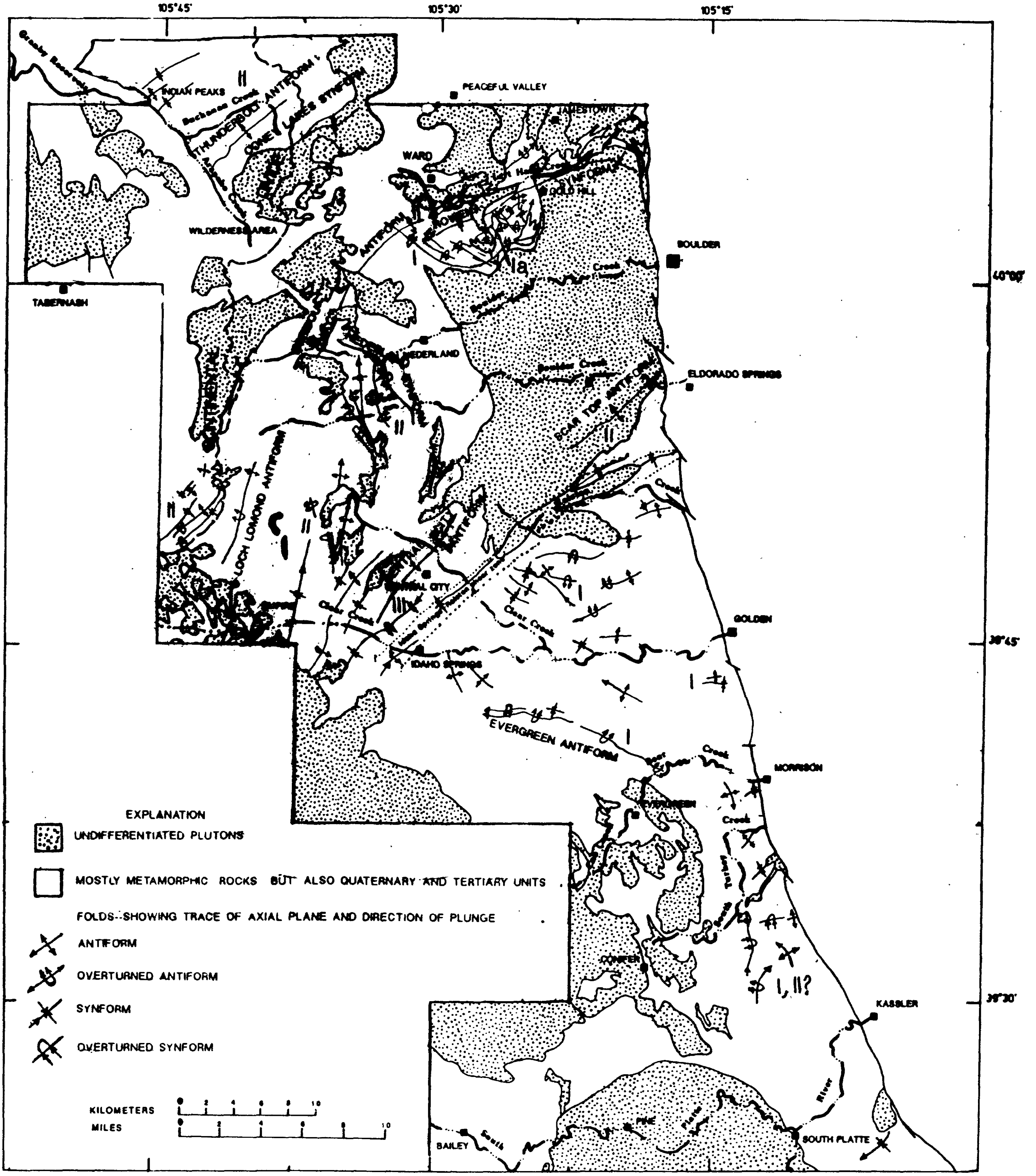



Figure 33.--Proterozoic fold patterns in central Front Range Proterozoic rocks.
Period I--the oldest, west-northwest-trending folds; Period Ia--north-northwest fold set younger than I but older than II. Period II--north-northeast-trending folds; Period III--the youngest folds, in and along the Idaho Springs-Ralston shear zone.

# APPENDIX I

## TABLES 1-18

## MODAL ANALYSES OF EARLY PROTEROZOIC METAMORPHIC ROCKS IN THE CENTRAL FRONT RANGE

[Sample numbers or map locality numbers with the following prefixes indicate the quadrangle or wilderness area where the sample was collected: AP, Allens Park; C, Conifer; CC, D, EWT, JG, Central City; E, S-Sp, DS, Evergreen; EP, East Portal; GG, Golden Gate; GH, Gold Hill; SP, Squaw Pass; IH, Indian Hills; IS, Idaho Springs; P, Pine; R, S-SP, Indian Peaks Wilderness area; J, Black Hawk; M, Morrison; ML, Monarch Lake; N, Nederland; RB, Ralston Buttes; SL, Strawberry Lake; T, Tungsten; W, WC, Ward.]

**Table 1.** Modes (volume percent) for biotite gneiss, central Front Range, Colorado.
(--, not found; Tr, trace)

| Locality No. | 160 | 165 | 287 | 295 | 209 | 214 | 215 | 221 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | T-74 | T-141 | J-174 | J-452 | N1a-64 | N104-64 | N118a-64 | N155-64 |
| K-feldspar | 32.4 | 8.3 | 7.0 | -- | 18.6 | Tr | 7.8 | 10.7 |
| Plagioclase | 20.9 | 22.1 | 6.1 | 8.4 | 26.4 | 19.8 | 45.6 | 26.2 |
| Quartz | 35.0 | 48.8 | 52.2 | 38.2 | 36.4 | 72.0 | 44.0 | 45.8 |
| Biotite | 8.0 | 17.6 | 31.3 | 21.1 | 15.7 | 5.8 | 4 | [1]10.0 |
| Opaque minerals | .4 | 1.6 | .1 | 1.1 | 2.6 | 1.6 | 1.5 | 1.0 |
| Zircon | .3 | Tr | .1 | Tr | Tr | .2 | Tr | Tr |
| Muscovite-sericite[3] | 3.0 | 1.6 | 3.2 | 30.9 | -- | -- | .1 | 5.4 |
| Apatite | -- | -- | -- | Tr | .3 | -- | Tr | -- |
| Chlorite | -- | -- | -- | -- | Tr | .6 | .6 | .9 |
| Sphene | -- | -- | -- | -- | -- | -- | Tr | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Calcite | -- | -- | -- | -- | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- |
| Corundum | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | .3 | -- | -- | -- | -- |

| Locality No. | 224 | 236 | 238 | 242 | 124 | 130 | 131 | 133 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N211-64 | N399-64 | N428-64 | N583-64 | W81-70 | W181-70 | W189-70 | W200-70 |
| K-feldspar | 22. | 2.0 | 30.2 | .2 | 18.2 | -- | 1.5 | 25.7 |
| Plagioclase | 18. | 29.9 | 22.4 | 30.6 | 23.1 | 58.3 | 47.8 | 21.8 |
| Quartz | 49. | 58.4 | 23.9 | 50.7 | 49.6 | 6.7 | .6 | 30.2 |
| Biotite | [1]10. | 7.3 | 13.8 | 13.2 | 7.3 | 26.6 | 37.2 | 18.9 |
| Opaque minerals | .4 | 2.0 | 1.6 | 1.0 | .3 | 6.0 | 7.9 | 2.8 |
| Zircon | Tr | .3 | .2 | Tr | .1 | .2 | Tr | Tr |
| Muscovite-sericite[3] | -- | Tr | 6.6 | 4.2 | .7 | 1.9 | 4.3 | -- |
| Apatite | -- | Tr | 1.3 | -- | .1 | .3 | -- | .3 |
| Chlorite | .6 | Tr | -- | .1 | .6 | -- | -- | -- |
| Sphene | -- | Tr | -- | -- | -- | -- | -- | .2 |
| Xenotime-monazite | -- | Tr | Tr | -- | -- | -- | -- | -- |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | .1 | -- | -- | -- | -- | -- | .1 |
| Epidote | -- | Tr | -- | -- | Tr | -- | .3 | -- |
| Corundum | -- | -- | -- | -- | -- | Tr | .4 | -- |
| Spinel | -- | -- | -- | -- | -- | -- | Tr | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 134 | 135 | 137 | 138 | 139 | 143 | 145 | 97 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W213-70 | W232-70 | W241-70 | W242b-70 | W246-70 | W270-70 | W275a-70 | W150-71 |
| K-feldspar | .2 | 47.3 | .3 | -- | 1.1 | 8.4 | 2.7 | 2.3 |
| Plagioclase | 15.5 | 23.1 | 48.4 | 29. | 33.6 | 35.4 | 40.4 | 82.8 |
| Quartz | 55.1 | 24.8 | 31.2 | 30. | 35.9 | 27.0 | 39.3 | .9 |
| Biotite | 13.3 | 2.8 | 18.4 | 27. | [1]19.2 | 28.6 | 16.3 | 10.8 |
| Opaque minerals | 1.7 | .7 | 1.7 | 1. | .2 | .1 | 1.0 | 2.7 |
| Zircon | Tr | Tr | Tr | Tr | Tr | -- | Tr | Tr |
| Muscovite-sericite[3] | 13.8 | .2 | Tr | 13. | 1.0 | .5 | .4 | -- |
| Apatite | -- | .3 | Tr | -- | -- | Tr | -- | .3 |
| Chlorite | .4 | .8 | -- | -- | -- | Tr | Tr | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | .1 |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | -- | Tr |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | .1 |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- |
| Corundum | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 1**. Modes (volume percent) for biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 107 | 109 | 82 | 83 | 353 | 354 | 359 | 360 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W252a-71 | W257-71 | W56-73 | W64-73 | RB3-80 | RB4-80 | RB9a-80 | RB10-80 |
| K-feldspar ----------- | -- | 2.5 | -- | -- | -- | -- | 3.3 | 19.2 |
| Plagioclase --------- | 62. | 30.6 | 40.3 | 18. | .5 | 4.1 | 37.2 | 24.2 |
| Quartz---------------- | 14. | 51.4 | 39.5 | 51. | 58.4 | 56.3 | 43.7 | 37.5 |
| Biotite---------------- | 18. | 12.9 | 18.9 | 31. | 19.0 | 17.9 | [2]13.4 | 13.9 |
| Opaque minerals --- | 5. | 1.3 | 1.0 | -- | .7 | 1.8 | 1 | Tr |
| Zircon ---------------- | Tr | Tr | -- | Tr | Tr | Tr | Tr | .1 |
| Muscovite-sericite[3]-- | -- | 1.3 | -- | -- | 2.1 | 19.6 | -- | 3.7 |
| Apatite----------------- | 1.0 | -- | -- | -- | Tr | .3 | .1 | Tr |
| Chlorite -------------- | Tr | -- | -- | -- | -- | Tr | -- | -- |
| Sphene --------------- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | Tr | .1 | -- |
| Calcite --------------- | -- | -- | -- | -- | -- | -- | 1.2 | .1 |
| Allanite -------------- | Tr | -- | -- | -- | -- | -- | .1 | Tr |
| Epidote--------------- | Tr | -- | .3 | -- | -- | -- | .8 | 1.3 |
| Corundum ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel ---------------- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline---------- | -- | -- | -- | -- | .3 | Tr | -- | -- |

| Locality No. --------- | 277 | 284 | 314 | 3 | 421 | 424 | 425 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | 1S1-80 | 1S8-80 | GG-5 | M-57 | C4-87 | P1-87 | P2-87 |
| K-feldspar ----------- | 19.0 | 1.5 | 2.5 | .3 | 15.5 | 14.1 | 6.0 |
| Plagioclase --------- | 30.5 | 30.3 | 30.3 | 49.8 | 49.7 | 40.4 | 46.9 |
| Quartz---------------- | 32.6 | 52.4 | 38.5 | 31.1 | 17.9 | 31.7 | 30.5 |
| Biotite---------------- | 15.0 | 11.9 | 20.5 | 17.3 | 14.7 | 12.8 | 14.5 |
| Opaque minerals --- | 1.8 | .8 | Tr | .1 | Tr | .6 | 1.0 |
| Zircon ---------------- | Tr | .3 | Tr | .1 | Tr | Tr | Tr |
| Muscovite-sericite[3] | -- | 2.1 | 6.1 | .6 | 2.2 | .1 | .8 |
| Apatite --------------- | .8 | -- | .3 | .3 | Tr | .3 | .3 |
| Chlorite -------------- | -- | .7 | -- | -- | -- | -- | -- |
| Sphene --------------- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | -- | -- | Tr | Tr | Tr |
| Calcite --------------- | -- | -- | 1.1 | .4 | -- | -- | -- |
| Allanite -------------- | .3 | -- | .3 | -- | -- | -- | -- |
| Epidote--------------- | Tr | -- | .4 | -- | -- | -- | -- |
| Corundum ----------- | -- | -- | -- | -- | -- | -- | -- |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline---------- | -- | -- | -- | -- | -- | -- | -- |

[1]Includes traces of rutile.

[2]Includes 0.1 percent hornblende.

[3]Muscovite-sericite is mostly sericite after plagioclase.

**Table 2.** Modes (volume percent) for garnet-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 266 | 211 | 215 | 231 | 233 | 247 | 248 | 251 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N-381 | N40a-64 | N118-64 | N360-64 | N363a-64 | N636a-64 | N656-64 | N705-64 |
| K-feldspar | 1.0 | 1.6 | 0.9 | 41.1 | 18.5 | 24.9 | 36.6 | 4.8 |
| Plagioclase | 25.0 | 35.3 | 59.0 | 16.8 | 21.7 | 20.9 | 20.4 | 22.7 |
| Quartz | 51.4 | 46.4 | 31.0 | 23.7 | 45.3 | 37.7 | 38.7 | 60.0 |
| Biotite | 15.6 | 14.8 | 6.0 | 17.0 | 10.0 | 13.2 | 3.1 | 8.1 |
| Garnet | .2 | 1.8 | Tr | Tr | 2.3 | 1.8 | 3 | 4.0 |
| Opaque minerals | .8 | .1 | 2.8 | .9 | 1.4 | .7 | .4 | .1 |
| Zircon | Tr | Tr | .1 | Tr | Tr | Tr | -- | Tr |
| Apatite | -- | Tr | .1 | -- | -- | -- | -- | -- |
| Rutile | -- | Tr | -- | -- | -- | Tr | -- | -- |
| Allanite | -- | -- | Tr | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | -- | .1 | -- | -- | .5 | .1 | .3 |
| Andalusite | -- | -- | -- | Tr | -- | -- | -- | -- |
| Calcite | -- | -- | Tr | Tr | .1 | -- | -- | -- |
| Chlorite | -- | -- | -- | -- | .7 | .3 | .4 | -- |
| Epidote | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende | -- | -- | -- | -- | -- | -- | -- | |
| Sphene | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 121 | 81 | 79 | 303 | 303 | 304 | 305 | 315 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W12a-70 | W20-73 | W15-1-73 | ML8-1 | ML8a-1 | ML-9 | ML-10 | IH-1-80 |
| K-feldspar | -- | 12.2 | -- | -- | 1.9 | -- | 1.1 | 9.4 |
| Plagioclase | 31.7 | 51.4 | 33.8 | 60.0 | 27.2 | 4.6 | 34.5 | 21.3 |
| Quartz | 49.3 | 25.2 | 38.0 | 29.8 | 28.1 | 71.3 | 34.5 | 21.7 |
| Biotite | 15.5 | 8.6 | 22.1 | 2.9 | 21.7 | 19.3 | 22.4 | 30.3 |
| Garnet | 3.0 | 2.0 | .2 | 6.4 | 17.7 | 4.3 | 6.1 | 2.7 |
| Opaque minerals | .5 | .3 | .9 | -- | .3 | .1 | -- | 2 7 |
| Zircon | Tr | Tr | -- | -- | -- | Tr | Tr | Tr |
| Apatite | -- | -- | .4 | -- | .2 | -- | Tr | Tr |
| Rutile | -- | -- | -- | -- | .4 | -- | -- | -- |
| Allanite | -- | -- | Tr | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | .3 | 4.1 | -- | .4 | -- | .5 | 11.9 |
| Andalusite | -- | -- | -- | -- | -- | .4 | -- | -- |
| Calcite | -- | -- | -- | -- | -- | -- | .4 | Tr |
| Chlorite | Tr | -- | .1 | .9 | 2.0 | -- | .5 | -- |
| Epidote | -- | Tr | .4 | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | Tr | -- | .1 | -- | -- | Tr |
| Hornblende | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 2.**--Modes (volume percent) for garnet-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 320 | 281 | 359 | 360 | 365 | 391 | 423 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | IH-6-80 | IS5-80 | RB9-80 | RB10a-80 | M-74 | M-77 | C6-87 |
| K-feldspar ----------- | 29.5 | 0.5 | 4.8 | 8.0 | 0.1 | 8.1 | 5.1 |
| Plagioclase----------- | 13.1 | 38.8 | 35.0 | 21.0 | 41.3 | 26.6 | 40.8 |
| Quartz ---------------- | 40.0 | 25.9 | 45.4 | 49.6 | 44.0 | 45.6 | 19.7 |
| Biotite ---------------- | 13.0 | [illegible] | 9.5 | 12.0 | 11.2 | 10.1 | 34.1 |
| Garnet ---------------- | Tr | Tr | .5 | 2.0 | 2.1 | Tr | .2 |
| Opaque minerals---- | 1.0 | 1.3 | .1 | Tr | .6 | 1.3 | Tr |
| Zircon ---------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr |
| Apatite --------------- | Tr | .2 | -- | -- | Tr | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | Tr | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] - | 2.0 | 15.0 | 4.7 | Tr | .6 | 8.3 | .1 |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- |
| Calcite---------------- | -- | .4 | -- | 1.5 | -- | -- | -- |
| Chlorite -------------- | -- | -- | -- | -- | .1 | -- | -- |
| Epidote--------------- | .3 | -- | -- | 5.2 | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | Tr |
| Hornblende ---------- | .7 | -- | -- | .7 | -- | -- | -- |
| Sphene --------------- | .4 | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | Tr | -- | -- | -- | -- | -- | -- |

[1]Includes some chlorite.

[2]Muscovite-sericite mostly retrograde after plagioclase.

**Table 3.** Modes (volume percent) for layers in a metagabbro dike; country rock is hornblende gneiss.

(--, not found; Tr, trace)

| | Host Rock | Altered Mafic Dike | | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. --------- | 219 | 219 | 219 | 219 | 219 | 219 | 219 |
| Sample No. ---------- | N132-64 | N132a-64 | N132b-64 | N132c-64 | N132d-64 | N132e-64 | N132f-64 |
| Plagioclase----------- | 31.3 | 8.6 | 39.2 | 13. | 4.4 | 4.0 | 4.5 |
| Quartz--------------- | 15.7 | 23.0 | 14.1 | 32. | 13.5 | 23.8 | 8.2 |
| Hornblende --------- | 44.4 | -- | -- | 16. | -- | -- | -- |
| Gedrite -------------- | -- | 18.4 | [1]24.4 | -- | [2]27.7 | 3.8 | 18.0 |
| Hypersthene --------- | -- | .4 | -- | -- | -- | -- | 13.8 |
| Pyroxene-(Ortho) --- | .5 | -- | -- | 2. | -- | -- | -- |
| Opaque minerals---- | 7.3 | 3.5 | 7.2 | .5 | 3.8 | 1.6 | 3.9 |
| Biotite--------------- | .3 | 1.6 | 4.2 | -- | 16.0 | [3]33.6 | [3]15.4 |
| Cordierite------------ | -- | -- | 1.6 | -- | 27.1 | -- | 24.0 |
| Apatite -------------- | .1 | .2 | .2 | Tr | .1 | -- | -- |
| Zircon --------------- | Tr | Tr | -- | Tr | Tr | Tr | Tr |
| Epidote-------------- | -- | -- | -- | 36. | -- | -- | -- |
| Sphene -------------- | .4 | -- | -- | .5 | -- | -- | -- |
| Garnet--------------- | -- | 44.1 | 9.1 | -- | -- | 33.2 | 4.2 |
| Spinel --------------- | -- | Tr | -- | -- | -- | -- | -- |
| Sericite-------------- | -- | -- | -- | -- | 7.4 | -- | 8.0 |

[1]Tremolite-actinolite mantles gedrite.
[2]Includes traces of cummingtonite.
[3]Includes traces of rutile.

**Table 4.** Modes (volume percent) for cordierite-biotite gneiss and cordierite-garnet-biotite gneiss ± staurolite, central Front Range, Colorado.

(--, not found; Tr, trace)

| | Cordierite-biotite gneiss | | | | Cordierite-garnet-biotite gneiss ± staurolite | | |
|---|---|---|---|---|---|---|---|
| Locality No. | 10 | 111 | 80 | Locality No. | 230 | 308 | 314 |
| Sample No. | GH232-76 | W259b-71 | W18-73 | Sample No. | N340a-64 | ML-14 | GG5a-80 |
| K-feldspar | 0.9 | 1.6 | 23.1 | K-feldspar | 6.1 | 3.4 | 0.5 |
| Plagioclase | 5.8 | 23.6 | 12.7 | Plagioclase | 4.8 | 25.5 | 13.8 |
| Quartz | 64.0 | 49.9 | 42.3 | Quartz | 59.3 | 49.3 | 63.8 |
| Cordierite | 17.3 | .5 | [1]10.5 | Cordierite | 1.9 | [1]1.5 | 2.3 |
| Biotite | 12.0 | 14.8 | 7.4 | Biotite | 19.5 | Tr | 11.5 |
| Opaque minerals | Tr | 1.0 | 1.4 | Opaque minerals | .3 | 1.0 | .3 |
| Apatite | -- | -- | Tr | Apatite | -- | -- | Tr |
| Zircon | Tr | .3 | Tr | Zircon | Tr | Tr | Tr |
| Xenotime-monazite | Tr | -- | Tr | Xenotime-monazite | -- | .3 | -- |
| Muscovite-sericite[2] | -- | 6.9 | 2.4 | Muscovite-sericite[2] | 5.2 | .1 | .5 |
| Andalusite | -- | .1 | -- | Chlorite | 2.8 | 17.3 | .5 |
| Calcite | -- | -- | .2 | Epidote | -- | 1.5 | -- |
| Isotropic mass | -- | 1.3 | -- | Garnet | .1 | .1 | 6.8 |
| | | | | Rutile | Tr | Tr | -- |
| | | | | Staurolite | -- | -- | Tr |

[1]Includes some pinnite.

[2]Muscovite-sericite mostly retrograde after plagioclase.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. --------- | 161 | 163 | 164 | 167 | 168 | 169 | 170 | 172 | 173 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | T-78 | T-86 | T-109 | T-153 | T-155 | T-163 | T-172 | T-196 | T-208 |
| K-feldspar------------ | 13.9 | 12.9 | 24.0 | 0.9 | 7.9 | 15.5 | 8.2 | 2.5 | 18.3 |
| Plagioclase----------- | 14.4 | 2.5 | 24.0 | 1.2 | 11.4 | 21.1 | 13.5 | 11.0 | 15.3 |
| Quartz ---------------- | 55.4 | 48.2 | 36.6 | 42.0 | 19.4 | 48.5 | 61.9 | 56.9 | 52.5 |
| Biotite ---------------- | 12.6 | 20.6 | 12.9 | 30.7 | 26.6 | 12.2 | 13.2 | 19.6 | 10.9 |
| Sillimanite ----------- | 1.1 | 12.6 | Tr | 21.0 | 27.8 | 2.0 | 1.8 | 5.0 | .2 |
| Opaque minerals---- | 2.5 | 1.3 | .9 | 1.6 | 1.7 | .3 | 1.0 | .5 | 1.9 |
| Zircon ---------------- | Tr | .2 | Tr | .2 | Tr | Tr | .2 | Tr | .2 |
| Muscovite-sericite[7] - | -- | -- | 1.6 | 2.4 | 5.2 | .4 | .2 | 3.9 | -- |
| Chlorite -------------- | .1 | -- | -- | -- | -- | -- | -- | .6 | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | -- | Tr | -- | Tr | -- | Tr | -- | Tr |

| Locality No. --------- | 175 | 176 | 179 | 180 | 182 | 183 | 184 | 213 | 214 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | T-230 | T-248 | T-326 | T-333 | T-364 | T-401 | T-414 | N87-64 | N104a-64 |
| K-feldspar------------ | .2 | .7 | 7.4 | 3.7 | Tr | -- | 2.4 | 35.0 | 5.7 |
| Plagioclase----------- | 18.4 | .7 | 1.8 | 14.0 | 30.3 | 3.7 | 6.4 | 11.8 | 22.9 |
| Quartz ---------------- | 34.1 | 36.7 | 35.9 | 45.9 | 52.9 | 54.5 | 62.7 | 24.5 | 32.4 |
| Biotite ---------------- | 41.5 | 29.5 | 32.6 | 23.6 | 13.6 | 30.5 | 21.4 | 14.1 | 17.2 |
| Sillimanite ----------- | .6 | 27.1 | 16.3 | 11.4 | Tr | 8.7 | 6.3 | 10.3 | 3.5 |
| Opaque minerals---- | 2.5 | 2.7 | 3.7 | .8 | 1.4 | 1.0 | .5 | 4.1 | 3.1 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | .1 | .2 | Tr | .2 | .1 |
| Muscovite-sericite[7] - | 1.8 | 2.6 | 2.3 | .6 | 1.7 | 1.4 | .3 | -- | 12.5 |
| Chlorite -------------- | -- | -- | -- | -- | -- | -- | -- | -- | 2.2 |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | .4 |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | .9 | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | -- | Tr | -- | -- | -- | Tr | Tr |

| Locality No. --------- | 225 | 241 | 185 | 117 | 126 | 132 | 136 | 138 | 140 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | N225a-64 | N555-64 | N18-65 | WC29-70 | W92-70 | W190-70 | W234a-70 | W242a-70 | W250-70 |
| K-feldspar------------ | 7.1 | 2.5 | -- | -- | 1. | 23.2 | 13.2 | 0.1 | -- |
| Plagioclase----------- | 20.6 | [1]19.4 | [2]25.0 | 5.7 | 3. | 20.4 | 19.5 | 42.3 | 2.9 |
| Quartz ---------------- | 48.1 | 69.7 | 37.3 | 64.5 | 20. | 23.2 | 23.0 | 8.3 | 44.8 |
| Biotite ---------------- | 9.9 | 3.6 | 32.5 | 17.6 | 35. | 20.0 | 14.2 | 36.9 | 11.3 |
| Sillimanite ----------- | 1.3 | Tr | 1.0 | 9.3 | 37. | 1.0 | .3 | .2 | 30.2 |
| Opaque minerals---- | 1.0 | 1.4 | Tr | 2.3 | 3. | .2 | 4.4 | 2.4 | 3.8 |
| Zircon ---------------- | .2 | Tr | Tr | .1 | Tr | -- | -- | .1 | Tr |
| Muscovite-sericite[7] - | 11.1 | 1.0 | -- | .5 | 1. | 12.0 | 19.0 | 9.5 | 7.0 |
| Chlorite -------------- | .5 | 2.4 | -- | -- | Tr | -- | -- | .2 | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Andalusite ----------- | .2 | -- | -- | -- | -- | -- | 6.4 | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | Tr | Tr | -- | Tr | -- | -- | -- |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. | 144 | 148 | 89 | 90 | 92 | 94 | 96 | 101 | 106 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W273-70 | W293-70 | W48-71 | W66-71 | W71-71 | W92b-71 | W105-71 | W172-71 | W248-71 |
| K-feldspar | 35.7 | -- | Tr | 3. | Tr | 2. | 1.6 | .6 | -- |
| Plagioclase | 20.3 | 18.3 | 1. | 4. | 7. | 22. | 44.7 | 17.5 | 19.8 |
| Quartz | 26.6 | 52.3 | 27 | 26. | 28. | 39. | [3]8.7 | 56.0 | 1.8 |
| Biotite | 14.0 | 9.1 | 8. | 7. | 1. | 14. | 40.9 | 24.4 | 41.3 |
| Sillimanite | .1 | Tr | 9. | 7. | 1. | 9. | Tr | Tr | 32.1 |
| Opaque minerals | .5 | 2.1 | 4. | 4. | 4. | 3. | [5]3.5 | 1.5 | 3.4 |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] | 2.8 | 16.2 | 43. | 42. | 54. | 11. | .3 | -- | 1.6 |
| Chlorite | -- | 2.0 | 8. | 7. | 5. | -- | -- | -- | Tr |
| Rutile | -- | -- | Tr | Tr | Tr | -- | -- | -- | Tr |
| Andalusite | -- | -- | Tr | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 113 | 84 | 78 | 79 | 73 | 65 | 67 | 54 | 55 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W265-71 | W18-72 | W12-1-73 | W15-2-73 | GH47-71 | GH32-72 | GH54-72 | GH162-73 | GH168-73 |
| K-feldspar | 12.0 | 11.4 | 10.4 | -- | 16.5 | 9.0 | 35.7 | 3.6 | 8.8 |
| Plagioclase | [1]22.0 | 8.2 | 39.1 | [1]45.3 | 4.2 | 9.6 | 30.2 | .9 | 5.5 |
| Quartz | 27.4 | 40.7 | 38.7 | 18.6 | 20.7 | 60.8 | 14.5 | 34.2 | 55.4 |
| Biotite | 14.0 | 25.1 | [4]6.4 | [4]33.5 | 23.5 | 15.9 | 8.4 | 29.1 | 16.5 |
| Sillimanite | 1.3 | 13.6 | .5 | .1 | 31.4 | 4.0 | 2.9 | 25.5 | 11.1 |
| Opaque minerals | [6]3.5 | [6].8 | [6].9 | 1.1 | 3.6 | .7 | [6].9 | 4.5 | 2.6 |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | -- | Tr | Tr |
| Muscovite-sericite[7] | 16.5 | .1 | 3.6 | .6 | .1 | -- | 7.3 | 2.2 | .1 |
| Chlorite | 3.3 | .1 | .2 | -- | -- | -- | -- | -- | -- |
| Rutile | Tr | -- | -- | -- | -- | -- | Tr | -- | -- |
| Andalusite | Tr | -- | .2 | -- | -- | -- | .1 | Tr | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | .5 | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | Tr | Tr | Tr | -- | Tr | Tr | Tr |

| Locality No. | 39 | 43 | 52 | 53 | 372 | 19 | 20 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | GH69-74 | GH158-74 | GH412-74 | GH-413-74 | GHB37-75 | GH153-75 | GH172-75 | GH183-75 | GH192-75 |
| K-feldspar | -- | -- | -- | 13.4 | -- | -- | 14.3 | 7.7 | 22.9 |
| Plagioclase | 22. | 3.7 | 1.9 | 16.7 | 8.7 | 2.2 | 15.9 | 19.2 | 21.4 |
| Quartz | -- | 24.8 | 24.5 | 57.8 | 23.6 | 43.5 | 38.2 | 51.6 | 30.6 |
| Biotite | 17. | 46.0 | 40.5 | 10.0 | 43.3 | 27.5 | 14.9 | 13.6 | 10.6 |
| Sillimanite | 16. | 24.9 | 31.6 | Tr | 16.6 | 22.5 | 10.0 | 1.6 | .9 |
| Opaque minerals | 3. | .3 | 1.0 | 1.1 | .6 | 2.8 | 2.3 | Tr | 1.1 |
| Zircon | Tr | Tr | -- | Tr | -- | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] | 42. | .3 | .5 | -- | 5.7 | 1.5 | .8 | 6.1 | 12.4 |
| Chlorite | -- | -- | -- | 1.0 | 1.5 | -- | 3.5 | .2 | .1 |
| Rutile | -- | -- | -- | Tr | -- | -- | Tr | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | Tr | -- | -- | Tr |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 25 | 26 | 29 | 30 | 6 | 8 | 9 | 11 | 271 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | GH233-75 | GH242-75 | GH305-75 | GH306-75 | GH3-76 | GH142-76 | GH204a-76 | GH262-76 | SP2-80 |
| K-feldspar----------- | -- | -- | -- | -- | 11.2 | 1.1 | -- | 5.0 | 8.5 |
| Plagioclase---------- | 21.9 | 4.8 | .4 | 16.9 | 15.9 | .1 | 21.7 | 19.5 | 15.4 |
| Quartz --------------- | 32.4 | 43.7 | 13.5 | 42.5 | 35.7 | 21.6 | 57.8 | 42.6 | 58.6 |
| Biotite --------------- | 8.1 | 25.9 | 47.7 | 16.0 | 26.6 | 51.5 | 15.0 | 25.0 | 14.1 |
| Sillimanite ---------- | .1 | 23.6 | 26.7 | 13.0 | 9.3 | 18.8 | .1 | 1.8 | Tr |
| Opaque minerals---- | .7 | 1.7 | 1.4 | .3 | .5 | 1.1 | .5 | Tr | .4 |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] - | 36.6 | .3 | 10.2 | 11.0 | .8 | 5.8 | 4.9 | 6.1 | 3.0 |
| Chlorite ------------- | .2 | -- | -- | .3 | -- | -- | -- | -- | -- |
| Rutile ---------------- | -- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline --------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite--------------- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |

| Locality No. --------- | 272 | 273 | 274 | 275 | 276 | 278 | 278 | 280 | 281 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS2a-80 | IS4-80 | IS5a-80 |
| K-feldspar----------- | 2. | 14.6 | 16.3 | 12.0 | 4.9 | 1.8 | 9.9 | 7.2 | .2 |
| Plagioclase---------- | 8. | 14.8 | 6.8 | 17.4 | 13.8 | 16.4 | 30.4 | 8.7 | 6.1 |
| Quartz --------------- | 28. | 19.5 | 24.5 | 51.6 | 40.4 | 36.4 | 38.6 | 48.9 | 79.1 |
| Biotite --------------- | 22. | 25.0 | 27.7 | 16.8 | 14.4 | 24.3 | 13.9 | 20.4 | 2.4 |
| Sillimanite ---------- | 14. | 9.4 | 21.0 | Tr | 14.5 | 16.5 | 3.1 | 11.7 | 1.2 |
| Opaque minerals---- | Tr | 1.8 | 1.3 | 1.1 | 1.2 | 1.4 | .1 | .8 | 1.5 |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] - | 26. | 14.9 | 2.4 | 1.1 | 10.8 | 3.2 | 4.0 | 2.3 | 8.8 |
| Chlorite ------------- | Tr | -- | -- | -- | Tr | -- | -- | -- | .1 |
| Rutile ---------------- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline --------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite--------------- | -- | Tr | Tr | -- | -- | -- | -- | -- | Tr |
| Xenotime-monazite- | -- | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |

| Locality No. --------- | 282 | 285 | 317 | 318 | 319 | 351 | 352 | 355 | 356 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | IS6-80 | IS9-80 | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 |
| K-feldspar----------- | 0.7 | 5.0 | 7.1 | 5.8 | 2.2 | -- | -- | -- | -- |
| Plagioclase---------- | 38.5 | 32.4 | 18.3 | 22.2 | 7.8 | 2.2 | 8.1 | .3 | 1.5 |
| Quartz --------------- | 46.4 | 36.9 | 48.8 | 61.2 | 62.9 | 52.1 | 49.0 | 45.5 | 43.7 |
| Biotite --------------- | 10.6 | [4]12.4 | 19.9 | -- | 16.3 | 25.4 | 25.7 | 31.0 | 18.5 |
| Sillimanite ---------- | 1.7 | 2.9 | Tr | 3.9 | 5.6 | 11.7 | 7.0 | 15.9 | Tr |
| Opaque minerals---- | .4 | 2.0 | .4 | Tr | Tr | 1.2 | 1.5 | .1 | 1.0 |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | Tr | .1 | Tr | .1 |
| Muscovite-sericite[7] - | 1.5 | 7.4 | 5.5 | 6.0 | 5.2 | 7.4 | 4.0 | 7.2 | 35.0 |
| Chlorite ------------- | .2 | 1.0 | -- | .9 | -- | -- | -- | -- | .1 |
| Rutile ---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | 4.5 | -- | -- |
| Tourmaline --------- | -- | -- | -- | -- | -- | -- | .1 | Tr | Tr |
| Apatite--------------- | Tr | -- | Tr | -- | Tr | Tr | Tr | Tr | -- |
| Xenotime-monazite- | Tr | -- | Tr | Tr | Tr | -- | -- | -- | Tr |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. | 357 | 358 | 4 | 368 | 340 | 289 | 291 | 293 | 294 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | RB7-80 | RB8-80 | M66 | M530b | CC-646 | J-246 | J-282 | J-313 | J-331 |
| K-feldspar | -- | .7 | .3 | -- | 14.3 | -- | 1.4 | 7.3 | 3.7 |
| Plagioclase | 2. | 9.8 | 4.0 | Tr | 5.4 | 25.9 | -- | 3.6 | 19.6 |
| Quartz | 1. | 55.6 | 69.4 | 57. | 31.4 | 51.9 | 50.2 | 21.6 | 56.8 |
| Biotite | 64. | 15.9 | 22.4 | 22. | 32.1 | 15.0 | 29.8 | 24.4 | 13. |
| Sillimanite | 31. | 5.3 | 1.7 | 2. | 16.3 | 1.0 | 16.1 | 8.0 | 1.9 |
| Opaque minerals | 1. | .3 | Tr | Tr | .7 | 2.7 | 1.2 | 1.9 | .9 |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] | 1. | 12.4 | 1.9 | 11. | Tr | 3.5 | 1.3 | 33.2 | 3.2 |
| Chlorite | -- | -- | .3 | 8. | Tr | -- | -- | -- | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | Tr | Tr | Tr | Tr |

| Locality No. | 296 | 297 | 298 | 322 | 418 | 419 | 422 |
|---|---|---|---|---|---|---|---|
| Sample No. | J-455a | J-462a | J-463 | E-1-80 | C1-87 | C2-87 | C5-87 |
| K-feldspar | -- | 0.1 | -- | 7.0 | 8.2 | 15.2 | 15.1 |
| Plagioclase | 4.8 | 10.0 | Tr | 37.9 | 31.2 | 19.7 | 17.6 |
| Quartz | 52.3 | 64.4 | 45.4 | 24.4 | 52.2 | 46.0 | 43.7 |
| Biotite | 16.4 | 5.0 | 12.3 | 23.3 | 6.2 | 13.5 | 14.8 |
| Sillimanite | 1.5 | .1 | Tr | 2.1 | .7 | .3 | 5.5 |
| Opaque minerals | .8 | 3.2 | 1.4 | Tr | .3 | .1 | -- |
| Zircon | Tr | Tr | Tr | Tr | .2 | Tr | .1 |
| Muscovite-sericite[7] | 23.9 | 16.8 | 36.2 | 5.3 | .9 | 5.2 | 2.9 |
| Chlorite | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | .1 | -- | -- | -- | -- | -- |
| Apatite | .3 | .3 | .2 | -- | -- | -- | -- |
| Xenotime-monazite | Tr | -- | Tr | Tr | .1 | Tr | .1 |
| Calcite | -- | -- | -- | -- | -- | -- | .2 (in veins) |

[1]Includes traces of calcite. Locality number 79 has 0.3; 281, 0.6; and 422, 0.2 percent calcite in plagioclase.
[2]All kaolinite.
[3]All corundum; no quartz.
[4]Includes traces of epidote in biotite. Locality numbers 78 and 79 have 0.1 percent and 285, 0.5 percent epidote.
[5]Includes traces of sphene.
[6]Includes traces of green spinel.
[7]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 6.** Modes (volume percent) for sillimanite-biotite gneiss and hornfelsic gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No.--------- | 21 | 22 | 32 | 34 | 14 | 28 |
|---|---|---|---|---|---|---|
| Sample No.---------- | GH175a-75 | GH176-75 | GH339-75 | GH353-75 | GH368-76 | GH-294-75 |
| K-feldspar----------- | -- | 0.1 | -- | 4.9 | -- | -- |
| Plagioclase---------- | 38.4 | 56.3 | 43.9 | 27.3 | 46.0 | 16.6 |
| Quartz -------------- | 26.1 | 21.6 | 28.1 | 47.3 | 30.7 | 29.8 |
| Biotite--------------- | 29.6 | 19.1 | 25.3 | 20.3 | 18.6 | 25.4 |
| | | | | | | |
| Opaque minerals --- | 3.9 | 1.3 | 1.0 | .1 | 3.4 | 2.8 |
| Zircon--------------- | Tr | -- | Tr | Tr | .1 | Tr |
| Muscovite-sericite[2] | .2 | -- | .5 | .1 | -- | .7 |
| Apatite-------------- | 1.0 | .5 | 1.2 | Tr | 1.0 | -- |
| | | | | | | |
| Chlorite------------- | Tr | Tr | -- | Tr | .1 | -- |
| Xenotime-monazite | Tr | -- | Tr | Tr | .1 | Tr |
| Allanite------------- | .1 | -- | -- | -- | -- | -- |
| Epidote ------------- | .7 | 1.1 | -- | -- | -- | -- |
| Sillimanite ---------- | -- | -- | -- | Tr | -- | 11.1 |

[2]Muscovite-sericite mostly a replacement of plagioclase and sillimanite.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 162 | 166 | 171 | 177 | 178 | 373 | 374 | 375 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | T-80 | T-146 | T-180 | T-251 | T-260a | N-24 | N-43 | N-95 |
| K-feldspar | 11.6 | 20.6 | 1.1 | -- | -- | 1.6 | 6.1 | 4.1 |
| Plagioclase | 20.3 | 23.5 | 3.6 | 2.5 | 8.6 | 5.0 | 5.6 | 3.8 |
| Quartz | 44.6 | 37.8 | 34.2 | 22. | 51.9 | 58.7 | 5.6 | 45.9 |
| Biotite | 15.2 | 11.8 | 32.7 | 40. | 30.6 | 19.4 | 14.2 | 30.0 |
| Garnet | Tr | .1 | .5 | 1. | Tr | 4.0 | 10.0 | 6.1 |
| Sillimanite | 7.2 | 4.7 | 25.6 | 34. | 7.6 | 9.2 | 3.5 | 7.7 |
| Opaque minerals | 1.0 | 1.1 | 1.1 | .5 | .1 | 1.4 | Tr | .5 |
| Zircon | Tr | Tr | Tr | Tr | .1 | Tr | Tr | -- |
| Muscovite-sericite[2] | .1 | .4 | 1.2 | -- | 1.1 | .1 | 54.9 | 1.6 |
| Spinel | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | Tr | -- | -- | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | Tr |
| Chlorite | -- | -- | -- | -- | -- | .6 | .1 | .3 |
| Apatite | -- | -- | -- | -- | -- | -- | Tr | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 376 | 377 | 378 | 255 | 379 | 257 | 257 | 380 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N-101 | N-128 | N-132 | N-167 | N-211 | N-223 | N223a | N377a |
| K-feldspar | 24.2 | -- | 19.4 | 10.3 | 26.0 | 2.2 | 24.6 | 2.5 |
| Plagioclase | 5.3 | 3.4 | 12.4 | 25.0 | 12.5 | 11.6 | 10.5 | 6.6 |
| Quartz | 20.4 | 52.0 | 41.5 | 42.8 | 38.7 | 30.6 | 12.9 | 52.6 |
| Biotite | 28.1 | 22.3 | 15.8 | 14.4 | 15.0 | 22.8 | 28.9 | 20.8 |
| Garnet | 6.5 | 12.7 | 6.7 | 2.2 | .4 | 5.1 | 8.7 | 7.2 |
| Sillimanite | 10.6 | 3.4 | .4 | 1.9 | 2.9 | 9.2 | 7.2 | 8.0 |
| Opaque minerals | .4 | Tr | .3 | 1.4 | 1.6 | .5 | Tr | 1.8 |
| Zircon | Tr | Tr | Tr | Tr | Tr | .1 | Tr | .1 |
| Muscovite-sericite[2] | 4.5 | 6.2 | 3.5 | 1.7 | 2.9 | 17.5 | 6.4 | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | Tr | Tr | -- | -- | Tr | Tr | Tr |
| Chlorite | -- | -- | Tr | -- | -- | .4 | .8 | .4 |
| Apatite | -- | -- | -- | .3 | -- | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 381 | 382 | 383 | 384 | 385 | 386 | 250 | 186 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N432-64 | N435-64 | N444-64 | N553-64 | N638-64 | N661-64 | N688-64 | N20a-65 |
| K-feldspar | 6.0 | 12.9 | 1.4 | 2.8 | 11.1 | 19.6 | 4.7 | 9.0 |
| Plagioclase | 8.8 | 13.2 | 30.5 | 14.3 | 23.2 | 11.1 | 20.9 | -- |
| Quartz | 58.1 | 34.6 | 49.4 | 56.8 | 45.7 | 51.3 | 57.8 | 44.7 |
| Biotite | 15.1 | 24.9 | 14.4 | 17.2 | 13.7 | 8.4 | 7.7 | 24.4 |
| Garnet | 4.8 | .5 | 1.7 | 1.8 | 6.0 | 7.7 | 6.2 | 5.2 |
| Sillimanite | 6.4 | 7.8 | 1.4 | 5.5 | Tr | .2 | .5 | 5.2 |
| Opaque minerals | .1 | 1.3 | Tr | .9 | .1 | .2 | 1.0 | 5.4 |
| Zircon | Tr | .1 | Tr | .2 | -- | -- | Tr | Tr |
| Muscovite-sericite[2] | .6 | 3.8 | 1.2 | .2 | Tr | 1.2 | 1.2 | 1.1 |
| Spinel | -- | -- | -- | -- | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | .1 | -- | -- | -- | -- | Tr | -- |
| Chlorite | .1 | .8 | Tr | .3 | .1 | .3 | -- | -- |
| Apatite | -- | -- | -- | -- | .1 | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | 5. |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | Tr | -- | Tr | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. | 188 | 189 | 190 | 191 | 202 | 202 | 203 | 204 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N125-65 | N142a-65 | N143-65 | N144-65 | N335c-65 | N335d-65 | N340-65 | N342-65 |
| K-feldspar | -- | -- | 2.2 | .4 | 22.7 | 11. | 10.8 | 15.0 |
| Plagioclase | -- | 2.4 | 1.7 | 16.6 | 17.0 | 23. | -- | 13.4 |
| Quartz | 15.9 | 57.2 | 55.3 | 18.0 | 47.6 | 50. | 34.0 | 43.8 |
| Biotite | 44.7 | 24.5 | 21.0 | 32.5 | 9.2 | 15. | 31.3 | 15.5 |
| Garnet | 5.9 | 5.3 | 9.8 | 3.1 | 2.2 | Tr | 8.0 | 7.5 |
| Sillimanite | 20.6 | 1.5 | 5.0 | 20.4 | 1.1 | Tr | 14.9 | 4.0 |
| Opaque minerals | 3.1 | Tr | .1 | 1.6 | .2 | Tr | .5 | .8 |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2] | .1 | 9.1 | 4.8 | 7.4 | -- | 1. | .5 | Tr |
| Spinel | Tr | -- | Tr | Tr | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | Tr | -- | -- |
| Rutile | -- | Tr | Tr | -- | -- | Tr | -- | -- |
| Chlorite | -- | -- | .1 | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | Tr |
| Kaolinite | 9.7 | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 205 | 118 | 149 | 152 | 88 | 412 | 413 | 414 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N347-65 | WC31-70 | W295-70 | W321a-70 | W41-71 | SL4-84 | SL5-84 | SL6-84 |
| K-feldspar | 4.9 | 0.2 | 1. | 4.3 | 5. | 3.6 | 6.4 | 18.3 |
| Plagioclase | 4.6 | 6.5 | 6. | 2.6 | 4. | 2.4 | .6 | 14.1 |
| Quartz | 58.0 | 41.0 | 19. | 70.8 | 43. | 59.5 | 33.3 | 36.8 |
| Biotite | 10.4 | 26.1 | 15. | 12.7 | 10. | 14.8 | 28.3 | 17.3 |
| Garnet | 10.8 | .7 | 4. | Tr | Tr | 7.3 | 5.0 | 2.7 |
| Sillimanite | 7.7 | 8.9 | 7. | 4.3 | Tr | 12.1 | 24.9 | 9.8 |
| Opaque minerals | .7 | 1.0 | 4. | .2 | Tr | .3 | 1.5 | 1.0 |
| Zircon | Tr | Tr | Tr | Tr | -- | Tr | Tr | Tr |
| Muscovite-sericite[2] | 2.9 | 15.0 | 43. | 5.1 | 34. | -- | -- | -- |
| Spinel | -- | -- | Tr | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite | -- | .6 | 1. | -- | 4. | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | Tr | Tr | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 69 | 60 | 37 | 49 | 18 | 324 | 325 | 325 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | GH15a-71 | GH214-73 | GH34-74 | GH338a-74 | GH91-75 | EP-1 | EP-2 | EP2a |
| K-feldspar | 12.0 | 4.3 | 9.2 | -- | 2.2 | 2.6 | 37.1 | 13.8 |
| Plagioclase | 5.9 | 19.6 | 10.9 | 4.2 | 25.0 | 21.0 | 5.0 | 5.2 |
| Quartz | 1.9 | 22.5 | 22.5 | 41.4 | 25.0 | 25.9 | 48.2 | 59.2 |
| Biotite | 37.4 | 34.2 | 26.7 | 32.5 | 34.8 | 28.3 | 6.9 | 15.4 |
| Garnet | 3.0 | 11.1 | 5.8 | 3.6 | Tr | 4.0 | .9 | Tr |
| Sillimanite | 36.5 | 18.0 | 20.2 | 17.5 | 10.4 | 15.8 | .5 | 4.8 |
| Opaque minerals | 1.8 | .3 | .2 | .4 | .2 | .5 | Tr | Tr |
| Zircon | -- | Tr | -- | Tr | Tr | -- | -- | Tr |
| Muscovite-sericite[2] | 1.5 | -- | 4.5 | .4 | 2.1 | .4 | .9 | 1.5 |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | Tr |
| Chlorite | -- | -- | -- | -- | .3 | 1.5 | .5 | .1 |
| Apatite | -- | -- | Tr | -- | -- | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | Tr | Tr | Tr | Tr | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 326 | 283 | 316 | 321 | 387 | 5 | 368 | 389 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | EP-3 | IS-7-80 | IH-2-80 | IH-7-80 | J-184 | M-67 | M530a | CC-871a |
| K-feldspar ----------- | 19.6 | 0.8 | 1.0 | -- | 7.4 | 4.7 | -- | 15.6 |
| Plagioclase----------- | 15.3 | 13.9 | 21.4 | 4.4 | 8.7 | 23.8 | .1 | 7.4 |
| Quartz---------------- | 20.7 | 37.8 | 41.0 | 66.8 | 37.5 | 45.3 | 51.8 | 31.2 |
| Biotite---------------- | 32.3 | 24.7 | 12.7 | 18.2 | 16.0 | 18.4 | 15.5 | 29.1 |
| Garnet---------------- | .1 | 1.1 | Tr | 1.3 | Tr | Tr | Tr | 4.8 |
| Sillimanite----------- | 11.6 | 13.3 | 1.0 | 8.8 | 17.6 | Tr | 3.5 | 10.7 |
| Opaque minerals---- | .1 | .2 | 2.2 | Tr | 2.6 | Tr | .1 | .4 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2]- | .3 | 7.4 | 20.7 | .5 | 9.8 | 7.8 | 17.1 | .8 |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | .6 | -- | -- | -- | -- | 11.9 | -- |
| Apatite --------------- | -- | .2 | -- | Tr | .4 | -- | -- | Tr |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | Tr | -- | Tr | -- | Tr | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | Tr | -- | -- | -- | -- |

| Locality No. --------- | 393 | 394 | 404 | 405 | 420 | 349 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | S-Sp-30a | S-Sp-30b | S-Sp-64 | DS58-7 | C3-87 | EWT-90b |
| K-feldspar ----------- | 6.4 | 9.8 | -- | -- | -- | 7.0 |
| Plagioclase----------- | 17.7 | 3.1 | .8 | Tr | 7.4 | 7.1 |
| Quartz---------------- | 55.9 | 60.5 | 71.7 | 61.0 | 41.1 | 41.2 |
| Biotite---------------- | 15.3 | 13.4 | 14.0 | 17.2 | 38.0 | 32.0 |
| Garnet---------------- | 2.6 | 1.4 | 4.2 | 6.0 | 1.7 | .5 |
| Sillimanite----------- | 2.1 | 11.8 | 9.1 | 15.8 | 8.6 | 10.3 |
| Opaque minerals---- | Tr | Tr | .2 | Tr | -- | 1.7 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2]- | -- | -- | -- | -- | 3.2 | .2 |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | -- | -- | -- | -- | -- |
| Apatite- -------------- | -- | -- | -- | -- | -- | Tr |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | Tr | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- |

[1]Isotropic alteration product of garnet.

[2]Muscovite-sericite mostly a replacement of sillimanite and plagioclase.

**Table 8.** Modes (volume percent) for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 252 | 187 | 192 | 201 | 207 | 174 | 181 | 121 | 123 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | N-34 | N121a-65 | N146-65 | N271-65 | N378-65 | T-227 | T-359 | W12b-70 | W64-70 |
| K-feldspar | 3.1 | 0.5 | 1. | 1.6 | 6.8 | 6.8 | 0.3 | 41.8 | 4.2 |
| Plagioclase | 27.9 | 3.2 | 1. | 11.4 | '' | 4.1 | 15.4 | 11.8 | 14.6 |
| Quartz | 41.2 | 24.7 | 11. | 31.7 | 45.1 | 30.1 | 72.4 | .9 | 46.8 |
| Cordierite | Tr | 32.3 | 27. | 12.6 | [2].0 | 3.3 | 6.9 | 11.3 | 14.0 |
| Biotite | 21.1 | 19.6 | [3]44. | 24.7 | 19.7 | 33.0 | 2.1 | 27.5 | 13.4 |
| Sillimanite | .5 | 7.8 | 14. | 6.4 | 2.6 | 19.1 | .3 | 5.0 | 1.6 |
| Opaque minerals | 1.0 | 2.9 | Tr | 5.5 | .1 | 3.6 | 2.0 | 1.3 | 2.8 |
| Zircon | Tr | .1 | Tr | .3 | Tr | Tr | Tr | Tr | .4 |
| Andalusite | .4 | .1 | 1. | -- | Tr | -- | -- | .4 | Tr |
| Rutile | Tr | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite | -- | Tr | Tr | -- | -- | -- | -- | -- | Tr |
| Chlorite | .9 | .4 | -- | -- | -- | -- | -- | -- | .6 |
| Muscovite-sericite[5] | 3.9 | 8.4 | 1. | 5.8 | 1.6 | -- | .6 | -- | 1.6 |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 125 | 146 | 150 | 156 | 157 | 119 | 95 | 100 | 103 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W89-70 | W278-70 | W317-70 | W330a-70 | W342-70 | WC49a-70 | W103-71 | W156-71 | W222a-71 |
| K-feldspar | 10.1 | 26. | Tr | 11.7 | 18.8 | 25.5 | 3.2 | 23.3 | 1. |
| Plagioclase | 10.6 | 3. | 1.5 | 25.7 | 10.8 | 13.5 | 27.9 | 7.3 | 20. |
| Quartz | 18.5 | 11. | 38.8 | 33.3 | 50.4 | 36.2 | 29.2 | 26.6 | 37. |
| Cordierite | .5 | 35. | 18.8 | 4.4 | 7.6 | 4.4 | 7.2 | 13.9 | 1. |
| Biotite | 38.4 | 7. | 9.3 | 9.7 | 3.4 | 10.8 | 27.8 | 11.2 | 18. |
| Sillimanite | 19.1 | 3. | 14.4 | 9.7 | 1.7 | 4.0 | .7 | 12.8 | 5. |
| Opaque minerals | 1.5 | 3. | 4.3 | 4.5 | 2.4 | 3.7 | 2.0 | 1.4 | 2. |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite | -- | 7. | Tr | -- | -- | 1.6 | .3 | -- | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite | -- | -- | -- | Tr | -- | -- | Tr | Tr | -- |
| Chlorite | -- | -- | .9 | .1 | .3 | -- | .1 | Tr | Tr |
| Muscovite-sericite[5] | 1.3 | .5 | 12.0 | .9 | 4.6 | .3 | 1.6 | 3.5 | 17. |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 110 | 85 | 86 | 72 | 62 | 63 | 66 | 56 | 58 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W258b-71 | W22-72 | W25-72 | GH40-71 | GH2-72 | GH3a-72 | GH42-72 | GH171-73 | GH190-73 |
| K-feldspar | 4.4 | 11.2 | 3.4 | -- | 13.1 | 24. | -- | 18.7 | -- |
| Plagioclase | -- | 20. | 4.2 | 7.4 | 38.1 | 8. | 7.7 | 3.1 | -- |
| Quartz | 30.0 | 44.8 | 55.4 | 11.8 | 13.2 | 25. | 42.6 | 58.0 | 1. |
| Cordierite | 17.3 | 6.6 | 14.5 | 26.0 | 11.0 | 10. | 8.2 | 4.8 | 80. |
| Biotite | 17.0 | 13.3 | 11.5 | 25.1 | 15.9 | 13. | 12.5 | 8.0 | 13. |
| Sillimanite | 2.6 | 1.3 | 8.8 | 17.2 | 7.8 | 16. | 13.2 | 6.5 | 5. |
| Opaque minerals | 2.4 | 2.7 | 1.5 | 2.3 | .9 | 4. | 2.9 | [4].6 | 1. |
| Zircon | Tr | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |
| Andalusite | -- | .1 | Tr | .8 | Tr | -- | .2 | -- | Tr |
| Rutile | -- | -- | Tr | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite | -- | Tr | Tr | .1 | -- | -- | .1 | -- | -- |
| Chlorite | -- | -- | Tr | 5.9 | -- | -- | 1.7 | -- | -- |
| Muscovite-sericite[5] | 26.3 | -- | .7 | 3.4 | -- | Tr | 10.9 | .3 | -- |
| Xenotime-monazite | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr | -- |

Footnotes follow at end of table.

**Table 8**. Modes (volume percent) for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. | 50 | 31 | 7 | 15 | 301 | 307 | 309 | 399 | 400 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | GH345-74 | GH331-75 | GH92-76 | GH370-76 | ML-6 | ML-12a | ML-15 | S-Sp-267 | S-Sp-268 |
| K-feldspar | 9.4 | .1 | -- | 21.9 | 25.7 | 1.5 | 1.5 | -- | 28.6 |
| Plagioclase | 5.5 | 69.2 | 7.1 | 8.4 | 14.9 | 11.1 | 22.0 | 13.5 | -- |
| Quartz | 35.0 | 2.4 | 35.6 | 29.8 | 37.2 | 44.0 | 41.6 | 46.6 | 44.4 |
| Cordierite | .4 | 4.4 | 4.7 | 26.7 | 9.1 | 14.7 | 22.0 | 23.4 | 8.8 |
| Biotite | 21.8 | 5.5 | 17.3 | -- | 2.4 | 23.1 | 8.9 | 16.2 | 8.7 |
| Sillimanite | 23.4 | 11.9 | 21.1 | 10.3 | 8.2 | 3.8 | 1.6 | .3 | 3.6 |
| Opaque minerals | 3.6 | 3.4 | 4.1 | 2.6 | 2.0 | .6 | 1.2 | Tr | Tr |
| Zircon | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr | Tr |
| Andalusite | -- | -- | .2 | .1 | -- | .3 | .3 | -- | -- |
| Rutile | Tr | -- | -- | Tr | Tr | -- | -- | -- | -- |
| Spinel-högbomite | -- | -- | -- | -- | -- | -- | Tr | -- | -- |
| Chlorite | -- | -- | 1.0 | .1 | -- | .3 | -- | -- | -- |
| Muscovite-sericite[5] | .9 | 3.1 | 8.9 | .1 | .4 | .6 | .9 | Tr | 5.9 |
| Xenotime-monazite | Tr | Tr | -- | Tr | Tr | Tr | Tr | Tr | -- |

| Locality No. | 398 | 396 | 401 | 402 | 403 | 406 | 409 |
|---|---|---|---|---|---|---|---|
| Sample No. | S-SP-277 | S-SP-348 | S-SP-364 | S-SP-389 | S-SP-392 | DS59-1 | E11-84 |
| K-feldspar | -- | -- | 15.6 | 2.6 | -- | -- | -- |
| Plagioclase | 2.5 | 1.4 | .3 | 1.3 | 3.0 | -- | 14.7 |
| Quartz | 63.0 | 60.4 | 61.3 | 66.6 | 58.8 | 60. | 55.7 |
| Cordierite | 18.2 | 14.3 | 14.6 | 17.8 | 19.8 | 6. | 6.5 |
| Biotite | 6.2 | 17.1 | 2.5 | 4.5 | 16.4 | 28. | 15.9 |
| Sillimanite | 5.8 | 5.2 | 1.7 | .2 | Tr | 6. | 6.7 |
| Opaque minerals | -- | Tr | -- | -- | .5 | Tr | .2 |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | -- | -- | -- | Tr | -- | -- |
| Spinel-högbomite | -- | -- | -- | -- | -- | -- | -- |
| Chlorite- | -- | -- | -- | -- | 1.5 | -- | .2 |
| Muscovite-sericite[5] | 4.3 | 1.6 | 4.0 | 7.0 | -- | -- | .1 |
| Xenotime-monazite | -- | Tr | Tr | Tr | Tr | -- | -- |

[1]Includes 1.8 percent kaolinite.

[2]All pinnite added to sericite. Pinnite replaced cordierite.

[3]Includes traces of allanite.

[4]Includes traces of apatite.

[5]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 9.** Modes (volume percent) for cordierite-magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 142 | 159 | 94 | 68 | 70 | 75 | 45 | 12 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W264-70 | W357-70 | W92a-71 | GH3-71 | GH32-71 | GH58-71 | GH180-74 | GH279-76 |
| K-feldspar | -- | 34.8 | -- | 17.4 | 0.5 | -- | 15.5 | 0.5 |
| Plagioclase | 1. | 8.0 | .5 | 13.7 | 2.4 | 6.9 | 7.5 | 10.2 |
| Quartz | 42. | 16.0 | 22.6 | 29.0 | 33.5 | 28.4 | 27.1 | 26.3 |
| Cordierite | 4. | 7.1 | 5.4 | 5.0 | 35.1 | 5.5 | 20.9 | 19.8 |
| Biotite | 11. | 10.8 | 34.8 | 9.3 | 15.1 | 21.2 | 5.3 | 23.6 |
| Sillimanite | 19. | 13.0 | 27.7 | 18.8 | 4.7 | 31.5 | 15.5 | 11.8 |
| Opaque minerals | 6. | 6.9 | 6.2 | 5.6 | 7.0 | 5.9 | 6.2 | 5.6 |
| Zircon | Tr | .1 | Tr | Tr | Tr | .1 | Tr | Tr |
| Chlorite | 2. | -- | Tr | -- | .7 | -- | -- | -- |
| Muscovite-sericite [1] | 25. | 3.3 | 2.8 | 1.2 | 1.0 | .4 | 2.0 | 2.2 |
| Spinel-högbomite | -- | -- | -- | -- | Tr | Tr | -- | -- |
| Xenotime-monazite | -- | Tr | -- | Tr | Tr | .1 | Tr | Tr |

[1]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 10**. Modes (volume percent) for magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 138 | 153 | 154 | 87 | 91 | 93 | 47 | 51 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W242-70 | W323-70 | W326-70 | W25-71 | W68-71 | W90-71 | GH268-74 | GH391-74 |
| K-feldspar | 1.9 | Tr | -- | 17. | 3. | -- | -- | 0.6 |
| Plagioclase | 37.0 | 16. | 5. | 12. | 7. | 6. | -- | 1.3 |
| Quartz | 8.0 | 47. | 37. | 22. | 23. | 29. | 11.2 | 66.3 |
| Biotite | 38.6 | 2. | Tr | 24. | 3. | -- | 43.1 | 12.7 |
| | | | | | | | | |
| Sillimanite | Tr | 3. | 2. | 20. | 5. | 9. | 39.9 | 14.9 |
| Opaque minerals | 4.0 | 5. | 5. | 5. | 6. | 6. | 5.6 | 3.7 |
| Zircon | Tr | Tr | Tr | Tr | -- | Tr | -- | Tr |
| Muscovite-sericite [1] | 10.5 | 22 | 46. | Tr | 46. | 41. | .2 | .5 |
| | | | | | | | | |
| Andalusite | Tr | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite | -- | 5. | 5. | Tr | 7. | 9. | -- | Tr |
| Rutile | -- | Tr | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | -- | Tr |

[1]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 253 | 256 | 258 | 259 | 263 | 263 | 264 | 265 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N91 | N179 | N297 | N143 | N338a | N338b | N342 | N361a |
| K-feldspar | 7.5 | 0.9 | 7.8 | 5.9 | 8.2 | 19.0 | 13.7 | 8.2 |
| Plagioclase | 6.6 | .5 | 17.3 | 20.4 | 5.2 | 4.4 | 2.3 | 24.7 |
| Quartz | [2]29.9 | 21.5 | 50.7 | 52.3 | 36.6 | 41.8 | 27.6 | 43.9 |
| Cordierite | 20.9 | 14.2 | 5.4 | 4.4 | 2.7 | .3 | 11.8 | 4.0 |
| Biotite | 18.9 | 32.2 | 13.8 | 13.7 | 27.9 | 22.4 | 18.7 | 15.4 |
| Garnet | 1.1 | 10.8 | Tr | Tr | 11.7 | 7.7 | 7.3 | Tr |
| Sillimanite | [4]6.6 | 12.9 | .3 | .1 | 5.8 | 3.8 | [4]4.4 | 2.0 |
| Opaque minerals | 4.1 | 5.1 | 1.7 | 1.6 | 1.3 | .5 | 2.9 | .4 |
| Zircon | Tr | Tr | Tr | Tr | .1 | Tr | .1 | Tr |
| Andalusite | .2 | Tr | -- | .1 | .3 | -- | -- | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | .9 | 1.1 | 3.0 | 1.5 | .2 | -- | 3.4 | .4 |
| Muscovite-sericite[5] | 3.3 | .8 | -- | -- | .2 | -- | 7.8 | 1.0 |
| Spinel-högbomite | Tr | Tr | Tr | Tr | Tr | Tr | Tr | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | Tr | -- | -- | -- | -- | -- | -- | -- |
| Apatite | Tr | -- | -- | -- | -- | .1 | -- | -- |

| Locality No. | 211 | 212 | 223 | 237 | 187 | 208 | 120 | 122 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N40-64 | N69A-64 | N206-64 | N409-64 | N121-65 | N412-65 | W6-70 | W18-70 |
| K feldspar | 19.9 | 5. | 17. | 20.2 | 4.6 | 31.2 | 27.0 | 7.6 |
| Plagioclase | 10.9 | 10. | 9. | [1]12.1 | 1.1 | 7.8 | 3.1 | 11.2 |
| Quartz | 42.1 | 45. | 50. | 23.7 | 10.0 | 1.2 | 26.5 | 47.7 |
| Cordierite | 2.0 | 25. | 1. | Tr | 42.0 | 21.2 | 1.7 | 2.4 |
| Biotite | 16.5 | 6. | 18. | 20.3 | 19.3 | 25.1 | 24.7 | 19.1 |
| Garnet | 1.7 | Tr | Tr | 2.6 | 1.3 | 1.7 | 1.8 | 2.9 |
| Sillimanite | 6.3 | 5. | 3. | 6.7 | 17.9 | 9.7 | 14.6 | 9.1 |
| Opaque minerals | .5 | 3. | 1. | 3.9 | 3.6 | 1.0 | Tr | Tr |
| Zircon | 1 | Tr | Tr | .2 | -- | Tr | Tr | -- |
| Andalusite | -- | Tr | -- | .3 | Tr | .1 | -- | Tr |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | Tr | Tr | .8 | -- | -- | -- | -- |
| Muscovite-sericite[5] | -- | Tr | Tr | 9.0 | .2 | 1.0 | .6 | -- |
| Spinel-högbomite | -- | -- | -- | Tr | Tr | Tr | -- | -- |
| Rutile | -- | Tr | Tr | .2 | Tr | -- | -- | -- |
| Xenotime-monazite[6] | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 127 | 128 | 129 | 151 | 152 | 155 | 102 | 108 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W97-70 | W121-70 | W141-70 | W319-70 | W321-70 | W328-70 | W190-70 | W256c-71 |
| K-feldspar | 7.5 | 16.4 | 6.1 | 7.7 | 20.5 | 34.7 | 15.9 | 3. |
| Plagioclase | 1.4 | 3.1 | 36.0 | .1 | 19.1 | 4.6 | 1.5 | 16. |
| Quartz | 24.0 | 55.8 | 24.5 | 17.7 | 30.6 | 18.8 | 9.7 | 21. |
| Cordierite | 17.1 | [3]8.7 | 7.1 | 23.8 | .3 | 16.2 | 35.0 | Tr |
| Biotite | 21.2 | 6.1 | 18.8 | 15.9 | 12.8 | 9.7 | 19.4 | 20. |
| Garnet | 18.5 | 1.5 | 2.6 | 1.8 | 1.6 | 3.7 | Tr | 1. |
| Sillimanite | 8.9 | 2.0 | 4.6 | 23.2 | 1.7 | 10.2 | 15.0 | [4]Tr |
| Opaque minerals | 1.4 | 1.2 | .3 | 1.2 | .3 | .5 | 2.6 | 2. |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | .3 | Tr |
| Andalusite | Tr | Tr | Tr | -- | Tr | .3 | .6 | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | 1.3 | -- | .3 | .3 | -- | -- | -- |
| Muscovite-sericite[5] | -- | 3.9 | -- | 8.2 | 12.8 | 1.3 | -- | 37. |
| Spinel-högbomite | Tr | -- | -- | .1 | -- | Tr | Tr | -- |
| Rutile | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.--Continued

| Locality No. | 115 | 116 | 77 | 80 | 343 | 343 | 344 | 349 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W267-71 | W281a-71 | W7-73 | W18-1-73 | CC783a | CC783-1 | CC-887 | EWT-90 |
| K-feldspar | Tr | 11.5 | Tr | .3 | Tr | Tr | 29.7 | 3.3 |
| Plagioclase | .3 | 5.3 | 19.6 | 24.6 | .2 | 6. | 10.6 | 8.0 |
| Quartz | 23.4 | 20.7 | 16.5 | 40.3 | 22.2 | 53. | 1.2 | 29.6 |
| Cordierite | 2.5 | 14.0 | 20.0 | [3]27.2 | [3]39.9 | 2. | 10.0 | 4.3 |
| Biotite | 27.2 | 11.0 | 18.2 | 2.9 | 7.0 | 21. | 20.8 | 28.9 |
| Garnet | .1 | 9.9 | Tr | Tr | 9.7 | 7. | 1.2 | 20.1 |
| Sillimanite | [4]27.2 | 16.3 | 12.7 | [4].5 | 17.5 | 10. | 20.1 | 5.7 |
| Opaque minerals | 2.5 | 4.2 | 7.1 | 3.4 | 3.3 | 1. | .5 | .1 |
| Zircon | Tr | Tr | .1 | Tr | .2 | Tr | .3 | Tr |
| Andalusite | -- | Tr | .6 | -- | -- | -- | -- | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | 3.5 | 1.5 | .4 | .3 | -- | -- | -- | -- |
| Muscovite-sericite[5] | 13.3 | 5.6 | 4.6 | .5 | -- | Tr | 5.6 | Tr |
| Spinel-högbomite | -- | Tr | -- | -- | Tr | Tr | Tr | -- |
| Rutile | Tr | -- | .1 | -- | Tr | Tr | Tr | -- |
| Xenotime-monazite[6] | -- | -- | .1 | -- | -- | -- | -- | -- |
| Apatite | -- | -- | .5 | Tr | -- | -- | -- | -- |

| Locality No. | 345 | 71 | 74 | 62 | 64 | 57 | 59 | 61 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | JG-38b | GH35-71 | GH55-71 | GH2-72 | GH4-72 | GH189-73 | GH195-73 | GH232-73 |
| K-feldspar | 1.6 | 2.4 | 4.4 | 14.4 | 31.2 | 5.3 | 11.5 | 17.4 |
| Plagioclase | 2.0 | 2.0 | 3.0 | 11.0 | 2.0 | 2.2 | 11.8 | 6.2 |
| Quartz | 26.1 | 1.7 | 19.3 | 39.7 | 34.6 | 13.6 | 26.2 | 23.0 |
| Cordierite | 16.4 | 22.7 | 11.8 | 10.0 | 9.1 | [3]11.8 | 13.5 | 4.3 |
| Biotite | 23.6 | 30.8 | 23.4 | 16.4 | 9.6 | 30.2 | 18.5 | 32.0 |
| Garnet | 17.3 | 1.8 | 13.9 | .3 | 3.4 | 4.0 | 2.9 | 1.1 |
| Sillimanite | 11.7 | 32.8 | 21.6 | 7.7 | 9.4 | 31.7 | 14.3 | 15.5 |
| Opaque minerals | 1.3 | 5.8 | .7 | .5 | .6 | 1.2 | .9 | Tr |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | -- | Tr |
| Andalusite | Tr | -- | -- | -- | .1 | -- | .1 | .5 |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | -- | .4 | -- | -- | -- | .2 | -- |
| Muscovite-sericite[5] | -- | -- | 1.5 | -- | -- | -- | -- | -- |
| Spinel-högbomite | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Rutile | -- | -- | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | -- | Tr | Tr | Tr | -- | [6].1 | .1 | Tr |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 35 | 36 | 38 | 40 | 41 | 42 | 44 | 46 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | GH12-74 | GH19-74 | GH52-74 | GH85-74 | GH133-74 | GH154-74 | GH177-74 | GH223-74 |
| K-feldspar | 9.4 | .3 | .8 | 6.6 | 19.3 | -- | 18.5 | 10.9 |
| Plagioclase | 10.6 | 10.7 | 1.1 | 6.4 | 6.2 | 11.4 | 10.1 | 2.7 |
| Quartz | 39.9 | 11.8 | 32.2 | 6.1 | 26.3 | 20.0 | 8.7 | 38.2 |
| Cordierite | 10.5 | Tr | 1.5 | 10.6 | 14.4 | [3].7 | 1.2 | 16.6 |
| Biotite | 17.9 | 40.0 | 21.3 | 31.8 | 22.0 | 44.0 | 36.6 | 22.6 |
| Garnet | 1.7 | .1 | .9 | Tr | 3.3 | 1.6 | Tr | .7 |
| Sillimanite | 9.7 | [4]25.0 | 21.6 | 34.9 | 8.1 | 16.0 | 23.3 | 4.8 |
| Opaque minerals | .3 | 2.6 | .9 | 3.4 | .4 | Tr | .2 | .7 |
| Zircon | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |
| Andalusite | -- | .1 | Tr | -- | -- | -- | -- | 1.1 |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | 1.4 | 4.7 | -- | -- | 5.9 | .9 | -- |
| Muscovite-sericite[5] | -- | 8.0 | 15.0 | .1 | -- | .4 | .5 | 1.7 |
| Spinel-högbomite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | Tr | Tr | -- | -- | Tr | -- | -- |
| Xenotime-monazite[6] | Tr | -- | -- | .1 | Tr | -- | Tr | Tr |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.--Continued

| Locality No.---------- | 48 | 27 | 16 | 323 | 324 | 299 | 300 | 303 | 306 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | GH327-74 | GH246-75 | GH372-76 | AP-19 | EP-1 | ML-1 | ML-3 | ML-8 | ML-11 |
| K-feldspar------------ | 3.8 | -- | 10.1 | 15.4 | 2.6 | 17.9 | 26.6 | 9.6 | 5.6 |
| Plagioclase----------- | 10.5 | 34.7 | 10.1 | 28.7 | 20.9 | 19.8 | 23.2 | 27.9 | 11.3 |
| Quartz ---------------- | 16.8 | 30.5 | 70.9 | 46.4 | 25.9 | 31.2 | 26.8 | 48.8 | 25.8 |
| Cordierite ------------ | 7.4 | [3]5.1 | 1.0 | 1.7 | .1 | 8.0 | [3]6.3 | .6 | 4.5 |
| Biotit------------------ | 30.4 | 19.3 | 7.0 | 6.7 | 28.3 | 15.2 | 11.8 | 10.0 | 21.6 |
| Garnet ---------------- | 13.2 | 2.7 | Tr | .6 | 4.0 | 1.4 | 1.2 | 1.1 | 30.3 |
| Sillimanite ----------- | 17.2 | 3.0 | .2 | .2 | 15.8 | 4.1 | 1.9 | 1.3 | Tr |
| Opaque minerals---- | .1 | -- | .7 | .3 | .5 | 1.4 | .8 | .1 | .5 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | -- | .1 | -- | Tr | -- |
| Andalusite ----------- | -- | .2 | -- | -- | -- | .8 | .8 | -- | -- |
| Staurolite------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite--------------- | .3 | .2 | -- | Tr | 1.5 | -- | -- | .3 | .1 |
| Muscovite-sericite[5] - | .4 | 4.3 | -- | -- | .4 | -- | .6 | .3 | .3 |
| Spinel-högbomite --- | -- | -- | Tr | Tr | -- | .1 | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite[6] | .1 | Tr | Tr | Tr | -- | Tr | -- | -- | -- |
| Apatite----------------- | -- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Locality No.---------- | 307 | 395 | 397 | 392 | 407 | 367 | 408 | 410 | 411 |
| Sample No. ---------- | ML-12 | S-SP-349 | S-SP-450 | S-SP452a | DS59-67a | M-497 | E10-84 | SL2-84 | SL3-84 |
| K-feldspar------------ | .5 | -- | -- | -- | -- | Tr | -- | 18.7 | 14.1 |
| Plagioclase----------- | 15.1 | .8 | .2 | .2 | 2.0 | 9.3 | 1.3 | 4.7 | 1.7 |
| Quartz- --------------- | 45.9 | 58.2 | 51.1 | 47.2 | 66.9 | 51.6 | 63.9 | 8.9 | 24.5 |
| Cordierite ------------ | 9.2 | 5.4 | 21.6 | 25.2 | 10.3 | 1.3 | 5.2 | 1.9 | 13.1 |
| Biotite ---------------- | 23.6 | 23.6 | 22.1 | 15.2 | 14.0 | 13.8 | 17.1 | 34.3 | 15.4 |
| Garnet ---------------- | 2.7 | 8.7 | 1.9 | 5.4 | 2.6 | 2.6 | 5.2 | 1.8 | 18.0 |
| Sillimanite ----------- | 1.6 | 3.3 | 2.8 | 6.6 | 3.9 | 11.6 | 7.2 | 29.3 | 12.6 |
| Opaque minerals---- | .5 | Tr | Tr | .2 | Tr | .3 | .1 | .2 | .5 |
| Zircon ---------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | .1 |
| Andalusite ----------- | .5 | -- | -- | -- | -- | Tr | -- | -- | -- |
| Staurolite------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite--------------- | .2 | -- | .3 | -- | Tr | 9.5 | -- | -- | -- |
| Muscovite-sericite[5] - | .2 | -- | -- | -- | .3 | -- | -- | .1 | -- |
| Spinel-högbomite --- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite[6] | -- | Tr | -- | Tr | -- | -- | -- | -- | -- |
| Apatite----------------- | -- | -- | -- | -- | -- | -- | -- | .1 | -- |

[1]Includes 0.8 percent kaolinite.
[2]Includes traces of corundum.
[3]Includes pinnite.
[4]Some or all sillimanite altered to muscovite.
[5]Most muscovite is replacement of plagioclase and sillimanite.
[6]Includes traces of sphene.

**Table 12.** Modes (volume percent) for four hornblende gneiss layers, central Front Range, Colorado.

[--, not found; Tr, trace]

| | Phoenix layer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Locality No. | 390 | 261 | 262 | 267 | 268 | 210 | 216 | 217 | 218 |
| Sample No. | N126 | N322a | N328 | N399 | N400a | N-2-64 | N124-64 | N125-64 | N127-64 |
| K-feldspar | -- | -- | 1.5 | -- | -- | -- | -- | 0.5 | -- |
| Plagioclase | 38.5 | 4.4 | 50.0 | 40.7 | 7. | 13.3 | 26.0 | 52.5 | 35.9 |
| Quartz | 1.0 | .2 | 11.3 | .1 | 21. | -- | -- | 27.8 | -- |
| Scapolite | -- | -- | 7.1 | -- | -- | -- | -- | -- | -- |
| Hornblende | 56.6 | 65.1 | 15.2 | 56.1 | 26. | 64.1 | 68.9 | 10.8 | 51.1 |
| Clinopyroxene | 1.2 | 14.4 | 4.5 | .5 | 5. | 17.9 | 3.7 | 1.1 | 10.8 |
| Orthopyroxene | Tr | -- | -- | -- | Tr | -- | -- | -- | -- |
| Opaque minerals | 2.7 | Tr | 3.0 | -- | 2. | Tr | Tr | .5 | Tr |
| Apatite | Tr | .4 | .6 | -- | Tr | .6 | -- | .1 | -- |
| Zircon | Tr | -- | -- | -- | Tr | -- | -- | .1 | -- |
| Biotite | -- | -- | -- | -- | -- | .8 | -- | 6.6 | -- |
| Allanite | -- | Tr | -- | -- | -- | .2 | -- | -- | -- |
| Sphene | Tr | -- | 2.3 | -- | 2. | -- | -- | -- | Tr |
| Calcite | -- | Tr | 3.4 | -- | 2. | .8 | -- | -- | .1 |
| Epidote | -- | -- | 1.1 | 1.6 | 35. | .3 | .3 | -- | -- |
| Sericite[4] | -- | 15.5 | -- | 1.0 | -- | 1.4 | 1.1 | -- | 2.1 |
| Chlorite | -- | -- | -- | -- | -- | .6 | -- | -- | -- |

| | Phoenix layer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Locality No. | 220 | 227 | 227 | 228 | 229 | 234 | 235 | 240 | 243 |
| Sample No. | N151-64 | N246-64 | [1]N246a-64 | N278-64 | N317-64 | N375-64 | N395-64 | N484-64 | N584-64 |
| K-feldspar | -- | 7.7 | Tr | -- | -- | 1.4 | 0.3 | -- | 0.1 |
| Plagioclase | 45.1 | 49.2 | 50.0 | [2]46.6 | 43.9 | 53.0 | 50.2 | 57.1 | 38.7 |
| Quartz | -- | 23.1 | 11.0 | 1.9 | 27.3 | 11.8 | 16.0 | 1.1 | 3.8 |
| Scapolite | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende | 38.4 | 7.8 | 29.4 | 39.6 | 18.8 | 8.4 | 27.6 | 28.0 | 45.6 |
| Clinopyroxene | 14.1 | -- | .3 | 10.1 | .1 | 19.3 | .6 | 3.0 | 9.8 |
| Orthopyroxene | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Opaque minerals | .3 | .7 | 7.5 | -- | 5.3 | 1.4 | 3.1 | 3.0 | .2 |
| Apatite | .1 | .4 | .1 | .4 | .1 | .7 | -- | -- | .1 |
| Zircon | -- | Tr | -- | -- | Tr | Tr | -- | -- | -- |
| Biotite | -- | 11.1 | -- | -- | 2.1 | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | Tr | -- | .1 | .1 | -- | .4 | .4 | -- | -- |
| Calcite | -- | -- | Tr | -- | .3 | 1.9 | .3 | 1.4 | 1.6 |
| Epidote | 1.3 | Tr | Tr | 1.1 | .1 | 1.2 | .6 | 2.4 | .1 |
| Sericite[4] | .7 | -- | -- | -- | .4 | .5 | .8 | 1.5 | -- |
| Chlorite | -- | Tr | 1.6 | .2 | 1.6 | -- | .1 | 2.5 | -- |

Footnotes follow at end of table.

**Table 12.** Modes (volume percent) for four hornblende gneiss layers, central Front Range, Colorado.--Continued

| | Phoenix layer | | | | | | Golden Gate layers | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Locality No. ------ | 245 | 246 | 249 | 193 | 198 | 199 | 310 | 311 | 312 | 313 |
| Sample No. ------- | N602-64 | [1]N625-64 | [1]N675-64 | N169-65 | N227-65 | N233-65 | [1]GG-1 | GG-2 | GG-3 | GG-4 |
| K-feldspar -------- | -- | -- | -- | Tr | 0.9 | -- | -- | -- | -- | -- |
| Plagioclase-------- | 47.3 | 1.6 | 25.1 | 33.0 | 34.6 | 35.2 | 26.8 | 35.4 | 12.6 | 34.9 |
| Quartz ------------ | 8.0 | -- | .4 | 11.3 | .8 | .2 | 10.9 | 9.9 | 44.0 | 3.1 |
| Scapolite --------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende ------- | 34.3 | 51.8 | 67.2 | 19.8 | 48.2 | -- | 60.6 | 52.3 | 30.8 | 56.9 |
| Clinopyroxene --- | Tr | 44.0 | 5.5 | .3 | 9.3 | 45.5 | -- | -- | 2.0 | -- |
| Orthopyroxene --- | -- | -- | .3 | -- | -- | -- | -- | -- | -- | -- |
| Opaque minerals- | 2.8 | Tr | -- | 3.9 | 2.3 | 4.0 | .8 | 1.2 | Tr | .3 |
| Apatite ----------- | .5 | -- | .1 | 2.1 | .6 | .4 | .4 | .4 | .7 | .1 |
| Zircon ------------ | .1 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Biotite ------------ | 5.6 | -- | -- | 29.2 | Tr | -- | .5 | .1 | .4 | 2.5 |
| Allanite ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene----------- -- | .1 | -- | Tr | -- | .6 | -- | -- | .7 | 1.9 | 1.1 |
| Calcite------------ | 1.0 | 1.6 | Tr | -- | .5 | Tr | Tr | 4.1 | 1.1 | .1 |
| Epidote ----------- | -- | 1.0 | 1.4 | .4 | 1.7 | [3]14.7 | -- | -- | .7 | -- |
| Sericite[4] ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite ---------- | .3 | -- | -- | -- | .5 | -- | -- | -- | -- | -- |

| | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. ------ | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. ------- | SP1-80 | SP1a-80 | M250a | M-276a | M279a | M300 | [1]M488a |
| K-feldspar -------- | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase-------- | 36.0 | 25. | 51.9 | 35.6 | 40.7 | 34.9 | .7 |
| Quartz ------------ | 1.5 | .5 | .8 | Tr | .9 | 1.0 | 12.1 |
| Scapolite --------- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende ------- | 49.4 | 25. | 44.2 | 56.6 | 56.5 | 62.3 | 25.8 |
| Clinopyroxene --- | 7.1 | 36. | .1 | 7.4 | -- | 1.1 | 20.4 |
| Orthopyroxene --- | -- | -- | -- | -- | -- | -- | -- |
| Opaque minerals- | .2 | .5 | .5 | Tr | .1 | -- | 5.8 |
| Apatite ----------- | -- | 1. | .2 | .2 | Tr | Tr | .1 |
| Zircon ------------ | -- | -- | .2 | -- | -- | -- | -- |
| Biotite ------------ | 1.0 | -- | -- | -- | -- | -- | -- |
| Allanite ---------- | -- | -- | -- | -- | -- | -- | .3 |
| Sphene ----------- | 3.4 | 8.0 | .4 | .1 | .7 | .7 | -- |
| Calcite------------ | 1.4 | 4.0 | -- | .8 | Tr | -- | -- |
| Epidote ----------- | -- | -- | 1.5 | -- | .3 | -- | .5 |
| Sericite[4] ---------- | -- | -- | -- | -- | -- | -- | 34.3 |
| Chlorite ---------- | -- | -- | .2 | -- | -- | -- | Tr |

[1]Amphibolite lens.
[2]Includes sericite.
[3]Includes some clinozoisite.
[4]Replaces plagioclase.

**Table 13.** Modes (volume percent) for hornblende gneiss and amphibolite layers finely interlayered with biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 302 | 302 | 303 | 333 | 334 | 336 | 335 | 337 | 338 | 206 | 98 | 116 | 366 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | ML-7 | ML-7A | ML-8A | R056 | R063 | R141 | R126 | R218 | R402 | [1]N354-65 | W151a-71 | W281-b-71 | [1]M488a |
| K-feldspar | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1. | -- | -- |
| Plagioclase | 35.2 | 29.2 | 23.5 | 11.0 | 49.0 | 27.4 | 53.8 | 28.0 | 42.9 | 24.7 | 33. | -- | .7 |
| Quartz | 12.1 | 5.9 | 2.1 | 11.5 | 11.4 | 21.5 | 7.8 | 22.7 | -- | 1.3 | 37. | -- | 12.1 |
| Hornblende | 38.0 | 50.9 | 23.2 | 62.2 | 23.6 | 32.1 | 34.9 | 32.3 | 48.0 | 48.8 | 19. | 77. | 25.8 |
| Clinopyroxene | 11.2 | 9.6 | 41.9 | -- | -- | -- | -- | -- | 7.3 | 22.0 | -- | 3. | 20.4 |
| Tremolite-actinolite | -- | -- | -- | -- | 2.7 | -- | -- | -- | -- | -- | -- | -- | -- |
| Biotite | .4 | .4 | -- | -- | 4.1 | 17.4 | 1.2 | 14.8 | .3 | -- | 10. | -- | -- |
| Apatite | .6 | .5 | .4 | Tr | .1 | .1 | .5 | .3 | .2 | -- | Tr | 1. | .1 |
| Opaque minerals | Tr | Tr | Tr | -- | .6 | .6 | 1.5 | .7 | .2 | 1.3 | Tr | 1. | 5.8 |
| Sphene | .2 | .4 | 3.4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote | .6 | 1.4 | 5.2 | 3.0 | .5 | .9 | -- | 1.2 | .3 | 1.6 | -- | 15. | .5 |
| Calcite | 1.3 | 1.4 | -- | -- | 1.3 | -- | -- | -- | .5 | .3 | -- | -- | -- |
| Sericite[2] | .4 | .3 | .3 | 11.3 | -- | -- | -- | -- | -- | -- | -- | 3. | 34.3 |
| Chlorite | -- | -- | -- | 1.0 | 6.7 | -- | .3 | -- | .3 | -- | -- | -- | Tr |
| Zircon | -- | -- | -- | -- | -- | -- | Tr | -- | -- | -- | Tr | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .3 |

[1]Amphibolite layer or lens; all other samples hornblende gneiss.
[2]Sericite replaces plagioclase.

**Table 14.** Modes (volume percent) for scattered mafic lenses in garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 107 | 111 | 99 | 98 | 116 | 76 | 77 | 33 | 369 | 370 | 286 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W252b-71 | W259a-71 | W152-71 | W151-71 | W281b-71 | W-4-73 | W-7a-73 | GH-350-75 | M532c-1 | M-597 | J121a |
| Plagioclase | -- | 26.0 | 27.5 | 31.0 | -- | 41.7 | 36.4 | 52.0 | 27.4 | 23.4 | 35.0 |
| Quartz | 22. | 12.1 | 41.7 | -- | -- | 18.2 | 16.3 | 18.2 | Tr | 44.1 | 13.2 |
| Hornblende | 37. | 36.5 | -- | 3.2 | 77. | 1.4 | 29.3 | 23.7 | 69.2 | 27.6 | 49.2 |
| Orthopyroxene | -- | -- | 6.1 | -- | -- | 17.5 | -- | -- | -- | -- | -- |
| Clinopyroxene | -- | -- | -- | 37.1 | 3. | -- | -- | -- | -- | -- | |
| | | | | | | | | | | | |
| Biotite | -- | 22.5 | 23.2 | 25.5 | -- | 13.8 | 14.6 | 4.9 | 2.2 | 4.0 | 2.0 |
| Apatite | Tr | .7 | Tr | -- | 1. | Tr | .3 | -- | Tr | Tr | Tr |
| Opaque minerals | 6. | 2.0 | .3 | 3.2 | 1. | 3.3 | 3.0 | .2 | .8 | -- | .5 |
| Allanite | -- | .1 | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Zircon | -- | Tr | Tr | -- | -- | -- | Tr | -- | Tr | .1 | Tr |
| | | | | | | | | | | | |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- | .4 | .1 | -- |
| Chlorite | -- | .1 | -- | -- | -- | -- | -- | .5 | -- | -- | -- |
| Muscovite-sericite[1] | 10. | -- | -- | Tr | 3. | 1.8 | .1 | -- | -- | .6 | -- |
| Epidote | 25. | Tr | 1.2 | -- | 15. | 2.3 | -- | -- | -- | .1 | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | .5 | -- | -- | .1 |

[1]Muscovite-sericite, a replacement of plagioclase.

**Table 15.** Modes (volume percent) for altered hornblende gneiss and amphibolite, located within Late Cretaceous-early Tertiary aureoles, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 199 | 244 | 244 | 193 | 225 | 226 |
|---|---|---|---|---|---|---|
| Sample No. | N233-65 | [1]N590a-64 | [1]N590a-1-64 | [1]N169-65 | [1]N225-64 | [1]N236-64 |
| K-feldspar | -- | 1.0 | -- | Tr | 0.1 | -- |
| Plagioclase | 35.2 | 43.4 | 37.0 | 33.0 | 45.6 | 2. |
| Quartz | .2 | -- | -- | 11.3 | 5.4 | -- |
| Hornblende | -- | 54.0 | 43.5 | 19.8 | 32.8 | 92. |
| Clinopyroxene | 45.5 | .2 | 16.0 | .3 | 14.9 | 2. |
| Biotite | -- | .5 | -- | 29.2 | -- | 3. |
| Opaque minerals | 4.0 | Tr | 3.1 | 3.9 | 1.1 | -- |
| Apatite | .4 | .2 | .1 | 2.1 | .1 | Tr |
| Zircon | -- | .1 | Tr | -- | -- | -- |
| Calcite | Tr | .4 | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- |
| Epidote-clinozoisite | 14.7 | .1 | .3 | .4 | -- | 1. |
| Chlorite | -- | .1 | -- | -- | -- | -- |
| Sphene | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- |

| Locality No. | 194 | 197 | 196 | 145 | 104 | 104 |
|---|---|---|---|---|---|---|
| Sample No. | N170-65 | N202-65 | N198-65 | W275b-70 | W223a-71 | W223b-71 |
| K-feldspar | -- | -- | -- | -- | -- | -- |
| Plagioclase | 52.9 | 47.0 | 37.4 | 33. | 42.1 | 35.4 |
| Quartz | 2.5 | 6.1 | 2.6 | 23. | 23.6 | 13.7 |
| Hornblende | 38.6 | 42.9 | 53.0 | 16. | 3.8 | 20.5 |
| Clinopyroxene | .7 | .6 | .6 | -- | -- | 1.3 |
| Tremolite-actinolite | -- | -- | -- | -- | -- | -- |
| Biotite | .6 | -- | -- | 19. | 26.3 | 18.0 |
| Opaque minerals | 3.6 | 1.0 | 2.8 | 8. | 1.0 | .5 |
| Apatite | .3 | .1 | .3 | 1. | .6 | .1 |
| Zircon | .1 | Tr | -- | Tr | -- | -- |
| Calcite | .1 | .8 | .3 | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | 8.1 |
| Epidote-clinozoisite | -- | 1.0 | 2.5 | -- | -- | -- |
| Chlorite | .3 | .5 | .1 | -- | -- | -- |
| Sphene | .3 | Tr | .4 | -- | .4 | 1.4 |
| Allanite | -- | -- | -- | Tr | .1 | -- |

[1]Amphibolite layer or lens. Amphibolite sample N590a-1-64 from contact with Late Cretaceous-early Tertiary intrusive; amphibolite sample N590a-64 is 4 m from a Late Cretaceous-early Tertiary intrusive contact.

**Table 16.** Modes (volume percent) for layers of calc-silicate gneiss and diopsidite in biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 108 | 112 | 105 | 107 | 116 | 371 | 290 | 279 | 346 | 103 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W256b-71 | W262b-71 | [1]W235-71 | W252c-71 | W281c-71 | GH-186-76 | J-277 | IS3-80 | D245a | [1]W222b-71 |
| K-feldspar | -- | -- | -- | -- | -- | 30.6 | -- | -- | -- | -- |
| Plagioclase | -- | 6. | -- | 5.0 | 9. | 19.4 | -- | 51.1 | 35. | -- |
| Quartz | 28. | 16. | 3.3 | 29.6 | 2. | -- | 7.4 | 5.8 | 30. | Tr |
| Hornblende | 9. | 13. | 15.4 | -- | 44. | -- | 4.6 | 11.4 | 3. | 13. |
| Biotite | [1]1. | .3 | -- | Tr | Tr | -- | -- | [2].2 | -- | -- |
| Clinopyroxene[3] | 27. | 37. | 73.3 | -- | 26 | 30.0 | 13.3 | 16.0 | 25. | 83. |
| Apatite | Tr | -- | .3 | 1.6 | 1. | -- | .1 | .5 | Tr | Tr |
| Zircon | -- | Tr | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | Tr | Tr | -- | -- | -- | 1.2 | 6.7 | 2.2 | Tr | Tr |
| Calcite | Tr | Tr | -- | -- | -- | -- | -- | 1.2 | -- | Tr |
| Epidote-clinozoisite | 36. | 27. | 6.5 | 38.9 | 8. | 16.3 | 66.2 | 10.9 | 7. | 4. |
| Chlorite | -- | -- | .9 | 12.0 | -- | -- | -- | -- | Tr | -- |
| Opaque minerals | -- | -- | -- | 1.4 | Tr | -- | 1.6 | .9 | Tr | -- |
| Muscovite-sericite[4] | -- | -- | -- | 11.5 | 10. | 2.5 | -- | -- | -- | -- |
| Garnet | -- | -- | -- | -- | -- | -- | .1 | -- | -- | -- |
| Scapolite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

[1]Diopsidite

[2]Traces of allanite present.

[3]Predominantly diopside.

[4]Muscovite-sericite an alteration product of plagioclase.

**Table 17.** Modes (volume percent) for interlayered calc-silicate gneiss and more mafic and silicic rocks, especially hornblende gneiss, from map localities 1, 2, and 13, Gold Hill area, and the Phoenix layer, Nederland quadrangle, localities 193, 198, 245, 260, and 268. Only calc-silicate gneiss has been shown here for the Phoenix layer; associated hornblende gneiss is reported in table 12, central Front Range, Colorado.

[--, not found; Tr, trace]

| | Hornblende-pyroxene gneiss | | Pyroxene gneiss | | | Calc-silicate gneiss |
|---|---|---|---|---|---|---|
| Locality No. -------- | 13 | 13 | 13 | 13 | 13 | 13 |
| Sample No. --------- | GH281-1-76 | GH281-4-76 | GH281-2-76 | GH281-2a-76 | GH281-3-76 | GH281-1a-76 |
| K-feldspar ---------- | Tr | -- | -- | -- | -- | -- |
| Plagioclase--------- | 38. | 34. | 28. | 45. | 35. | 2.0 |
| Quartz--------------- | -- | -- | 10. | 9. | 30. | 5.9 |
| Hornblende -------- | 13. | 12. | 1. | 3. | 3. | .6 |
| Clinopyroxene[1] ---- | 29. | 42. | 38. | 30. | 25. | 30.9 |
| Apatite ------------- | 1. | Tr | 1. | 1. | Tr | .7 |
| Opaque minerals--- | .5 | Tr | Tr | Tr | Tr | .1 |
| Allanite ------------ | -- | -- | -- | Tr | Tr | -- |
| Zircon -------------- | -- | -- | -- | Tr | -- | -- |
| Scapolite ----------- | -- | -- | -- | -- | -- | -- |
| Calcite-------------- | Tr | 1. | Tr | -- | -- | -- |
| Chlorite ------------ | -- | -- | -- | -- | Tr | -- |
| Muscovite-sericite[2] | 3. | -- | -- | -- | -- | -- |
| Epidote------------- | 11. | 10. | 19. | 8. | 7. | 55.7 |
| Sphene ------------- | 4.5 | 1. | 3. | 4. | Tr | 4.1 |
| Garnet-------------- | -- | -- | -- | -- | -- | -- |

| | Diopsidite | | | Quartz-feldspar gneiss | Impure quartzite |
|---|---|---|---|---|---|
| Locality No. -------- | 1 | 1 | 1 | 1 | 1 |
| Sample No. --------- | GH1-77 | GH1-3-77 | GH1-5-77 | GH1-1-77 | GH1-4-77 |
| K-feldspar ---------- | -- | -- | -- | 31.8 | 1.5 |
| Plagioclase--------- | Tr | -- | -- | 3.2 | 2.3 |
| Quartz--------------- | -- | -- | Tr | 58.2 | 88.5 |
| Hornblende -------- | 7. | 1. | -- | 1.0 | 2.7 |
| Clinopyroxene[1] ---- | 52. | 97. | 83. | 3.6 | 4.0 |
| Apatite ------------- | -- | -- | -- | Tr | .1 |
| Opaque minerals--- | 2. | -- | -- | -- | .3 |
| Allanite ------------ | -- | -- | -- | -- | -- |
| Zircon -------------- | -- | -- | -- | -- | -- |
| Scapolite ----------- | -- | 2.0 | -- | -- | -- |
| Calcite-------------- | Tr | -- | 5. | -- | -- |
| Chlorite ------------ | -- | -- | 10. | -- | -- |
| Muscovite-sericite[2] | -- | -- | 2. | -- | -- |
| Epidote------------- | 34. | -- | Tr | .8 | .5 |
| Sphene ------------- | 2. | -- | -- | 1.4 | .1 |
| Garnet-------------- | 3. | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 17.** Modes (volume percent) for interlayered calc-silicate gneiss and more mafic and silicic rocks, especially hornblende gneiss, from map localities 1, 2, and 13, Gold Hill area, and the Phoenix layer, Nederland quadrangle, localities 193, 198, 245, 260, and 268. Only calc-silicate gneiss has been shown here for the Phoenix layer; associated hornblende gneiss is reported in table 12, central Front Range, Colorado.--Continued

| | Calc-silicate gneiss | | | Pyroxene gneiss | Calc- silicate gneiss | | |
|---|---|---|---|---|---|---|---|
| Locality No. -------- | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Sample No. --------- | GH1-2-77 | GH1-6-77 | GH1-6a-77 | GH1-7-77 | GH2-1-77 | GH2-2-77 | GH2-3-77 |
| K-feldspar ---------- | -- | -- | -- | 1.6 | -- | -- | -- |
| Plagioclase--------- | 20.6 | 26.3 | 21.2 | 69.8 | 34.4 | 59.7 | 50.3 |
| Quartz -------------- | 6.9 | 1.4 | .9 | 6.9 | -- | 7.4 | -- |
| Hornblende --------- | 1.5 | 28.0 | 22.2 | 1.5 | 12.4 | 7.8 | 4.4 |
| Clinopyroxene[1] ---- | 49.2 | 31.6 | 39.9 | 17.8 | 42.8 | 17.8 | 40.2 |
| Apatite ------------- | -- | -- | .1 | .1 | .5 | .3 | .3 |
| Opaque minerals--- | Tr | Tr | Tr | .1 | .2 | Tr | Tr |
| Allanite ------------ | -- | -- | -- | -- | -- | -- | -- |
| Zircon -------------- | -- | -- | -- | -- | -- | -- | -- |
| Scapolite ----------- | 15.8 | 10.1 | 13.2 | .2 | -- | -- | -- |
| Calcite-------------- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite ------------ | -- | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | -- | -- | .1 | -- | -- | -- |
| Epidote ------------- | 3.7 | 1.1 | 1.0 | 1.4 | 7.5 | 5.6 | 3.0 |
| Sphene ------------- | 2.2 | 1.5 | 1.5 | .5 | 2.2 | 1.4 | 1.8 |
| Garnet -------------- | .1 | -- | -- | -- | -- | -- | -- |

| | Pyroxene gneiss | Hornblende-pyroxene-gneiss | Calc-silicate gneiss from the Phoenix layer | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. -------- | 2 | 2 | 260 | 268 | 193 | 198 | 245 |
| Sample No. --------- | GH2-4-77 | GH2-6-77 | N321a | N400b | N169a-65 | N227a-65 | N602a-64 |
| K-feldspar ---------- | -- | -- | 1. | -- | -- | -- | -- |
| Plagioclase--------- | 19. | 27.4 | 8. | Tr | 24.4 | 58.6 | 14.4 |
| Quartz -------------- | 22. | .1 | 5. | 21. | 44.4 | 4.7 | 24.1 |
| Hornblende --------- | 2. | 41.0 | 1. | 5. | 6. | 7.9 | .7 |
| Biotite -------------- | -- | -- | -- | -- | .1 | -- | -- |
| Clinopyroxene[1] ---- | 22. | 29.6 | 21. | 21. | -- | 22.7 | -- |
| Apatite ------------- | -- | .4 | Tr | Tr | .8 | Tr | -- |
| Opaque minerals--- | -- | -- | Tr | Tr | 2.6 | 1.3 | .1 |
| Allanite ------------ | -- | -- | -- | -- | -- | -- | -- |
| Zircon -------------- | -- | -- | -- | Tr | -- | -- | -- |
| Scapolite ----------- | -- | -- | -- | 15. | -- | -- | -- |
| Calcite-------------- | -- | -- | 26. | 4. | .1 | .9 | 1.0 |
| Chlorite ------------ | 1. | -- | -- | -- | -- | -- | 2.7 |
| Muscovite-sericite[2] | 1. | -- | -- | Tr | 1.1 | -- | -- |
| Epidote ------------- | 32. | .6 | -- | -- | -- | -- | -- |
| Epidote-clinozoisite | -- | -- | 36. | 23. | 11.4 | 2.5 | 53.7 |
| Sphene ------------- | 1. | .9 | 2. | 2. | 1.2 | 1.4 | 3.3 |
| Garnet -------------- | -- | -- | -- | 5. | 13.3 | Tr | -- |

[1]Predominantly diopside; but there maybe unidentified remnants of other clinopyroxenes.
[2]Muscovite-sericite is an alteration of plagioclase.

**Table 18.** Modes (volume percent) for impure quartzite associated with hornblende gneiss and calc-silicate gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| | With hornblende gneiss | | | With cal-silicate gneiss | With sillimanite-biotite gneiss |
|---|---|---|---|---|---|
| Locality No. | 269 | 232 | 233 | 1 | 239 |
| Sample No. | N-408-63 | N361-64 | N363a1-64 | GH1-4-77 | N473-64 |
| K-feldspar | -- | 6.0 | -- | 1.5 | 5.0 |
| Plagioclase | 1.7 | 29.4 | 5.4 | 2.3 | 18.0 |
| Quartz | 85.6 | 56.0 | 67.4 | 88.5 | 51.0 |
| Hornblende | 10.1 | -- | -- | 2.7 | -- |
| Clinopyroxene | .6 | -- | -- | 4.0 | -- |
| Opaque minerals | .1 | .5 | [1]2.6 | .3 | 2.0 |
| Apatite | .1 | -- | Tr | .1 | -- |
| Biotite | -- | .8 | 1.0 | -- | 5.0 |
| Epidote | 1.8 | .5 | -- | .5 | -- |
| Sphene | -- | .3 | -- | .1 | -- |
| Allanite | Tr | -- | -- | -- | -- |
| Chlorite | -- | 6.4 | 16.0 | -- | 2.0 |
| Muscovite-sericite[2] | -- | -- | 1.4 | -- | 14.0 |
| Garnet | -- | -- | 5.2 | -- | -- |
| Sillimanite | -- | -- | -- | -- | 3.0 |
| Calcite | -- | -- | 1.0 | -- | -- |
| Zircon | -- | Tr | -- | -- | -- |
| Rutile | -- | -- | -- | -- | Tr |

[1]Pyrite.

[2]Muscovite-sericite replaces plagioclase.

# APPENDIX II

## TABLES 19-27, 33-35, AND 37

## STANDARD WET CHEMICAL ANALYSES, SEMIQUANTITATIVE, QUANTATIVE, OPTICAL, AND X-RAY SPECTROGRAPHIC ANALYSES, MODES, AND NORMATIVE AND TRACE MINERALS OF EARLY PROTEROZOIC METAMORPHIC ROCKS IN THE CENTRAL FRONT RANGE

[Sample numbers or map locality numbers with the following prefixes indicate the quadrangle where sample was collected: AP, Allens Park; A, A1, CC, D, EWT, JG, GO, Mary, ST, S, Central City; E, DS, Evergreen; EP, East Portal; GG, Golden Gate; GH, Gold Hill; IH, Indian Hills; SP, Squaw Pass; IS, Idaho Springs; M, Morrison; ML, Monarch Lake; N, Nederland; RB, Ralston Buttes; W, WC, Ward.]

**Table 19.** Standard wet chemical analyses and semiquantitative spectrographic analyses for biotite from biotitic, felsic, and hornblende gneisses, and calculated composition of biotite, central Front Range, Colorado.

[N.d., not looked for; N, not detected; L, detected but below limit of determination; bulk chemical analyses by E.L. Munson; semiquantitative spectrographic analyst, L.A. Bradley]

| Rock type | Biotite gneiss | Sillimanite-biotite gneiss | Pegmatite in sillimanite-biotite gneiss | | Felsic gneiss (microcline gneiss) | | Hornblende gneiss |
|---|---|---|---|---|---|---|---|
| | All from Central City areea | | | | | | Golden Gate |
| Map Locality | 503 | 501 | 504 | 505 | 500 | 502 | 313 |
| Sample No. | ST-14 | ST-2 | ST-7 | ST-10 | ST-1 | ST-5 | GG-4 |
| Laboratory No. | D102138 | D102139 | D102140 | D102141 | D102142 | D102143 | D102144 |
| **Bulk chemical analyses in weight percent** | | | | | | | |
| $SiO_2$ | 36.43 | 35.14 | 34.03 | 36.43 | 35.48 | 35.96 | 37 43 |
| $Al_2O_3$ | 21.19 | 18.64 | 19.21 | 15.97 | 16.36 | 14.90 | 15.77 |
| $Fe_2O_3$ | 2.18 | 2.37 | 3.50 | 3.32 | 2.84 | 3.10 | 2.88 |
| FeO | 18.43 | 19.51 | 20.98 | 18.31 | 21.60 | 21.06 | 14.98 |
| MgO | 6.09 | 7.49 | 5.92 | 9.24 | 7.25 | 8.34 | 12.46 |
| CaO | .00 | .00 | .00 | .00 | .00 | .09 | 1.33 |
| $Na_2O$ | .38 | .21 | .27 | .15 | .20 | .23 | .34 |
| $K_2O$ | 8.42 | 9.39 | 9.45 | 9.53 | 9.28 | 9.33 | 8.01 |
| $H_2O+$ | N.d. | 3.00 | 2.99 | 2.60 | 3.08 | 2.89 | 3.88 |
| $H_2O-$ | .08 | .02 | .03 | .04 | .04 | .05 | .22 |
| $TiO_2$ | 2.37 | 3.47 | 2.78 | 2.91 | 2.08 | 2.73 | 2.13 |
| [1]$P_2O_5$ | N.d. | .01 | .05 | .00 | N.d. | .03 | N.d. |
| MnO | N.d. | .19 | .25 | .48 | .44 | .26 | .20 |
| F | N.d. | .34 | .33 | .99 | 1.36 | .80 | .29 |
| Cl | N.d. | .05 | .13 | .18 | N.d. | .10 | N.d. |
| Subtotal | 95.57 | 99.83 | 99.92 | 100.15 | 100.01 | 99.87 | 99.92 |
| Less O | N.d. | .15 | .17 | .46 | .57 | .36 | .12 |
| Total | 95.57 | 99.68 | 99.75 | 99.69 | 99.44 | 99.51 | 99.80 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | |
| Mn | 1,000 | 1,000 | 1,500 | 3,000 | 3,000 | 3,000 | 1,000 |
| Ba | 700 | 700 | 700 | 700 | 150 | 1,000 | 1,500 |
| Ce | N | N | 200 | N | N | N | N |
| Co | 70 | 100 | 70 | 50 | 10 | 70 | 100 |
| Cr | 300 | 1,000 | 1,000 | 20 | 5 | 50 | 500 |
| Cu | 20 | 50 | 20 | 20 | 5 | 10 | 200 |
| Ga | 70 | 70 | 100 | 100 | 100 | 100 | 50 |
| La | N | N | 200 | N | N | N | N |
| Mo | 10 | 20 | 10 | 10 | 10 | 7 | 7 |
| Nb | 20 | 20 | 20 | 50 | 50 | 20 | N |
| Nd | N | N | 200 | N | N | N | N |
| Ni | 200 | 200 | 200 | 10 | L | 15 | 70 |
| Pb | 20 | 50 | 50 | 50 | N | 20 | N |
| Sc | 70 | 50 | 50 | 50 | 20 | 20 | 10 |
| Sn | N | 20 | 30 | 70 | 70 | N | N |
| Sr | 10 | 10 | 10 | 10 | 10 | 15 | 20 |
| V | 300 | 500 | 700 | 100 | 20 | 150 | 300 |
| Y | 50 | 50 | 1,500 | 10 | 50 | 50 | N |
| Yb | 5 | 2 | 70 | 3 | 5 | 2 | 3 |
| Zn | N | 500 | 500 | N | N | N | N |
| Zr | 200 | 100 | 200 | N | N | 50 | 70 |

Footnotes follow at end of table.

**Table 19.** Standard wet chemical analyses and semiquantitative spectrographic analyses for biotite from biotitic, felsic, and hornblende gneisses, and calculated composition of biotite, central Front Range, Colorado.--Continued

| Rock type --------- | Biotite gneiss | Sillimanite-biotite gneiss | Pegmatite in sillimanite-biotite gneiss | | Felsic gneiss (microcline gneiss) | | Hornblende gneiss |
|---|---|---|---|---|---|---|---|
| Locality ---------- | All from Central City area | | | | | | Golden Gate |
| Map locality No. | ST-14 | ST-2 | ST-7 | ST-10 | ST-1 | ST-5 | GG-4 |
| Laboratory No. -- | D102138 | D102139 | D102140 | D102141 | D102142 | D102143 | D102144 |
| | Composition of biotite on the basis of 24 anions | | | | | | |
| Si------------------- | 5.593 | 5.424 | 5.320 | 5.634 | 5.534 | 5.633 | 5.615 |
| Al ------------------ | 2.407 | 2.576 | 2.680 | 2.366 | 2.466 | 2.367 | 2.385 |
| | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| Al ------------------ | 1.428 | .815 | .859 | .545 | .542 | .383 | .403 |
| Ti ------------------ | .274 | .403 | .327 | .338 | .244 | .322 | .240 |
| $Fe^{+3}$---------------- | .252 | .275 | .412 | .386 | .333 | .365 | .325 |
| $Fe^{+2}$---------------- | 2.367 | 2.519 | 2.743 | 2.368 | 2.818 | 2.759 | 1.879 |
| Mn ----------------- | .025 | .025 | .033 | .063 | .058 | .035 | .025 |
| Mg ----------------- | 1.394 | 1.723 | 1.379 | 2.130 | 1.686 | 1.947 | 2.786 |
| | 5.74 | 5.76 | 5.75 | 5.83 | 5.68 | 5.81 | 5.66 |
| Ca ------------------ | -- | -- | -- | -- | -- | .015 | .214 |
| Na------------------ | .113 | .063 | .082 | .045 | .061 | .070 | .099 |
| K ------------------- | 1.650 | 1.849 | 1.885 | 1.880 | 1.847 | 1.864 | 1.533 |
| | 1.76 | 1.91 | 1.97 | 1.93 | 1.91 | 1.95 | 1.84 |
| F-------------------- | N.d. | .166 | .163 | .484 | .671 | .396 | .138 |
| Cl ------------------ | N.d. | .013 | .034 | .047 | N.d. | .027 | N.d |
| OH ----------------- | 2.991 | 3.068 | 3.087 | 2.641 | 3.163 | 2.967 | 3.662 |
| | N.d. | 3.25 | 3.28 | 3.17 | 3.83 | 3.39 | 3.80 |

[1] $P_2O_5$ is included in $Al_2O_3$.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.

[Analyst for wet chemical analysis of sample with map locality number 388, L.N. Tarrant. Analysts for rapid-rock analyses with sample for locality numbers 329, H.F. Phillip, P.L.D. Elmore, P.W. Scott, K.E. White; 21 and 292, G.H. Smith; 109, 134, 137, 143, Leonard Shapiro; 277, 284, 353, 354, Deborah Kobilis. Analysts for spectrographic analyses for samples from map locality numbers 21, 109, 134, 137, 143, J.L. Harris; 277, 284, 353, 354, Leung Mei. N.d., not determined; N, not detected; --, not found; <, less than; Tr, trace]

| Map locality No. ---- | 388 | 329 | 292 | 134 | 137 | 143 |
|---|---|---|---|---|---|---|
| Sample No. --------- | EWT5a-54 | A1-278-55 | A1-29-55 | W213-70 | W241-70 | W270-70 |
| Lab No. ------------- | A1 | 140575 | 140576 | W178102 | W178103 | W178104 |
| Chemical analyses in weight percent | | | | | | |
| $SiO_2$ ---------------- | 76.33 | 72.0 | 67.9 | 75.4 | 65.1 | 69.8 |
| $Al_2O_3$ ---------------- | 12.30 | 11.9 | 12.7 | 10.8 | 16.1 | 13.7 |
| $Fe_2O_3$ ---------------- | 1.08 | 1.9 | 2.4 | 2.9 | 2.3 | 1.1 |
| FeO ----------------- | 1.75 | 3.2 | 2.9 | 2.4 | 3.4 | 2.9 |
| MgO ----------------- | .59 | 1.5 | 1.8 | 1.6 | 2.1 | 2.5 |
| CaO ----------------- | 2.41 | 1.7 | 1.2 | .34 | 3.8 | 2.2 |
| $Na_2O$ ---------------- | 3.13 | 2.6 | .11 | 1.0 | 3.6 | 2.3 |
| $K_2O$ ----------------- | 1.02 | 2.2 | 4.8 | 3.1 | 2.0 | 4.3 |
| $H_2O+$ --------------- | .42 | 1.0 | 2.5 | 1.5 | .88 | .92 |
| $H_2O-$ ---------------- | .17 | N.d. | N.d. | .15 | .09 | .11 |
| $TiO_2$ ---------------- | .27 | .58 | .74 | .80 | .76 | .33 |
| $P_2O_5$ ---------------- | .03 | .15 | .16 | .06 | .24 | .17 |
| MnO ---------------- | .03 | .12 | .08 | .03 | .06 | .06 |
| $CO_2$ ----------------- | .01 | .64 | 2.0 | .02 | .00 | .04 |
| F -------------------- | N.d. | N.d. | N.d. | .11 | .23 | .24 |
| Cl ------------------- | N.d. | N.d. | N.d. | <.01 | .01 | .01 |
| S (total) ------------- | N.d. | .25 | .21 | .02 | .01 | .04 |
| Total --------------- | 99.54 | 101. | 99. | 100. | 100. | 100. |
| Bulk density -------- | 2.65 | N.d. | N.d. | 2.66 | 2.74 | 2.70 |
| Powder density sink/float ---------- | 2.69 | N.d. | N.d. | 2.76 | 2.76 | 2.96 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | |
| B -------------------- | N.d. | N.d. | N.d. | N | N | N |
| Ba ------------------- | N.d. | N.d. | N.d. | 318 | 279 | 624 |
| Be ------------------- | N.d. | N.d. | N.d. | 1 | N | 3 |
| Ce ------------------- | N.d. | N.d. | N.d. | 51 | 54 | 43 |
| Co ------------------- | N.d. | N.d. | N.d. | 8 | 12 | 5 |
| Cr ------------------- | N.d. | N.d. | N.d. | 66 | 24 | 2 |
| Cu ------------------- | N.d. | N.d. | N.d. | N | 24 | 22 |
| Ga ------------------- | N.d. | N.d. | N.d. | 7 | 15 | 12 |
| Gd ------------------- | N.d. | N.d. | N.d. | 4 | 4 | 4 |
| La ------------------- | N.d. | N.d. | N.d. | 17 | 21 | 17 |
| Mo ------------------- | N.d. | N.d. | N.d. | 1 | 1 | 1 |
| Nb ------------------- | N.d. | N.d. | N.d. | 18 | 3 | 4 |
| Nd ------------------- | N.d. | N.d. | N.d. | N | 20 | 19 |
| Ni -------------------- | N.d. | N.d. | N.d. | 34 | 19 | 1 |
| Pb ------------------- | N.d. | N.d. | N.d. | 3 | 13 | 17 |
| Rb ------------------- | N.d. | N.d. | N.d. | 150 | 100 | 200 |
| Sc ------------------- | N.d. | N.d. | N.d. | 9 | 10 | 8 |
| Sn ------------------- | N.d. | N.d. | N.d. | 4 | 5 | 3 |
| Sr ------------------- | N.d. | N.d. | N.d. | 81 | 407 | 141 |
| V -------------------- | N.d. | N.d. | N.d. | 71 | 93 | 37 |
| Y -------------------- | N.d. | N.d. | N.d. | 4 | 15 | 8 |
| Yb ------------------- | N.d. | N.d. | N.d. | N | 1 | N |
| Zn ------------------- | N.d. | N.d. | N.d. | 45 | 76 | 53 |
| Zr ------------------- | N.d. | N.d. | N.d. | 111 | 101 | 53 |

Footnote follows at end of table.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.--Continued

| Map locality No. | 388 | 329 | 292 | 134 | 137 | 143 |
|---|---|---|---|---|---|---|
| Sample No. | EWT5a-54 | A1-278-55 | A1-29-55 | W213-70 | W241-70 | W270-70 |
| Lab No. | A1 | 140575 | 140576 | W178102 | W178103 | W178104 |
| Modes in volume percent | | | | | | |
| K-feldspar | N.d. | N.d. | N.d. | .2 | .3 | 8.4 |
| Plagioclase | N.d. | N.d. | N.d. | 15.5 | 48.4 | 35.4 |
| Quartz | N.d. | N.d. | N.d. | 55.1 | 31.2 | 27.0 |
| Biotite | N.d. | N.d. | N.d. | 13.3 | 18.4 | 28.6 |
| Opaque minerals | N.d. | N.d. | N.d. | 1.7 | 1.7 | .1 |
| Zircon | N.d. | N.d. | N.d. | Tr | Tr | -- |
| Muscovite-sericite[1] | N.d. | N.d. | N.d. | 13.8 | Tr | .5 |
| Apatite | N.d. | N.d. | N.d. | -- | Tr | Tr |
| Chlorite | N.d. | N.d. | N.d. | .4 | -- | Tr |
| Allanite | N.d. | N.d. | N.d. | -- | -- | -- |
| Epidote | N.d. | N.d. | N.d. | -- | -- | -- |
| Xenotime-monazite | N.d. | N.d. | N.d. | -- | -- | -- |
| Tourmaline | N.d. | N.d. | N.d. | -- | -- | -- |

| Map locality No. | 109 | 21 | 353 | 354 | 277 | 284 |
|---|---|---|---|---|---|---|
| Sample No. | W257-71 | GH175a-75 | RB3-80 | RB4-80 | IS1-80 | IS8-80 |
| Lab No. | W178105 | W192422 | W211761 | W211762 | W211774 | W211781 |
| Chemical analyses in weight percent | | | | | | |
| $SiO_2$ | 77.1 | 61.4 | 74.9 | 73.5 | 65.6 | 68.0 |
| $Al_2O_3$ | 10.9 | 16.1 | 11.0 | 12.5 | 14.5 | 15.4 |
| $Fe_2O_3$ | 1.6 | 3.3 | 3.8 | 3.7 | 3.3 | 2.2 |
| FeO | 2.7 | 4.5 | 3.1 | 2.4 | 3.3 | 2.8 |
| MgO | 1.3 | 2.3 | 1.7 | 1.5 | 1.7 | 1.3 |
| CaO | 2.3 | 3.5 | .18 | .77 | 2.9 | 1.2 |
| $Na_2O$ | 2.4 | 2.8 | .13 | 1.2 | 2.7 | 3.5 |
| $K_2O$ | 1.5 | 2.6 | 3.4 | 3.1 | 3.4 | 2.7 |
| $H_2O+$ | .91 | 1.3 | 1.5 | 1.3 | .58 | .7 |
| $H_2O-$ | .08 | .32 | .14 | .14 | .11 | .13 |
| $TiO_2$ | .58 | 1.4 | 1.0 | 1.1 | 2.6 | 1.2 |
| $P_2O_5$ | .08 | .66 | .07 | .09 | .69 | .11 |
| MnO | .03 | .08 | .08 | .07 | .11 | .05 |
| $CO_2$ | .01 | .02 | .02 | .02 | .02 | .03 |
| F | .10 | .04 | .06 | .07 | .21 | .08 |
| Cl | <.01 | .27 | .002 | .002 | .026 | .008 |
| S (total) | .02 | .02 | .01 | .01 | .01 | .01 |
| Total | 100. | 100. | 101. | 101. | 100. | 99. |
| Bulk density | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | 2.96 | N.d. | N.d. | N.d. | N.d. | N.d. |

Footnote follows at end of table.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.--Continued

| Map locality No. ---- | 109 | 21 | 353 | 354 | 277 | 284 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | W257-71 | GH175a-75 | RB3-80 | RB4-80 | IS1-80 | IS8-80 |
| Lab No. ------------- | W178105 | W192422 | W211761 | W211762 | W211774 | W211781 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | |
| B ---------------------- | N | N | 190 | 7 | N | N |
| Ba --------------------- | 135 | 1,400 | 740 | 420 | 1,200 | 820 |
| Be --------------------- | N | 6 | N | 2 | 3 | 2 |
| Ce --------------------- | 64 | 360 | N | N | 150 | N |
| Co --------------------- | 6 | 18 | 18 | 14 | 16 | 14 |
| Cr --------------------- | 56 | 46 | 200 | 120 | 26 | 110 |
| Cu --------------------- | N | 240 | 4 | 7 | 30 | 4 |
| Ga --------------------- | 9 | 44 | 14 | 12 | 22 | 18 |
| Gd --------------------- | 4 | 15 | N | N | N | N |
| La --------------------- | 37 | 150 | 56 | 40 | 97 | 48 |
| Mo --------------------- | N | 3 | N | N | N | N |
| Nb --------------------- | 6 | 40 | 11 | 11 | 17 | 9 |
| Nd --------------------- | 8 | 190 | 48 | N | 53 | 58 |
| Ni --------------------- | 20 | 28 | 49 | 42 | 17 | 24 |
| Pb --------------------- | 11 | 28 | 10 | 17 | 42 | 26 |
| Rb --------------------- | 100 | N | N | N | N | N |
| Sc --------------------- | 5 | 18 | 12 | 13 | 18 | 15 |
| Sn --------------------- | N | N | N | N | 2 | N |
| Sr --------------------- | 123 | 580 | 46 | 160 | 760 | 280 |
| V ---------------------- | 61 | 120 | 87 | 80 | 92 | 69 |
| Y ---------------------- | 13 | 34 | 24 | 17 | 28 | 42 |
| Yb --------------------- | 1 | 5 | 3 | 2 | 4 | 6 |
| Zn --------------------- | 79 | 160 | 79 | 66 | 110 | 67 |
| Zr --------------------- | 114 | 690 | 110 | 150 | 150 | 160 |
| Modes in volume percent | | | | | | |
| K-feldspar ----------- | 2.5 | -- | -- | -- | 19.0 | 1.5 |
| Plagioclase ----------- | 30.6 | 38.4 | .5 | 4.1 | 30.5 | 30.3 |
| Quartz ---------------- | 51.4 | 26.1 | 58.4 | 56.3 | 32.6 | 52.4 |
| Biotite ---------------- | 12.9 | 29.6 | 19.0 | 17.9 | 15.0 | 11.9 |
| Opaque minerals---- | 1.3 | 3.9 | .7 | 1.8 | 1.8 | .8 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | .3 |
| Muscovite-sericite[1] - | 1.3 | .2 | 21.1 | 19.6 | -- | 2.1 |
| Apatite --------------- | -- | 1.0 | Tr | .3 | .8 | -- |
| Chlorite -------------- | -- | -- | -- | Tr | -- | .7 |
| Allanite -------------- | -- | .1 | -- | -- | .3 | -- |
| Epidote --------------- | -- | .7 | -- | -- | Tr | -- |
| Xenotime-monazite-- | -- | -- | -- | Tr | -- | -- |
| Tourmaline ---------- | -- | -- | .3 | Tr | -- | -- |

[1]Muscovite-sericite is primarily an alteration of plagioclase.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range. Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 340, C.L. Parker; 368, E.S. Daniels. Analysts for rapid-rock analyses for samples number 90, Leonard Shapiro; 73, Hezekiah Smith; 29, Kay Coates and Hezekiah Smith; all others by Deborah Kobilis. Analysts for spectrographic analyses for samples of map number 340, J.C. Hamilton; 368, A.L. Sutton, Jr.; 29, Norma Rait; 19, 23, 26, 28, 73, 90, J.L. Harris; all others by Leung Mei. N.d., not determined; N, not detected; --, not found; Tr, trace; <, less than]

| Map locality No.---- | 368 | 340 | 90 | 73 | 19 | 23 | 26 | 28 | 29 | 322 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | M530b | CC-646 | W66-71 | GH-47-71 | GH153-75 | GH183-75 | GH242-75 | GH294-75 | GH-305-75 | E1-80 |
| Lab No. ------------- | D101108 | I4155 | W178101 | W192418 | W192421 | W192423 | W192424 | W192425 | W194506 | W211758 |
| **Chemical analyses in weight percent** | | | | | | | | | | |
| $SiO_2$ ------------------ | 70.65 | 62.67 | 59.3 | 56.9 | 64.0 | 73.5 | 59.3 | 41.4 | 52.4 | 64.6 |
| $Al_2O_3$ ---------------- | 12.90 | 19.12 | 19.4 | 23.5 | 19.0 | 14.1 | 23.2 | 31.6 | 25.2 | 19.4 |
| $Fe_2O_3$ ---------------- | 1.08 | 2.11 | 6.3 | 5.2 | 4.5 | 1.9 | 5.3 | 6.2 | 2.8 | 1.1 |
| FeO------------------ | 5.02 | 5.13 | 3.0 | 4.3 | 4.0 | 2.0 | 5.0 | 7.9 | 6.3 | 4.2 |
| MgO------------------ | 3.10 | 2.44 | 2.0 | 2.4 | 1.9 | .82 | 2.4 | 3.8 | 2.6 | 1.7 |
| CaO ------------------ | .00 | .29 | .18 | .17 | .03 | .48 | .12 | .18 | 1.4 | .58 |
| $Na_2O$ ---------------- | .42 | .72 | .86 | .65 | .03 | 1.6 | .27 | .33 | .65 | .63 |
| $K_2O$ ------------------ | 3.93 | 4.50 | 4.2 | 4.3 | 2.6 | 3.8 | 2.7 | 4.9 | 4.3 | 4.9 |
| $H_2O+$ ---------------- | 2.10 | 1.48 | 2.8 | .66 | 2.3 | 1.4 | 1.4 | 1.7 | 1.9 | 1.8 |
| $H_2O-$ ----------------- | .08 | .17 | .20 | .20 | .32 | .25 | .22 | .26 | .40 | .27 |
| $TiO_2$ ----------------- | .31 | .95 | 1.0 | 1.2 | 1.0 | .50 | 1.1 | 1.4 | 1.1 | 1.3 |
| $P_2O_5$ ----------------- | .02 | .05 | .15 | .06 | .05 | .04 | .06 | .15 | .85 | .07 |
| MnO------------------ | .05 | .04 | .06 | .04 | .03 | .05 | .10 | .06 | .10 | .09 |
| $CO_2$ ------------------ | .00 | .02 | .01 | .02 | .02 | .02 | .02 | .02 | .01 | .05 |
| F -------------------- | .14 | .02 | .06 | .21 | .13 | .04 | .07 | .45 | .16 | .10 |
| Cl -------------------- | .02 | .11 | <.01 | .01 | .03 | .01 | .02 | .04 | .01 | .024 |
| S (total)- ------------ | -- | -- | .02 | .01 | .00 | .01 | .01 | .00 | N.d. | .01 |
| Subtotal ----------- | 99.82 | 99.82 | 99. | 100. | 100. | 100. | 101. | 101. | 100. | 100. |
| Less O--------------- | .06 | .03 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d | N.d. | N.d. |
| Total --------------- | 99.76 | 99.79 | 99. | 100. | 100. | 100. | 101. | 101. | 100. | 100. |
| Bulk density--------- | N.d. | N.d. | 2.79 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float- ---------- | 2.78 | 2.84 | 2.80 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | | |
| B --------------------- | N | N | N | N | N | N | N | 15 | N | N |
| Ba-------------------- | 500 | 1,000 | 529 | 550 | 190 | 730 | 250 | 260 | 220 | 740 |
| Be-------------------- | 1 | N | 1 | N | 2 | 5 | 10 | 7 | 3 | 2 |
| Ce-------------------- | N | N | 111 | 100 | 250 | 110 | 140 | 210 | 75 | 88 |
| Co-------------------- | 3 | 20 | 18 | 26 | 16 | 9 | 22 | 23 | 12 | 18 |
| Cr-------------------- | N | 300 | 109 | 170 | 120 | 47 | 140 | 240 | 54 | 94 |
| Cu -------------------- | 2 | 7 | 3 | 9 | 16 | 14 | 4 | 11 | 34 | 13 |
| Er-------------------- | N | N | N | N | N | N | N | N | N | N |
| Ga -------------------- | 30 | 50 | 25 | 49 | 68 | 18 | 47 | 100 | 31 | 24 |
| Gd -------------------- | N | N | 9 | N | N | N | N | N | N | N |
| In -------------------- | N | N | N | N | N | N | N | N | N | N |
| La-------------------- | N | 70 | 56 | 34 | 67 | 58 | 49 | 63 | 30 | 69 |
| Mo -------------------- | N | 7 | N | 4 | 8 | 3 | 4 | 4 | N | N |
| Nb -------------------- | N | 45 | 6 | 10 | 57 | 11 | 18 | 33 | 10 | 18 |
| Nd -------------------- | N | N | 44 | N | N | 55 | N | 50 | N | 46 |
| Ni-------------------- | N | 150 | 43 | 69 | 38 | 17 | 57 | 64 | 29 | 39 |
| Pb-------------------- | 10 | 15 | 6 | 29 | 16 | 26 | 14 | 21 | N | 34 |
| Pr -------------------- | N | N | N | N | N | N | N | N | N | N |
| Rb-------------------- | -- | -- | 200 | -- | -- | -- | -- | -- | -- | -- |
| Sc-------------------- | 10 | 30 | 17 | 19 | 19 | 10 | 18 | 20 | 10 | 18 |
| Sn-------------------- | N | N | 5 | N | 15 | N | N | 27 | 11 | N |
| Sr -------------------- | 10 | 300 | 93 | 78 | 16 | 180 | 32 | 30 | 31 | 180 |
| V--------------------- | N | 150 | 89 | 120 | 87 | 49 | 120 | 150 | 70 | 88 |
| Y--------------------- | 50 | 50 | 43 | 15 | 10 | 30 | 11 | 29 | 35 | 19 |
| Yb -------------------- | <7 | 7 | 5 | 5 | 1 | 4 | 2 | 6 | 6 | 3 |
| Zn-------------------- | N | N | 80 | 150 | 280 | 33 | 140 | 250 | 93 | 86 |
| Zr- ------------------- | 150 | 150 | 138 | 69 | 340 | 170 | 280 | 230 | 94 | 85 |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. | 368 | 340 | 90 | 73 | 19 | 23 | 26 | 28 | 29 | 322 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | M530b | CC-646 | W66-71 | GH-47-71 | GH153-75 | GH183-75 | GH242-75 | GH294-75 | GH-305-75 | E1-80 |
| Lab No. | D101108 | 14155 | W178101 | W192418 | W192421 | W192423 | W192424 | W192425 | W194506 | W211758 |
| **Modes in volume percent** | | | | | | | | | | |
| K-feldspar | -- | 14.3 | 3.0 | 16.5 | -- | 7.7 | -- | 13.6 | -- | 7.0 |
| Plagioclase | Tr | 5.4 | 4 | 4.2 | 2.2 | 19.2 | 4.8 | 16.6 | .4 | 37.9 |
| Quartz | 57 | 31.4 | 26 | 20.7 | 43.5 | 51.6 | 43.7 | 29.8 | 13.5 | 24.4 |
| Biotite | 22 | 32.1 | 7 | 23.5 | 27.5 | 13.6 | 25.9 | 25.4 | 47.7 | 23.3 |
| Sillimanite | 2 | 16.3 | 7 | 31.4 | 22.5 | 1.6 | 23.6 | 11.1 | 26.7 | 2.1 |
| Opaque minerals | Tr | .7 | 4 | 3.6 | 2.8 | Tr | 1.7 | 2.8 | 1.4 | Tr |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] | 11 | Tr | 42 | .1 | 1.5 | 6.1 | .3 | .7 | 10.2 | 5.3 |
| Chlorite | 8 | Tr | 7 | -- | -- | .2 | -- | -- | -- | -- |
| Rutile | -- | -- | Tr | -- | -- | -- | Tr | -- | -- | -- |
| Andalusite | Tr | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Map locality No. | 271 | 272 | 273 | 274 | 275 | 276 | 278 | 280 | 282 | 285 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | SP2-80 | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS4-80 | IS6-80 | IS9-80 |
| Lab. No. | W211752 | W211753 | W211754 | W211755 | W211756 | W211757 | W211775 | W211777 | W211779 | W211782 |
| **Chemical analyses in weight percent** | | | | | | | | | | |
| $SiO_2$ | 81.3 | 64.3 | 59.1 | 59.4 | 76.0 | 69.5 | 64.8 | 72.2 | 71.9 | 75.3 |
| $Al_2O_3$ | 8.6 | 18.6 | 19.8 | 22.9 | 10.8 | 16.6 | 18.7 | 13.4 | 15.4 | 13.0 |
| $Fe_2O_3$ | 1.7 | 2.4 | 3.5 | 2.9 | 2.3 | 3.4 | 3.2 | 2.3 | .98 | 1.2 |
| FeO | 2.0 | 3.6 | 4.8 | 5.3 | 3.0 | 3.0 | 4.8 | 3.7 | 2.4 | 1.6 |
| MgO | .68 | 1.7 | 2.0 | 1.7 | 1.2 | 1.6 | 1.7 | 1.7 | 1.1 | .88 |
| CaO | 1.4 | .63 | .96 | .57 | 1.2 | .91 | .55 | .63 | 1.7 | 1.1 |
| $Na_2O$ | 1.4 | 1.4 | 1.8 | .8 | 2.3 | 2.0 | 1.3 | .52 | 3.4 | 2.3 |
| $K_2O$ | 2.4 | 4.4 | 5.4 | 4.0 | 2.5 | 2.7 | 3.3 | 2.6 | 1.9 | 3.0 |
| $H_2O+$ | .61 | 1.8 | 1.6 | 1.1 | .65 | .13 | 1.1 | 2.1 | .86 | 1.1 |
| $H_2O-$ | .10 | .10 | .11 | .03 | .07 | .14 | .08 | .37 | .11 | .27 |
| $TiO_2$ | .78 | 1.5 | 1.7 | 1.7 | .78 | 1.2 | 1.7 | 1.7 | .92 | .48 |
| $P_2O_5$ | .04 | .07 | .13 | .13 | .09 | .06 | .06 | .02 | .07 | .06 |
| MnO | .06 | .10 | .12 | .11 | .09 | .11 | .11 | .08 | .06 | .03 |
| $CO_2$ | .02 | .04 | .03 | .03 | .12 | .09 | .01 | .02 | .04 | .03 |
| F | .04 | .16 | .14 | .10 | .04 | .09 | .13 | .09 | .06 | .04 |
| Cl | .01 | .018 | .024 | .004 | .001 | .017 | .028 | .007 | .008 | .007 |
| S (total) | .01 | .01 | .02 | .01 | .02 | .01 | .01 | .01 | .01 | .01 |
| Subtotal | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 100. |
| Less O | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 100. |
| Bulk density | N.d | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No.---- | 271 | 272 | 273 | 274 | 275 | 276 | 278 | 280 | 282 | 285 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | SP2-80 | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS4-80 | IS6-80 | IS9-80 |
| Lab. No. ------------ | W211752 | W211753 | W211754 | W211755 | W211756 | W211757 | W211775 | W211777 | W211779 | W211782 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | | |
| B--------------------- | N | N | N | N | N | N | N | N | N | N |
| Ba-------------------- | 430 | 500 | 1,100 | 480 | 270 | 450 | 390 | 280 | 380 | 940 |
| Be-------------------- | 1 | 2 | 2 | 2 | N | 2 | 2 | 2 | 2 | 1 |
| Ce-------------------- | N | N | N | N | N | N | N | N | N | N |
| Co-------------------- | 8 | 12 | 22 | 21 | 12 | 16 | 18 | 21 | 9 | 3 |
| Cr-------------------- | 53 | 55 | 120 | 120 | 110 | 95 | 110 | 110 | 49 | 11 |
| Cu-------------------- | 4 | 4 | 5 | 22 | 3 | 6 | 31 | 10 | 6 | 6 |
| Er-------------------- | N | N | N | N | N | N | N | N | N | N |
| Ga-------------------- | 8 | 21 | 25 | 26 | 10 | 25 | 27 | 18 | 15 | 13 |
| Gd-------------------- | N | N | N | N | N | N | N | N | N | N |
| In-------------------- | N | N | N | N | N | N | N | N | N | N |
| La-------------------- | 32 | 43 | 38 | 49 | 41 | 64 | 42 | 60 | 40 | 35 |
| Mo-------------------- | N | N | N | N | N | N | N | N | N | 1 |
| Nb-------------------- | 9 | 15 | 11 | 12 | 10 | 14 | 15 | 18 | 16 | 7 |
| Nd-------------------- | N | 43 | 40 | 43 | 34 | 66 | 32 | 61 | N | 49 |
| Ni-------------------- | 15 | 20 | 44 | 48 | 24 | 22 | 31 | 40 | 15 | 7 |
| Pb-------------------- | 26 | 41 | 48 | 28 | 26 | 26 | 20 | 12 | 30 | 17 |
| Pr-------------------- | N | N | N | N | N | N | N | N | N | N |
| Rb-------------------- | N | N | N | N | N | N | N | N | N | N |
| Sc-------------------- | 8 | 14 | 23 | 22 | 11 | 16 | 16 | 20 | 10 | 12 |
| Sn-------------------- | 5 | 4 | 2 | N | N | 3 | 4 | 2 | 4 | 5 |
| Sr-------------------- | 160 | 190 | 290 | 99 | 240 | 210 | 140 | 93 | 340 | 280 |
| V--------------------- | 48 | 66 | 110 | 120 | 72 | 78 | 75 | 95 | 48 | 18 |
| Y--------------------- | 22 | 62 | 34 | 25 | 23 | 43 | 17 | 18 | 14 | 40 |
| Yb-------------------- | 3 | 5 | 5 | 4 | 2 | 5 | 2 | 3 | 2 | 6 |
| Zn-------------------- | 43 | 100 | 110 | 120 | 74 | 94 | 120 | 130 | 68 | 24 |
| Zr-------------------- | 260 | 170 | 100 | 110 | 290 | 170 | 190 | 200 | 130 | 260 |
| **Modes in volume percent** | | | | | | | | | | |
| K-feldspar ---------- | 8.5 | 2 | 14.6 | 16.3 | 12.0 | 4.9 | 1.8 | 7.2 | .7 | 5.0 |
| Plagioclase --------- | 15.4 | 8 | 14.8 | 6.8 | 17.4 | 13.8 | 16.4 | 8.7 | 38.5 | 32.4 |
| Quartz--------------- | 58.6 | 28 | 19.5 | 24.5 | 51.6 | 40.4 | 36.4 | 48.9 | 46.4 | 36.9 |
| Biotite-------------- | 14.1 | 22 | 25.0 | 27.7 | 16.8 | 14.4 | 24.3 | 20.4 | 10.6 | 11.9 |
| Sillimanite---------- | Tr | 14 | 9.4 | 21.0 | Tr | 14.5 | 16.5 | 11.7 | 1.7 | 2.9 |
| Opaque minerals --- | .4 | Tr | 1.8 | 1.3 | 1.1 | 1.2 | 1.4 | .8 | .4 | 2.0 |
| Zircon--------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1]- | 3.0 | 26 | 14.9 | 2.4 | 1.1 | 10.8 | 3.2 | 2.3 | 1.5 | 7.4 |
| Chlorite------------- | -- | Tr | -- | -- | -- | Tr | -- | -- | .2 | 1.0 |
| Rutile--------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Andalusite----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr | -- |
| Apatite-------------- | -- | -- | Tr | Tr | -- | -- | -- | -- | Tr | -- |
| Epidote-------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .5 |
| Tourmaline---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No | 317 | 318 | 319 | 351 | 352 | 355 | 356 | 357 | 358 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 | RB7-80 | RB8-80 |
| Lab. No. | W211769 | W211770 | W211771 | W211759 | W211760 | W211763 | W211764 | W211765 | W211766 |
| **Chemical analyses in weight percent** | | | | | | | | | |
| $SiO_2$ | 68.8 | 69.6 | 74.3 | 70.3 | 71.4 | 68.6 | 65.2 | 46.5 | 76.9 |
| $Al_2O_3$ | 14.5 | 15.2 | 13.4 | 13.7 | 14.2 | 15.2 | 15.7 | 28.5 | 12.2 |
| $Fe_2O_3$ | 2.4 | 1.6 | 1.3 | 3.1 | 2.9 | 2.2 | 3.8 | 3.2 | 1.9 |
| FeO | 3.6 | 3.2 | 3.4 | 4.5 | 3.6 | 5.2 | 4.1 | 7.1 | 3.0 |
| MgO | 1.9 | 1.4 | 1.0 | 2.1 | 1.6 | 2.4 | 2.1 | 3.3 | 1.1 |
| CaO | 1.0 | .92 | .69 | .65 | .94 | .24 | .29 | .50 | .71 |
| $Na_2O$ | 2.0 | 2.3 | 1.0 | 1.3 | 1.7 | .14 | .55 | .99 | 1.1 |
| $K_2O$ | 4.3 | 3.7 | 2.9 | 2.9 | 2.4 | 3.4 | 5.2 | 4.3 | 2.2 |
| $H_2O+$ | 1.2 | 1.2 | 1.7 | 1.2 | 1.1 | 2.1 | 2.2 | 3.2 | .89 |
| $H_2O-$ | .09 | .39 | .38 | .10 | .11 | .36 | .30 | .57 | .10 |
| $TiO_2$ | 1.0 | 1.0 | 1.3 | 1.3 | 1.2 | 1.4 | 1.4 | 3.0 | .98 |
| $P_2O_5$ | .07 | .06 | .10 | .14 | .12 | .11 | .12 | .13 | .12 |
| MnO | .11 | .08 | .05 | .09 | .11 | .08 | .08 | .09 | .09 |
| $CO_2$ | .02 | .02 | .04 | .03 | .05 | .03 | .06 | .04 | .05 |
| F | .12 | .07 | .06 | .07 | .05 | .09 | .09 | .13 | .04 |
| Cl | .020 | .019 | .008 | .006 | .004 | .015 | .005 | .013 | .007 |
| S (total) | .01 | .01 | .01 | .01 | .01 | .01 | .01 | .01 | <.01 |
| Subtotal | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. |
| Less O | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. |
| Bulk density | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | |
| B | N | N | 16 | 7 | 70 | 21 | 30 | 13 | 23 |
| Ba | 810 | 1,100 | 440 | 300 | 360 | 360 | N | 380 | 290 |
| Be | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 |
| Ce | N | N | N | N | N | N | N | N | N |
| Co | 14 | 11 | 14 | 18 | 20 | 21 | 20 | 24 | 11 |
| Cr | 39 | 61 | 75 | 140 | 150 | 140 | N | 230 | 130 |
| Cu | 17 | 3 | 8 | 32 | 10 | 13 | 3 | 4 | 4 |
| Er | N | N | N | N | N | N | N | 12 | N |
| Ga | 19 | 18 | 14 | 13 | 16 | 17 | 17 | 40 | 10 |
| In | N | N | N | N | N | N | 7 | N | N |
| La | 41 | 45 | 42 | 49 | 36 | 38 | N | 45 | 30 |
| Mo | N | N | N | N | N | N | N | N | N |
| Nb | 17 | 17 | 15 | 15 | 16 | 18 | 8 | 11 | 9 |
| Nd | 48 | 55 | 41 | 38 | N | N | N | 38 | 33 |
| Ni | 15 | 18 | 28 | 51 | 60 | 61 | 49 | 73 | 30 |
| Pb | 43 | 49 | 22 | 24 | 23 | 10 | 13 | 20 | 18 |
| Sc | 15 | 12 | 13 | 14 | 13 | 17 | N | 16 | 10 |
| Sn | 5 | N | N | N | N | N | N | 5 | 5 |
| Sr | 270 | 310 | 200 | 210 | 240 | 20 | 73 | 100 | 150 |
| V | 50 | 57 | 72 | 81 | 85 | 90 | 79 | 98 | 58 |
| Y | 44 | 12 | 24 | 19 | 22 | 25 | 21 | 22 | 34 |
| Yb | 7 | 1 | 2 | 2 | 2 | 3 | 2 | 5 | 5 |
| Zn | 95 | 56 | 73 | 130 | 130 | 140 | N | 160 | 64 |
| Zr | 180 | 120 | 180 | 190 | 130 | 160 | 91 | 120 | 150 |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No.---- | 317 | 318 | 319 | 351 | 352 | 355 | 356 | 357 | 358 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 | RB7-80 | RB8-80 |
| Lab. No. ------------- | W211769 | W211770 | W211771 | W211759 | W211760 | W211763 | W211764 | W211765 | W211766 |
| **Modes in volume percent** | | | | | | | | | |
| K-feldspar ----------- | 7.1 | 5.8 | 2.2 | -- | -- | -- | -- | -- | .7 |
| Plagioclase ---------- | 18.3 | 22.2 | 7.8 | 2.2 | 8.1 | .3 | 1.5 | 2 | 9.8 |
| Quartz---------------- | 48.8 | 61.2 | 62.9 | 52.1 | 49.0 | 45.5 | 43.7 | 1 | 55.6 |
| Biotite---------------- | 19.9 | -- | 16.3 | 25.4 | 25.7 | 31.0 | 18.5 | 64 | 15.9 |
| Sillimanite---------- | Tr | 3.9 | 5.6 | 11.7 | 7.0 | 15.9 | Tr | 31 | 5.3 |
| Opaque minerals --- | .4 | Tr | Tr | 1.2 | 1.5 | .1 | 1.0 | 1 | .3 |
| Zircon---------------- | Tr | Tr | Tr | Tr | .1 | Tr | .1 | Tr | Tr |
| Muscovite-sericite[1]- | 5.5 | 6.0 | 5.2 | 7.4 | 4.0 | 7.2 | 35.0 | 1 | 12.4 |
| Chlorite-------------- | -- | .9 | -- | -- | -- | -- | .1 | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite----------- | -- | -- | -- | -- | 4.5 | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | Tr | -- | -- | -- | Tr | -- | -- |
| Apatite--------------- | Tr | -- | Tr | Tr | Tr | Tr | .1 | -- | Tr |
| Epidote--------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline---------- | -- | -- | -- | -- | .1 | Tr | Tr | -- | -- |

[1]Muscovite-sericite mostly retrograde after plagioclase and sillimanite.

**Table 22.** Chemical and spectrographic analyses and modes for garnet-biotite gneiss and garnet-hornblende-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 247, P.D.L. Elmore, S.D. Botts, Gillison Chloe, J.L. Glenn, Hezekiah Smith, Lowell Artis, James Kelsey; 17, H.F. Phillip, P.D.L. Elmore, P.W. Scott, K.E. White; all other analyses by Leung Mei. Analysts for spectrographic analyses with map locality number 17, R.G. Havens; all others by J.L. Harris. N.d., not determined; N, not detected; N.A., not available; --, not found; <, less than; Tr, trace]

| | Garnet-biotite gneiss | | | | | Garnet-hornblende-biotite gneiss | |
|---|---|---|---|---|---|---|---|
| Map locality No. | 247 | 303 | 305 | 315 | 281 | 17 | 320 |
| Sample No. | N636-64 | ML8a-1 | ML-10 | IH1-80 | IS5-80 | A1-24a-55 | IH6-80 |
| Lab No. | W173200 | W197383 | W197384 | W211767 | W211778 | 140570 | W211772 |
| Chemical analyses in weight percent | | | | | | | |
| $SiO_2$ | 68.4 | 60.8 | 60.7 | 53.9 | 65.6 | 58.1 | 74.8 |
| $Al_2O_3$ | 12.8 | 15.6 | 15.6 | 13.4 | 18.1 | 14.3 | 10.8 |
| $Fe_2O_3$ | 2.0 | 1.8 | 2.0 | 10.9 | 1.4 | 4.5 | 2.6 |
| FeO | 4.7 | 8.5 | 8.4 | 9.8 | 2.5 | 5.4 | 3.2 |
| MgO | 2.4 | 2.4 | 2.3 | 2.3 | 1.5 | 3.0 | .74 |
| CaO | .83 | 3.0 | 2.4 | 1.7 | 11.8 | 5.2 | .80 |
| $Na_2O$ | 1.8 | 2.0 | 2.0 | 2.2 | 3.1 | 1.2 | 1.4 |
| $K_2O$ | 5.1 | 3.0 | 3.0 | 2.6 | 1.9 | 2.6 | 5.0 |
| $H_2O+$ | .97 | 1.9 | 1.4 | .91 | 1.2 | 1.8 | .62 |
| $H_2O-$ | .13 | .13 | .12 | .13 | .12 | N.d. | .07 |
| $TiO_2$ | .60 | .67 | .67 | 1.1 | .59 | 1.4 | 1.0 |
| $P_2O_5$ | .09 | .15 | .16 | .15 | .10 | .62 | .12 |
| MnO | .07 | .13 | .13 | 1.5 | .14 | .14 | .11 |
| $CO_2$ | <.05 | .34 | .41 | .07 | .31 | .70 | .12 |
| F | .10 | .10 | .10 | .10 | .07 | N.d. | .03 |
| Cl | N.d. | .02 | .02 | .03 | .065 | N.d. | .004 |
| S (total) | N.d. | .02 | .03 | N.d. | .01 | .19 | .01 |
| Total | 100. | 101. | 99. | 101. | 101. | 99. | 101. |
| Bulk density | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d |
| Powder density sink/float | 3.12 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | |
| Ba | 1,000 | 310 | 300 | N | 300 | 300 | 1,500 |
| Be | N | 2 | 2 | 1 | 3 | 1 | 2 |
| Ce | 300 | 97 | 59 | N | N | 150 | 78 |
| Co | 10 | 12 | 13 | 21 | 7 | 70 | 9 |
| Cr | 150 | 67 | 75 | 65 | 22 | 30 | 2 |
| Cu | 7 | 11 | 12 | 440 | 7 | 70 | 10 |
| Eu | N | N | N | N | N | N | 3 |
| Ga | 20 | 22 | 24 | 24 | 23 | 15 | 42 |
| Ge | N | N | N | 2 | N | N | 2 |
| La | 100 | 36 | 22 | 35 | 44 | 150 | 47 |
| Mo | 3 | 3 | 2 | N | N | 15 | N |
| Nb | 10 | 10 | 9 | 7 | 10 | N | 19 |
| Nd | N | N | N | N | N | 150 | 35 |
| Ni | 30 | 20 | 19 | 28 | 10 | 70 | 4 |
| Pb | 30 | 20 | 19 | 31 | 22 | 15 | 49 |
| Pt | N | N | N | 5 | N | N | N |
| Sc | 20 | 16 | 14 | 8 | 15 | 30 | 17 |
| Sn | N | N | N | N | 2 | N | 7 |
| Sr | 150 | 170 | 140 | 160 | 290 | 700 | 160 |
| V | 50 | 75 | 74 | 59 | 35 | 300 | 9 |
| Y | 70 | 22 | 19 | 11 | 47 | 70 | 38 |
| Yb | 7 | 4 | 4 | 1 | 12 | <10 | 9 |
| Zn | N | 230 | 230 | N | 77 | Tr | 140 |
| Zr | 200 | 110 | 65 | 120 | 250 | 300 | 220 |

Footnotes follow at end of table.

**Table 22.** Chemical and spectrographic analyses and modes for garnet-biotite gneiss and garnet-hornblende-biotite gneiss, central Front Range, Colorado.--Continued

| | Garnet-biotite gneiss | | | | | Garnet-hornblende-biotite gneiss | |
|---|---|---|---|---|---|---|---|
| Map locality No. ---- | 247 | 303 | 305 | 315 | 281 | 17 | 320 |
| Sample No. ---------- | N636-64 | ML8a-1 | ML-10 | IH1-80 | IS5-80 | A1-24a-55 | IH6-80 |
| Lab No. ------------- | W173200 | W197383 | W197384 | W211767 | W211778 | 140570 | W211772 |
| | Modes in volume percent | | | | | | |
| K-feldspar ----------- | 24.9 | 1.9 | 1.1 | 9.4 | .5 | N.A. | 29.5 |
| Plagioclase---------- | 20.9 | 27.2 | 34.5 | 21.3 | 38.8 | N.A. | 13.1 |
| Quartz---------------- | 37.7 | 28.1 | 34.5 | 21.7 | 25.9 | N.A. | 40.0 |
| Biotite --------------- | 13.2 | 21.7 | 22.4 | 30.3 | 17.9 | N.A. | 13.0 |
| Garnet --------------- | 1.8 | 17.7 | 6.1 | 2.7 | Tr | N.A. | Tr |
| Opaque minerals---- | .7 | .3 | -- | 2.7 | 1.3 | N.A. | 1.0 |
| Hornblende --------- | -- | -- | -- | -- | -- | N.A. | .7 |
| Zircon --------------- | Tr | -- | Tr | Tr | Tr | N.A. | -- |
| Allanite ------------- | -- | -- | -- | -- | -- | N.A. | Tr |
| Rutile ---------------- | Tr | .4 | -- | -- | -- | N.A. | -- |
| Muscovite-sericite[1] - | .5 | .4 | .5 | 11.9 | [2]15.0 | N.A. | 2.0 |
| Chlorite ------------- | .3 | 2.0 | .5 | -- | N.d. | N.A. | -- |
| Apatite -------------- | -- | .2 | Tr | Tr | .2 | N.A. | Tr |
| Xenotime-monazite- | -- | .1 | -- | Tr | -- | N.A. | -- |
| Calcite--------------- | -- | -- | .4 | Tr | .4 | N.A. | -- |
| Sphene -------------- | -- | -- | -- | -- | -- | N.A. | .4 |
| Epidote-------------- | -- | -- | -- | -- | -- | N.A. | 3 |

[1]Muscovite-sericite is mostly an alteration of plagioclase.
[2]Included in biotite.

**Table 23.** Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 257, 368, and 389, E.S. Daniels; 349 by C.L. Parker. Analysts for rapid-rock analyses for samples with map locality number 255 by P.L.D. Elmore, Lowell Artis, J.L. Glenn, Gillison Chloe, Hezekiah Smith, James Kelsey, and S.D. Botts; 88, 118, 149, and 152 by Leonard Shapiro; 18, by Kay Coates and Hezekiah Smith; 325, Z.A. Hamlin; 283, 316, 321, by Deborah Kobilis. Analysts for spectrographic analyses of samples from map locality numbers 88, 118, 149, 152, 325, J.L. Harris; 257, 389, Joseph Haffty; 368, A.L. Sutton, Jr.; 18, Norma Rait; 349, J.C. Hamilton; 283, 316, 321, Leung Mei. N.d., not determined; N, not detected; --, not found; <, less than; >, greater than; Tr, trace]

| Map locality No. ---- | 389 | 257 | 368 | 255 | 118 | 149 | 152 |
|---|---|---|---|---|---|---|---|
| Sample No. --------- | CC-871a | N223a | M530a | N-167 | WC31-70 | W295-70 | W321a-70 |
| Lab No. ------------- | D100276 | D100278 | D101107 | W173199 | W178097 | W178099 | W178100 |
| Chemical analyses in weight percent | | | | | | | |
| $SiO_2$ ------------------ | 57.93 | 53.88 | 71.22 | 49.5 | 54.4 | 53.5 | 78.6 |
| $Al_2O_3$ ---------------- | 21.82 | 23.61 | 12.34 | 19.4 | 22.2 | 25.6 | 11.0 |
| $Fe_2O_3$ ---------------- | 1.08 | 1.24 | 1.04 | 5.9 | 1.6 | 1.9 | 1.4 |
| FeO ------------------- | 7.02 | 6.71 | 5.87 | 6.2 | 7.7 | 6.6 | 2.6 |
| MgO ------------------ | 2.91 | 2.75 | 2.87 | 3.3 | 2.4 | 2.3 | 1.5 |
| CaO ------------------- | .46 | .39 | .00 | 4.5 | .40 | .33 | .35 |
| $Na_2O$ ---------------- | .94 | 1.18 | .35 | 4.1 | .86 | .69 | .38 |
| $K_2O$ ------------------ | 5.17 | 7.39 | 3.06 | 2.2 | 5.1 | 5.3 | 2.1 |
| $H_2O+$ --------------- | 1.21 | 1.28 | 2.34 | 1.6 | 2.6 | 3.0 | 1.2 |
| $H_2O-$ ---------------- | .10 | .09 | .14 | .16 | .15 | .15 | .13 |
| $TiO_2$ ------------------ | 1.09 | .90 | .30 | 1.7 | 1.2 | 1.0 | .69 |
| $P_2O_5$ ------------------ | .07 | .08 | .02 | .42 | .11 | .11 | .05 |
| MnO ------------------ | .05 | .12 | .12 | .07 | .15 | .08 | .02 |
| $CO_2$ ------------------- | .01 | .04 | .00 | .15 | .01 | .01 | .03 |
| F ----------------------- | .14 | .15 | .13 | .12 | .23 | .10 | .05 |
| Cl --------------------- | .02 | .05 | .02 | N.d. | .09 | .03 | .03 |
| S (total) -------------- | N.d. | N.d. | N.d. | N.d. | .04 | .00 | .01 |
| Subtotal ------------ | 100.02 | 99.86 | 99.82 | 99. | 99. | 100. | 100. |
| Less 0 -------------- | .06 | .07 | .05 | N.d. | N.d. | N.d. | N.d. |
| Total --------------- | 99.96 | 99.79 | 99.77 | 99. | 99. | 100. | 100. |
| Bulk density --------- | N.d. | N.d. | N.d. | 2.86 | 2.81 | 2.80 | 2.52 |
| Powder density sink/float ----------- | N.d. | N.d. | 2.79 | 3.12 | 2.92 | 2.88 | 2.72 |
| Spectrographic analyses in parts per million | | | | | | | |
| B ---------------------- | N | N | N | N | N | N | N |
| Ba --------------------- | 700 | 1,500 | 300 | 300 | 467 | 709 | 254 |
| Be --------------------- | N | N | 1 | 1 | N | N | N |
| Ce --------------------- | 300 | 300 | N | 300 | 97 | 135 | 73 |
| Co --------------------- | 20 | 20 | 3 | 50 | 17 | 16 | 7 |
| Cr --------------------- | 150 | 150 | N | 500 | 144 | 117 | 50 |
| Cu --------------------- | 20 | 10 | 30 | 50 | 15 | 11 | N |
| Ga --------------------- | 30 | 30 | 50 | 30 | 30 | 23 | 9 |
| Gd --------------------- | -- | -- | -- | N | 7 | 7 | 8 |
| La --------------------- | 50 | 70 | N | 100 | 44 | 71 | 42 |
| Mo --------------------- | N | N | 15 | 5 | 2 | 2 | N |
| Nb --------------------- | N | N | N | 10 | 10 | 8 | 7 |
| Nd --------------------- | 150 | 200 | -- | N | 27 | 56 | 26 |
| Ni --------------------- | 100 | 100 | N | 70 | 72 | 53 | 17 |
| Pb --------------------- | 15 | 30 | 10 | 10 | 6 | 9 | 3 |
| Pr --------------------- | -- | -- | -- | -- | 8 | 10 | 6 |
| Rb --------------------- | -- | -- | -- | -- | 200 | 200 | 100 |
| Sc --------------------- | 30 | 30 | 7 | 20 | 31 | 20 | 5 |
| Sn --------------------- | N | N | N | N | 6 | 6 | N |
| Sr --------------------- | 200 | 300 | 7 | 1,000 | 124 | 110 | 41 |
| V ---------------------- | 150 | 150 | N | 300 | 143 | 113 | 54 |
| Y ---------------------- | 30 | 30 | 30 | 70 | 43 | 32 | 14 |
| Yb --------------------- | 3 | 3 | <5 | 7 | 5 | 4 | 1 |
| Zn --------------------- | N | N | N | N | 81 | 115 | 43 |
| Zr --------------------- | 150 | 100 | 150 | 100 | 109 | 109 | 295 |

**Table 23**. Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. ---- | 389 | 257 | 368 | 255 | 118 | 149 | 152 |
|---|---|---|---|---|---|---|---|
| Sample No. --------- | CC-871a | N223a | M530a | N-167 | WC31-70 | W295-70 | W321a-70 |
| Lab No. ------------ | D100276 | D100278 | D101107 | W173199 | W178097 | W178099 | W178100 |
| | | | | Modes in volume percent | | | |
| K-feldspar ---------- | 15.6 | 24.6 | -- | 10.3 | .2 | 1.0 | 4.3 |
| Plagioclase---------- | 7.4 | 10.5 | .1 | 25.0 | 6.5 | 6 | 2.6 |
| Quartz --------------- | 31.2 | 12.9 | 51.8 | 42.8 | 41.0 | 19 | 70.8 |
| Biotite --------------- | 29.1 | 28.9 | 15.5 | 14.4 | 26.1 | 15 | 12.7 |
| Garnet --------------- | 4.8 | 8.7 | Tr | 2.2 | .7 | 4 | Tr |
| Sillimanite---------- | 10.7 | 7.2 | 3.5 | 1.9 | 8.9 | 7 | 4.3 |
| Opaque minerals---- | .4 | Tr | .1 | 1.4 | 1.0 | 4 | .2 |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] - | .8 | 6.4 | 17.1 | 1.7 | 15.0 | 43 | 5.1 |
| Spinel --------------- | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite ---------- | -- | -- | -- | -- | -- | Tr | Tr |
| Rutile---------------- | -- | Tr | -- | -- | -- | -- | -- |
| Chlorite ------------- | -- | .8 | 11.9 | -- | .6 | .1 | -- |
| Apatite -------------- | Tr | -- | -- | .3 | -- | -- | -- |
| Monazite-xenotime- | -- | -- | -- | -- | -- | -- | -- |

| Map locality No. ---- | 88 | 18 | 325 | 349 | 283 | 316 | 321 |
|---|---|---|---|---|---|---|---|
| Sample No. -------- | W41-71 | GH91-75 | EP2a | EWT90b | IS7-80 | IH2-80 | IH7-80 |
| Lab No. ------------ | W178098 | W194505 | W197378 | I4158 | W211780 | W211768 | W211773 |
| | | | | Chemical analyses in weight percent | | | |
| $SiO_2$ ---------------- | 68.5 | 55.0 | 47.6 | 63.23 | 67.5 | 69.3 | 70.8 |
| $Al_2O_3$--------------- | 15.1 | 25.0 | 15.3 | 17.39 | 17.4 | 15.1 | 14.1 |
| $Fe_2O_3$--------------- | 1.8 | .92 | 5.7 | 3.03 | 1.1 | 4.0 | 2.1 |
| FeO ------------------ | 3.3 | 6.7 | 7.0 | 5.95 | 4.4 | 2.5 | 3.5 |
| MgO ----------------- | 2.8 | 2.5 | 3.1 | 2.67 | 1.5 | 1.2 | 1.5 |
| CaO------------------ | .42 | 1.0 | 6.8 | 6.36 | 1.0 | 1.0 | 1.8 |
| $Na_2O$ --------------- | 1.1 | 1.8 | 5.6 | .62 | 1.5 | 2.3 | 3.3 |
| $K_2O$----------------- | 3.6 | 3.7 | 1.3 | 3.69 | 2.6 | 3.4 | 2.0 |
| $H_2O+$ --------------- | 3.1 | 1.9 | 4.3 | 1.30 | 1.5 | 1.2 | .98 |
| $H_2O-$ --------------- | .12 | .32 | .61 | .20 | .17 | .08 | .19 |
| $TiO_2$ ---------------- | .47 | 1.0 | 2.2 | 1.08 | 1.5 | 1.0 | .9 |
| $P_2O_5$ ---------------- | .10 | .07 | .9 | .06 | .08 | .07 | .05 |
| MnO----------------- | .05 | .06 | .23 | .09 | .26 | .20 | .11 |
| $CO_2$------------------ | .00 | .01 | .00 | .01 | .04 | .05 | .05 |
| F--------------------- | .17 | .07 | .11 | .01 | .08 | .09 | .07 |
| Cl -------------------- | >.01 | .02 | .01 | .11 | .020 | .013 | .013 |
| S (total) ------------ | .00 | N.d. | .01 | .00 | .01 | .01 | .02 |
| Subtotal------------ | 100. | 100. | 101. | 99.80 | 101. | 101. | 101. |
| Less 0 -------------- | N.d. | N.d. | N.d. | .03 | N.d. | N.d. | N.d. |
| Total --------------- | 100. | 100. | 101. | 99.77 | 101. | 101. | 101. |
| Bulk density -------- | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ---------- | 2.72 | N.d. | N.d. | 2.88 | N.d. | N.d. | N.d. |

Footnote follows at end of table.

**Table 23.** Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. | 88 | 18 | 325 | 349 | 283 | 316 | 321 |
|---|---|---|---|---|---|---|---|
| Sample No. | W41-71 | GH91-75 | EP2a | EWT90b | IS7-80 | IH2-80 | IH7-80 |
| Lab No. | W178098 | W194505 | W197378 | 14158 | W211780 | W211768 | W211773 |
| Spectrographic analyses in parts per million | | | | | | | |
| B | N | N | 40 | N | N | N | N |
| Ba | 287 | 550 | 320 | 1,000 | 460 | 840 | 250 |
| Be | 2 | 3 | 2 | N | 2 | 2 | 3 |
| Ce | 111 | 97 | 80 | N | N | N | 100 |
| Co | 4 | 15 | 23 | 30 | 22 | 13 | 11 |
| Cr | 13 | 100 | 6 | 200 | 70 | 63 | N |
| Cu | N | 17 | 27 | 15 | 50 | 5 | 100 |
| Ga | 14 | 40 | 30 | 50 | 18 | 16 | 16 |
| Gd | 7 | N | N | -- | N | N | N |
| La | 67 | 35 | 32 | 70 | 60 | 34 | 71 |
| Mo | N | N | 2 | 7 | N | N | N |
| Nb | 10 | 8 | 12 | 15 | 18 | 15 | 14 |
| Nd | 43 | N | N | N | 51 | 34 | N |
| Ni | 8 | 36 | 11 | 100 | 28 | 14 | 16 |
| Pb | 4 | 26 | 23 | 10 | 28 | 25 | 29 |
| Pr | 9 | N | N | N | N | N | N |
| Rb | 200 | -- | N | -- | N | N | N |
| Sc | 4 | 15 | 9 | 50 | 19 | 11 | N |
| Sn | 5 | N | N | N | N | N | 3 |
| Sr | 34 | 180 | 420 | 300 | 220 | 260 | 300 |
| V | 35 | 96 | 94 | 200 | 79 | 49 | 59 |
| Y | 39 | 96 | 22 | 50 | 28 | 15 | 43 |
| Yb | 3 | 10 | 5 | 7 | 3 | 4 | 4 |
| Zn | 37 | 120 | 140 | 150 | 93 | 79 | 130 |
| Zr | 163 | 66 | 150 | N | 200 | 130 | 160 |
| Modes in volume percent | | | | | | | |
| K-feldspar | 5.0 | 2.2 | 13.8 | 7.0 | .8 | 1.0 | -- |
| Plagioclase | 4 | 25.0 | 5.2 | 7.1 | 13.9 | 21.4 | 4.4 |
| Quartz | 43 | 25.0 | 59.2 | 41.2 | 37.8 | 41.0 | 66.8 |
| Biotite | 10 | 34.8 | 15.4 | 32.0 | 24.7 | 12.7 | 18.2 |
| Garnet | Tr | Tr | Tr | .5 | 1.1 | Tr | 1.3 |
| Sillimanite | Tr | 10.4 | 4.8 | 10.3 | 13.3 | 1.0 | 8.8 |
| Opaque minerals | Tr | .2 | Tr | 1.7 | .2 | 2.2 | Tr |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] | 34 | 2.1 | 1.5 | .2 | 7.4 | 20.7 | .5 |
| Spinel | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | Tr | -- | -- | -- | -- | -- | -- |
| Rutile | Tr | -- | Tr | -- | -- | -- | -- |
| Chlorite | 4 | .3 | .1 | -- | .6 | -- | -- |
| Apatite | -- | -- | -- | Tr | .2 | -- | Tr |
| Monazite-xenotime | -- | -- | -- | -- | -- | Tr | -- |

[1]Muscovite-sericite replaces plagioclase.

**Table 24.** Chemical and spectrographic analyses and modes for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 121, 123, 156, Leonard Shapiro; 192, P.D.L. Elmore, Hezekiah Smith, Lowell Artis, Gillison Chloe, S.D. Botts, J.L. Glenn; 58, Hezekiah Smith; 31 and 63, Kay Coates, and Hezekiah Smith; 301 and 309, Z.A. Hamlin. Analysts for spectrographic analyses for samples with locality numbers 121, 123, 156, 192, 301, 309, J.L. Harris; 31 and 63, Norma Rait. N.d., not determined; N, not detected; --, not found; <, less than; Tr, trace]

| Map Locality No. --- | 121 | 123 | 156 | 192 | 63 | 58 | 31 | 301 | 309 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W12b-70 | W64-70 | W330a-70 | N146-65 | GH3a-72 | GH190-73 | GH331-75 | ML-6 | ML-15 |
| Lab No. -------------- | W178089 | W178090 | W178091 | W168101 | W194509 | W184717 | W194507 | W197380 | W197386 |
| | | | | Chemical analyses in weight percent | | | | | |
| $SiO_2$ ------------------ | 50.5 | 71.3 | 64.8 | 56.5 | 56.1 | 47.6 | 73.0 | 59.7 | 66.7 |
| $Al_2O_3$------------------ | 21.3 | 12.8 | 17.3 | 22.5 | 23.8 | 32.0 | 12.6 | 20.5 | 17.2 |
| $Fe_2O_3$------------------ | 2.9 | 2.4 | 5.0 | .72 | 5.6 | 1.0 | 4.9 | 5.3 | 2.5 |
| FeO ------------------- | 8.3 | 3.9 | 2.9 | 8.2 | 4.3 | 9.0 | 3.3 | 2.6 | 3.6 |
| MgO------------------ | 3.5 | 2.1 | 1.7 | 3.1 | 2.2 | 6.8 | 1.2 | 1.7 | 2.1 |
| CaO------------------- | .63 | 1.0 | .92 | .65 | .52 | .16 | .13 | .39 | .93 |
| $Na_2O$ ----------------- | 1.7 | 1.8 | 1.7 | .85 | .95 | .29 | .21 | 1.5 | 1.4 |
| $K_2O$------------------- | 6.4 | 2.7 | 3.5 | 4.4 | 3.5 | .43 | 1.2 | 4.3 | 2.5 |
| $H_2O+$ ----------------- | 1.6 | 1.4 | 1.2 | 1.4 | .93 | 1.3 | .81 | 1.4 | 1.8 |
| $H_2O-$------------------ | .14 | .12 | .15 | .15 | .39 | .12 | .40 | .36 | .36 |
| $TiO_2$ ------------------ | 1.4 | .79 | .98 | 1.0 | 1.1 | .47 | 1.1 | .89 | .40 |
| $P_2O_5$ ------------------ | .13 | .06 | .09 | .08 | .06 | .01 | .03 | .12 | .08 |
| MnO------------------ | .10 | .03 | .05 | .14 | .06 | .12 | .05 | .63 | .07 |
| $CO_2$------------------ | .04 | .01 | .02 | <.05 | .00 | .02 | .01 | .00 | .00 |
| F----------------------- | .12 | .07 | .05 | N.d. | .04 | .02 | .06 | .13 | .06 |
| Cl --------------------- | .03 | .02 | .02 | N.d. | .02 | N.d. | N.d. | .02 | .01 |
| S (total) -------------- | .10 | .01 | .00 | N.d. | N.d. | .13 | N.d. | .01 | .01 |
| Total ---------------- | 99. | 100. | 100. | 100. | 99. | 99. | 100. | 100. | 100. |
| Bulk density --------- | 2.71 | 2.70 | 2.83 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ----------- | 2.84 | 2.72 | 2.83 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| | | | Semiquantitative spectrographic analyses in parts per million | | | | | | |
| Ba -------------------- | 1,200 | 296 | 458 | N | 440 | N | 70 | 530 | 340 |
| Be -------------------- | 3 | N | N | N | 2 | 67 | N | 5 | 19 |
| Ce -------------------- | 109 | 49 | 75 | 500 | 100 | N | 44 | 75 | 100 |
| Co-------------------- | 24 | 11 | 23 | 30 | 21 | 22 | 12 | 16 | 13 |
| Cr -------------------- | 141 | 81 | 107 | 100 | 130 | 196 | 67 | 110 | 820 |
| Cu-------------------- | 22 | N | N | 70 | N | 9,460 | 3 | 6 | 59 |
| Ga-------------------- | 55 | 11 | 27 | 15 | 37 | 44 | 16 | 42 | 26 |
| La -------------------- | 54 | 27 | 34 | 150 | 45 | N | 18 | 26 | 43 |
| Mo ------------------- | 1 | 1 | N | 7 | N | N | N | N | 6 |
| Nb-------------------- | 11 | 4 | 11 | 15 | 7 | N | 6 | 13 | 5 |
| Nd-------------------- | 39 | 19 | 19 | 150 | N | N | N | N | N |
| Ni -------------------- | 63 | 45 | 64 | 70 | 45 | 58 | 30 | 38 | 440 |
| Pb -------------------- | 12 | 6 | 38 | 10 | 28 | 12 | 10 | 40 | 12 |
| Pr -------------------- | 8 | 4 | 5 | -- | N | N | N | N | N |
| Rb-------------------- | N | 70 | 100 | -- | N | N | N | N | N |
| Sc -------------------- | 3 | 4 | 16 | 20 | 18 | 3 | 11 | 13 | 5 |
| Sn-------------------- | N | 4 | 9 | N | 9 | N | N | N | 11 |
| Sr -------------------- | 3 | 148 | 198 | 10 | 94 | 3 | 19 | 130 | 62 |
| V --------------------- | 24 | 76 | 121 | 70 | 100 | 24 | 70 | 83 | 73 |
| Y --------------------- | N | 17 | 9 | 50 | 16 | N | 5 | 20 | 8 |
| Yb-------------------- | N | 1 | 1 | 5 | 3 | N | 1 | 6 | 1 |
| Zn-------------------- | 299 | 85 | 99 | N | 130 | 299 | 110 | 110 | 89 |
| Zr -------------------- | 188 | 128 | 136 | 300 | 65 | 188 | 150 | 93 | 81 |

Footnote follows at end of table.

**Table 24.** Chemical and spectrographic analyses and modes for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map Locality No. --- | 121 | 123 | 156 | 192 | 63 | 58 | 31 | 301 | 309 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W12b-70 | W64-70 | W330a-70 | N146-65 | GH3a-72 | GH190-73 | GH331-75 | ML-6 | ML-15 |
| Lab No. -------------- | W178089 | W178090 | W178091 | W168101 | W194509 | W184717 | W194507 | W197380 | W197386 |
| | | | | Modes in volume percent | | | | | |
| K-feldspar ---------- | 41.8 | 4.2 | 11.7 | 1 | 24 | -- | .1 | 25.7 | 1.5 |
| Plagioclase---------- | 11.8 | 14.6 | 25.7 | 1 | 8 | -- | 2.4 | 14.9 | 22.0 |
| Quartz--------------- | .9 | 46.8 | 33.3 | 11 | 25 | 1 | 69.2 | 37.2 | 41.6 |
| Cordierite----------- | 11.3 | 14.0 | 4.4 | 27 | 10 | 80 | 4.4 | 9.1 | 22.0 |
| Biotite--------------- | 27.5 | 13.4 | 9.7 | 44 | 13 | 13 | 5.5 | 2.4 | 8.9 |
| Sillimanite---------- | 5.0 | 1.6 | 9.7 | 14 | 16 | 5 | 11.9 | 8.2 | 1.6 |
| Opaque minerals---- | 1.3 | 2.8 | 4.5 | Tr | 4 | 1 | 3.4 | 2.0 | 1.2 |
| Zircon--------------- | Tr | .4 | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite ---------- | .4 | Tr | -- | 1 | -- | Tr | -- | -- | .3 |
| Rutile---------------- | -- | -- | -- | Tr | -- | -- | -- | Tr | -- |
| Spinel-Högbomite -- | -- | Tr | Tr | Tr | -- | -- | -- | -- | Tr |
| Chlorite ------------- | -- | .6 | .1 | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[1] - | -- | 1.6 | .9 | 1 | Tr | -- | 3.1 | .4 | .9 |
| Allanite ------------- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | -- | -- | -- | -- | Tr | Tr | Tr |

[1]Muscovite-sericite replaces plagioclase.

**Table 25.** Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 345, 349, 367, C.L. Parker. Analysts for rapid-rock analysts for samples from map locality numbers 108, 116, 122, 127, 128, 152, 155, Leonard Shapiro; 35, Hezekiah Smith; 300, 306, 323, Z.A. Hamlin; 230, 263, 343, S.A. Botts, Gillison Chloe, J.L. Glenn, Hezekiah Smith, P.D.L. Elmore, Lowell Artis, James Kelsey. Analysts for spectrographic analyses for samples with map locality numbers 345, 349, 367, J.C. Hamilton; all others by J.L. Harris. N.d., not determined; N, not detected; --, not looked for; <, less than; Tr, trace; x, greater than trace amount found]

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 349 | 345 | 116 | 122 | 127 | 128 | 152 | 155 | 35 |
| Sample No. | EWT-90 | JG-38b | W281a-71 | W18-70 | W97-70 | W121-70 | W321-70 | W328-70 | GH12-74 |
| Lab No. | I4156 | I4157 | W178081 | W178084 | W178085 | W178086 | W178087 | W178088 | W192419 |
| | Chemical analyses in weight percent | | | | | | | | |
| $SiO_2$ | 57.28 | 58.06 | 63.0 | 69.0 | 54.9 | 76.1 | 65.8 | 61.4 | 65.8 |
| $Al_2O_3$ | 21.13 | 20.76 | 19.6 | 15.6 | 21.4 | 11.3 | 16.3 | 20.1 | 18.5 |
| $Fe_2O_3$ | 2.22 | 1.55 | 3.4 | 1.0 | 2.5 | 1.0 | 2.2 | .74 | .80 |
| FeO | 7.90 | 9.72 | 4.3 | 5.7 | 9.2 | 4.3 | 4.4 | 6.1 | 4.8 |
| MgO | 3.04 | 3.23 | 1.2 | 2.1 | 2.6 | 1.6 | 1.9 | 2.2 | 1.9 |
| CaO | .65 | .33 | .12 | .82 | .05 | .08 | .56 | .39 | .66 |
| $Na_2O$ | .97 | .39 | .89 | 1.0 | .48 | .48 | 1.4 | 1.1 | 1.5 |
| $K_2O$ | 3.56 | 3.25 | 3.6 | 2.8 | 4.4 | 3.0 | 4.7 | 5.1 | 3.1 |
| $H_2O+$ | 1.47 | 1.10 | 1.7 | 1.3 | 1.5 | 1.5 | 1.8 | 1.2 | 1.2 |
| $H_2O-$ | .20 | .17 | .28 | .14 | .18 | .21 | .25 | .15 | .23 |
| $TiO_2$ | 1.02 | 1.00 | .90 | .80 | 1.3 | .76 | .91 | .93 | .75 |
| $P_2O_5$ | .07 | .07 | .05 | .03 | .04 | .02 | .09 | .09 | .05 |
| MnO | .14 | .10 | .10 | .10 | .12 | .05 | .07 | .06 | .03 |
| $CO_2$ | .02 | .01 | .01 | .01 | .01 | .01 | .01 | .02 | .02 |
| F | .01 | .01 | .07 | .09 | .10 | .05 | .08 | .03 | .02 |
| Cl | .11 | .12 | .01 | .03 | .03 | .03 | .03 | .02 | .01 |
| S (total) | N.d. | N.d. | .01 | .06 | .00 | .00 | .00 | .00 | .01 |
| Subtotal | 99.79 | 99.87 | 99. | 100. | 99. | 100. | 100. | 100. | 99. |
| Less 0 | .03 | .03 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 99.76 | 99.84 | 99. | 100. | 99. | 100. | 100. | 100. | 99. |
| Bulk density | N.d. | N.d. | 2.80 | 2.78 | 2.83 | 2.73 | 2.70 | 2.78 | N.d. |
| Powder density sink/float | 2.94 | 3.01 | 2.80 | 2.78 | 3.00 | 2.76 | 2.76 | 2.78 | N.d. |
| | Semiquantitative spectrographic analyses in parts per million | | | | | | | | |
| Ba | 1,000 | 1,000 | 570 | 372 | 781 | 393 | 618 | 680 | 600 |
| Be | N | N | 2 | 1 | 3 | N | N | N | 3 |
| Ce | N | N | 122 | 73 | 98 | 54 | 77 | 105 | 91 |
| Co | 30 | 30 | 24 | 17 | 29 | 13 | 20 | 17 | 14 |
| Cr | 200 | 200 | 126 | 61 | 194 | 94 | 139 | 93 | 68 |
| Cu | 30 | 7 | 14 | 20 | 22 | 51 | 2 | 4 | 27 |
| Ga | 50 | 70 | 33 | 20 | 38 | 15 | 27 | 27 | 34 |
| Gd | N | N | 9 | 7 | 10 | 9 | 7 | 7 | N |
| La | 70 | 70 | 67 | 34 | 33 | 31 | 51 | 67 | 40 |
| Mo | 7 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |
| Nb | 15 | 15 | 10 | 10 | 13 | 11 | 11 | 9 | 10 |
| Nd | N | N | 45 | 19 | 18 | 20 | 31 | 38 | 48 |
| Ni | 100 | 100 | 66 | 45 | 69 | 73 | 69 | 53 | 34 |
| Pb | 30 | 15 | 21 | 12 | 22 | 14 | 32 | 21 | 30 |
| P | N | N | 9 | 6 | 6 | 5 | 7 | 10 | N |
| Rb | N | N | 150 | 150 | 300 | 150 | 150 | 150 | N |
| Sc | 50 | 50 | 15 | 9 | 53 | 8 | 18 | 12 | 19 |
| Sn | N | N | 8 | 4 | 11 | 3 | 5 | 4 | N |
| Sr | 300 | 150 | 156 | 178 | 134 | 95 | 219 | 199 | 78 |
| V | 200 | 200 | 161 | 99 | 179 | 99 | 125 | 101 | 120 |
| Y | 50 | 50 | 25 | 27 | 60 | 30 | 34 | 30 | 15 |
| Yb | 7 | 7 | 3 | 2 | 6 | 2 | 3 | 3 | 5 |
| Zn | N | N | 126 | 98 | 168 | 84 | 108 | 109 | 150 |
| Zr | 150 | 150 | 149 | 189 | 174 | 227 | 184 | 210 | 69 |

Footnotes at the end of table.

**Table 25.** Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. ------- | 349 | 345 | 116 | 122 | 127 | 128 | 152 | 155 | 35 |
| Sample No. ------------ | EWT-90 | JG-38b | W281a-71 | W18-70 | W97-70 | W121-70 | W321-70 | W328-70 | GH12-74 |
| Lab No. ---------------- | I4156 | I4157 | W178081 | W178084 | W178085 | W178086 | W178087 | W178088 | W192419 |
| | Modes in volume percent | | | | | | | | |
| K-feldspar ------------- | 3.3 | 1.6 | 11.5 | 7.6 | 7.5 | 16.4 | 20.5 | 34.7 | 9.4 |
| Plagioclase------------- | 8.0 | 2.0 | 5.3 | 11.2 | 1.4 | 3.1 | 19.1 | 4.6 | 10.6 |
| Quartz------------------ | 29.6 | 26.1 | 20.7 | 47.7 | 24.0 | 55.8 | 30.6 | 18.8 | 39.9 |
| Cordierite-------------- | 4.3 | 16.4 | 14.0 | 2.4 | 17.1 | [2]8.7 | .3 | 16.2 | 10.5 |
| Biotite----------------- | 28.9 | 23.6 | 11.0 | 19.1 | 21.2 | 6.1 | 12.8 | 9.7 | 17.9 |
| Garnet------------------ | 20.1 | 17.3 | 9.9 | 2.9 | 18.5 | 1.5 | 1.6 | 3.7 | 1.7 |
| Sillimanite------------- | 5.7 | 11.7 | 16.3 | 9.1 | 8.9 | 2.0 | 1.7 | 10.2 | 9.7 |
| Opaque minerals------- | .1 | 1.3 | 4.2 | Tr | 1.4 | 1.2 | .3 | .5 | .3 |
| Zircon ----------------- | Tr | Tr | Tr | -- | Tr | Tr | Tr | Tr | Tr |
| Andalusite ------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr | .3 | -- |
| Chlorite ---------------- | -- | -- | 1.5 | -- | -- | 1.3 | .3 | -- | -- |
| Muscovite-sericite[3] ---- | Tr | -- | [2]5.6 | 3.9 | 12.8 | 1.3 | -- | -- | -- |
| Spinel-högbomite------ | -- | Tr | Tr | -- | Tr | -- | -- | Tr | -- |
| Rutile------------------ | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite --- | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Apatite ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | Cordierite-garnet-sillimanite-biotite gneiss | | Cordierite-garnet-biotite gneiss |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. ------- | 323 | 300 | 306 | 263 | 263 | 343 | 108 | 367 | 230 |
| Sample No. ------------ | AP-1 | ML-3 | ML-11 | N338a | N338b | CC-783-1 | W256c-71 | M-497 | N340a-64 |
| Lab No. ---------------- | W197377 | W197379 | W197385 | W173197 | W173198 | W169537 | W178078 | I4195 | W169536 |
| | Chemical analyses in weight percent | | | | | | | | |
| $SiO_2$ ------------------ | 70.0 | 67.7 | 54.3 | 58.6 | 69.2 | 59.6 | 59.6 | 72.38 | 75.8 |
| $Al_2O_3$----------------- | 14.4 | 15.8 | 17.4 | 17.2 | 15.6 | 23.8 | 18.7 | 13.26 | 10.2 |
| $Fe_2O_3$----------------- | 1.1 | 1.6 | 4.4 | 2.4 | .86 | 2.6 | 1.9 | .85 | 1.7 |
| FeO -------------------- | 1.9 | 2.5 | 12.8 | 9.3 | 5.4 | 6.5 | 6.0 | 5.26 | 4.0 |
| MgO -------------------- | .9 | 1.2 | 3.4 | 3.5 | 2.0 | 2.9 | 2.6 | 2.28 | 2.8 |
| CaO--------------------- | 1.2 | 2.1 | 1.2 | .47 | .62 | .17 | 1.1 | .17 | .52 |
| $Na_2O$ ----------------- | 2.7 | 2.3 | .82 | .56 | .75 | .08 | 1.8 | 1.74 | .57 |
| $K_2O$------------------- | 5.4 | 4.3 | 2.7 | 3.3 | 3.3 | 2.0 | 4.8 | 1.63 | 2.2 |
| $H_2O+$ ---------------- | .74 | 1.3 | 1.2 | 1.4 | 1.2 | .92 | 2.3 | 1.57 | 1.4 |
| $H_2O-$ ----------------- | .13 | .21 | .13 | .40 | .27 | .08 | .18 | .32 | .08 |
| $TiO_2$ ------------------ | .42 | .53 | .79 | 1.8 | .65 | 1.3 | .97 | .20 | .37 |
| $P_2O_5$------------------ | .05 | .13 | .18 | .09 | .17 | .06 | .05 | .02 | .05 |
| MnO -------------------- | .35 | .04 | 1.1 | .10 | .05 | .07 | .17 | .10 | .09 |
| $CO_2$ ------------------- | .02 | .14 | .01 | <.05 | <.05 | <.05 | .01 | .02 | <.05 |
| F----------------------- | .11 | .07 | .10 | .13 | .09 | N.d. | .10 | .09 | N.d. |
| Cl ---------------------- | .02 | .02 | .02 | N.d. | N.d. | N.d. | .03 | .01 | N.d. |
| S (total) --------------- | .00 | .01 | .04 | N.d. | N.d. | N.d. | .01 | N.d. | N.d. |
| Subtotal--------------- | 99. | 100. | 101. | 99. | 100. | 100. | 100. | 99.00 | 100. |
| Less 0 ---------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .04 | N.d. |
| Total ------------------ | 99. | 100. | 101. | 99. | 100. | 100. | 100. | 99.86 | 100. |
| Bulk density ----------- | N.d. | N.d. | N.d. | 2.81 | 2.77 | N.d. | 2.83 | N.d. | N.d. |
| Powder density sink/float ---- | N.d. | N.d. | N.d. | 3.12 | 3.12 | N.d. | 2.83 | 2.74 | N.d. |

Footnotes follow at end of table.

**Table 25.** Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | Cordierite-garnet-sillimanite-biotite gneiss | | Cordierite-garnet-biotite gneiss |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 323 | 300 | 306 | 263 | 263 | 343 | 108 | 367 | 230 |
| Sample No. | AP-1 | ML-3 | ML-11 | N338a | N338b | CC-783-1 | W256c-71 | M-497 | N340a-64 |
| Lab No. | W197377 | W197379 | W197385 | W173197 | W173198 | W169537 | W178078 | I4195 | W169536 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | |
| Ba | 570 | 700 | 370 | 500 | 500 | -- | 502 | 500 | -- |
| Be | N | N | N | N | N | -- | 1 | N | -- |
| Ce | N | N | 95 | 300 | 300 | -- | 133 | N | -- |
| Co | 8 | 9 | 24 | 30 | 15 | -- | 19 | N | -- |
| Cr | 69 | 64 | 96 | 300 | 200 | -- | 108 | 1 | -- |
| Cu | 3 | 8 | 28 | 20 | 20 | -- | 2 | 300 | -- |
| Ga | 24 | 20 | 27 | 30 | 20 | -- | 32 | 30 | -- |
| Gd | N | N | N | N | N | -- | 8 | -- | -- |
| La | 19 | 19 | 23 | 100 | 100 | -- | 77 | 50 | -- |
| Mo | N | N | 3 | 5 | 3 | -- | N | 5 | -- |
| Nb | 8 | 8 | 7 | 10 | 7 | -- | 12 | N | -- |
| Nd | N | N | N | N | N | -- | 60 | N | -- |
| Ni | 18 | 28 | 54 | 150 | 70 | -- | 47 | N | -- |
| Pb | 42 | 36 | 26 | 7 | 10 | -- | 13 | N | -- |
| Pr | N | N | N | N | N | -- | 10 | -- | -- |
| Rb | N | N | N | N | N | -- | 200 | -- | -- |
| Sc | 6 | 10 | 11 | 50 | 20 | -- | 20 | 7 | -- |
| Sn | N | N | N | N | N | -- | 7 | N | -- |
| Sr | 160 | 280 | 100 | 70 | 150 | -- | 126 | 30 | -- |
| V | 50 | 54 | 81 | 200 | 100 | -- | 113 | N | -- |
| Y | 7 | 9 | 15 | 70 | 50 | -- | 40 | 70 | -- |
| Yb | 1 | 3 | 2 | 7 | 5 | -- | 5 | 10 | -- |
| Zn | 32 | 38 | 81 | N | N | -- | 163 | N | -- |
| Zr | 59 | 39 | 100 | 300 | 500 | -- | 176 | 150 | -- |
| Modes in volume percent | | | | | | | | | |
| K-feldspar | 15.4 | 26.6 | 5.6 | 8.2 | 19.0 | Tr | [1]x | Tr | 6.1 |
| Plagioclase | 28.7 | 23.2 | 11.3 | 5.2 | 4.4 | 6 | x | 9.3 | 4.8 |
| Quartz | 46.4 | 26.8 | 25.8 | 36.6 | 41.8 | 53 | x | 51.6 | 59.3 |
| Cordierite | 1.7 | [2]6.3 | 4.5 | 2.7 | .3 | 2 | x | 1.3 | 1.9 |
| Biotite | 6.7 | 11.8 | 21.6 | 27.9 | 22.4 | 21 | x | 13.8 | 19.5 |
| Garnet | .6 | 1.2 | 30.3 | 11.7 | 7.7 | 7 | x | 2.6 | .1 |
| Sillimanite | .2 | 1.9 | Tr | 5.8 | 3.8 | 10 | x | 11.6 | -- |
| Opaque minerals | .3 | .8 | .5 | 1.3 | .5 | 1 | x | .3 | .3 |
| Zircon | Tr | -- | -- | .1 | Tr | Tr | Tr | Tr | Tr |
| Andalusite | -- | .8 | -- | .3 | -- | -- | -- | Tr | -- |
| Chlorite | Tr | -- | .1 | -- | -- | -- | -- | 9.5 | 2.8 |
| Muscovite-sericite[3] | -- | .6 | .3 | .2 | -- | Tr | x | -- | 5.2 |
| Spinel-högbomite | Tr | -- | -- | Tr | Tr | Tr | -- | Tr | -- |
| Rutile | -- | -- | -- | -- | -- | Tr | -- | -- | Tr |
| Xenotime-monazite | Tr | -- | -- | -- | -- | -- | -- | Tr | -- |
| Apatite | -- | -- | -- | -- | .1 | -- | -- | -- | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | Tr | -- |

[1]Thin section poor.
[2]Includes pinnite.
[3]Muscovite-sericite replaces plagioclase and sillimanite.

**Table 26.** Chemical and spectrographic analyses and modes for cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 153, 154, 158, Leonard Shapiro; 51, Hezekiah Smith; 195, P.D.L. Elmore, Lowell Artis, Hezekiah Smith, Gillison Chloe, S.D. Botts, J.L. Glenn. Analyst for all spectrographic analyses J.L. Harris. N.d., not determined; --, not found; >, greater than; <, less than; Tr, trace]

| | Cordierite-magnetite-sillimanite-biotite gneiss | | Magnetite-sillimanite-biotite gneiss | | |
|---|---|---|---|---|---|
| Map locality No. | 158 | 195 | 153 | 154 | 51 |
| Sample No. | W346-70 | N196A-64 | W323-70 | W326-70 | GH391-74 |
| Lab No. | W178094 | W168100 | W178095 | W178096 | W192420 |
| **Chemical analyses in weight percent** | | | | | |
| $SiO_2$ | 44.7 | 53.4 | 70.0 | 60.0 | 69.3 |
| $Al_2O_3$ | 28.2 | 26.5 | 14.0 | 19.2 | 16.0 |
| $Fe_2O_3$ | 9.7 | 4.1 | 5.0 | 5.2 | 3.6 |
| FeO | 6.4 | 6.8 | 2.6 | 3.4 | 3.8 |
| MgO | 3.4 | 3.1 | 1.4 | 2.0 | 1.8 |
| CaO | .63 | .12 | .29 | .35 | .22 |
| $Na_2O$ | 1.4 | .43 | 1.2 | .86 | .47 |
| $K_2O$ | 2.3 | 2.6 | 2.7 | 4.1 | 2.1 |
| $H_2O+$ | 1.6 | 1.2 | 1.9 | 2.8 | 1.2 |
| $H_2O$ | .21 | .20 | .12 | .18 | .19 |
| $TiO_2$ | 1.4 | 1.4 | 1.0 | .93 | .99 |
| $P_2O_5$ | .05 | .09 | .13 | .10 | .03 |
| MnO | .11 | .11 | .04 | .05 | .05 |
| $CO_2$ | .01 | < .05 | .02 | .01 | .03 |
| F | .18 | N.d. | .04 | .12 | .02 |
| Cl | < .01 | N.d. | < .01 | < .01 | .02 |
| S (total) | .01 | N.d. | .00 | .01 | .01 |
| Total | 100. | 100. | 100. | 99. | 100. |
| Bulk density | 2.98 | N.d. | 2.80 | 2.80 | N.d. |
| Powder density sink/float | 3.08 | N.d. | 2.80 | 2.80 | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | |
| Ba | 206 | N | 412 | 404 | 290 |
| Be | 2 | 3 | N | 1 | 1 |
| Ce | 01 | 700 | 82 | 59 | 120 |
| Co | 27 | 30 | 13 | 17 | 17 |
| Cr | 113 | 150 | 92 | 102 | 91 |
| Cu | N | 5 | N | N | 4 |
| Ga | 30 | 30 | 10 | 27 | 23 |
| Gd | 7 | N | 8 | 5 | N |
| La | 48 | 300 | 53 | 29 | 49 |
| Mo | 2 | 3 | 2 | 1 | 3 |
| Nb | 10 | 20 | 10 | 6 | 19 |
| Nd | 22 | 300 | 27 | 19 | N |
| Ni | 61 | 100 | 40 | 47 | 41 |
| Pb | 7 | 10 | 12 | 4 | 13 |
| Pr | 8 | N | N | N | N |
| Rb | 150 | N | 70 | 150 | N |
| Sc | 8 | 30 | 10 | 11 | 18 |
| Sn | 11 | 15 | 8 | 7 | N |
| Sr | 68 | 200 | 123 | 87 | 45 |
| V | 103 | 100 | 88 | 99 | 99 |
| Y | 12 | 100 | 28 | 20 | 15 |
| Yb | 1 | 10 | 2 | 2 | 1 |
| Zn | 222 | N | 94 | 84 | 130 |
| Zr | 213 | 500 | 366 | 117 | 140 |

Footnote follows at end of table.

**Table 26.** Chemical and spectrographic analyses and modes for cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-magnetite-sillimanite-biotite gneiss | | Magnetite-sillimanite-biotite gneiss | | |
|---|---|---|---|---|---|
| Map locality No. ----- | 158 | 195 | 153 | 154 | 51 |
| Sample No. ----------- | W346-70 | N196A-64 | W323-70 | W326-70 | GH391-74 |
| Lab No. ---------------- | W178094 | W168100 | W178095 | W178096 | W192420 |
| | Modes in volume percent | | | | |
| K-feldspar ------------ | 1 | 12 | Tr | -- | .6 |
| Plagioclase ----------- | 19 | 2 | 16 | 5 | 1.3 |
| Quartz ---------------- | 7 | 17 | 47 | 37 | 66.3 |
| Cordierite ------------ | 1 | 33 | -- | -- | -- |
| Biotite ---------------- | 26 | 10 | 2 | Tr | 12.7 |
| Sillimanite ----------- | 38 | 15 | 3 | 2 | 14.9 |
| Opaque minerals ----- | 8 | 6 | 5 | 5 | 3.7 |
| Zircon ----------------- | Tr | Tr | Tr | Tr | Tr |
| Chlorite---------------- | -- | Tr | 5 | 5 | Tr |
| Muscovite-sericite[1] -- | Tr | 5 | 22 | 46 | .5 |
| Rutile ------------------ | -- | -- | Tr | Tr | -- |
| Epidote ---------------- | Tr | -- | -- | -- | -- |
| Monazite-xenotime -- | -- | -- | -- | -- | Tr |

[1]Muscovite-sericite a replacement of plagioclase and perhaps sillimanite.

**Table 27.** Chemical and spectrographic analyses and modes for thermal cordierite-sillimanite-magnetite-biotite gneiss and thermal biotite-gneiss hornfels, central Front Range, Colorado.

[Analysts for a standard wet chemical analyses for samples from map locality numbers 212 and 223, C.L. Parker. Analysts for rapid-rock chemical analyses for samples from locality numbers 192, 200, 222, P.L.D. Elmore, S.D. Botts, Lowell Artis, Hezekiah Smith, Gillison Chloe, J.L. Glenn; 141 and 147, Leonard Shapiro; 21 and 28, Hezekiah Smith. Analysts for spectrographic analyses for samples from locality numbers 212 and 223, Harriet Neiman; J.L. Harris, all other analyses. N.d., not determined; N, not detected; --, not found; >, greater than; <, less than; Tr, trace]

| | Thermal cordierite-magnetite-sillimanite-biotite gneiss | | | | | | | Thermal biotite-gneiss hornfels | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 212 | 222 | 223 | 192 | 200 | 141 | 147 | 21 | 28 |
| Sample No. | N69a-64 | N196a-64 | N206-64 | N146-65 | N236-65 | W256-70 | W281-70 | GH175a-75 | GH294-75 |
| Lab No. | D100744 | W168100 | D100743 | W168101 | W168102 | W178092 | W178093 | W192422 | W192425 |
| | Chemical analyses in weight percent | | | | | | | | |
| $SiO_2$ | 60.01 | 53.4 | 59.83 | 56.5 | 52.2 | 56.6 | 47.4 | 61.4 | 41.4 |
| $Al_2O_3$ | 21.14 | 26.5 | 20.82 | 22.5 | 24.6 | 20.9 | 21.6 | 16.1 | 31.6 |
| $Fe_2O_3$ | 4.87 | 4.1 | 2.30 | .72 | 3.9 | 5.8 | 5.9 | 3.3 | 6.2 |
| FeO | 4.39 | 6.8 | 5.35 | 8.2 | 5.7 | 4.8 | 8.3 | 4.5 | 7.9 |
| MgO | 2.13 | 3.1 | 2.39 | 3.1 | 2.9 | 2.6 | 4.4 | 2.3 | 3.8 |
| CaO | .25 | .12 | .38 | .65 | .74 | .63 | 1.2 | 3.5 | .18 |
| $Na_2O$ | .72 | .43 | .68 | .85 | 2.0 | 1.3 | 1.5 | 2.8 | .33 |
| $K_2O$ | 3.79 | 2.6 | 4.98 | 4.4 | 5.0 | 4.2 | 4.6 | 2.6 | 4.9 |
| $H_2O+$ | 1.00 | 1.2 | 1.73 | 1.4 | 1.4 | 1.2 | 1.4 | 1.3 | 1.7 |
| $H_2O-$ | .23 | .20 | .18 | .15 | .20 | .17 | .26 | .32 | .26 |
| $TiO_2$ | 1.03 | 1.4 | .94 | 1. | 1.2 | 1.2 | 1.8 | 1.4 | 1.4 |
| $P_2O_5$ | .06 | .09 | .04 | .08 | .10 | .10 | .08 | .66 | .15 |
| MnO | .09 | .11 | .09 | .14 | .08 | .12 | .14 | .08 | .06 |
| $CO_2$ | .02 | <.05 | .07 | <.05 | <.05 | .00 | .01 | .02 | .02 |
| F | .25 | N.d. | .09 | N.d. | N.d. | .11 | .13 | .27 | .45 |
| Cl | .02 | N.d. | .04 | N.d. | N.d. | <.01 | .03 | .04 | .04 |
| S (total) | N.d. | N.d. | N.d. | N.d. | N.d. | .00 | .03 | .02 | .00 |
| Subtotal | 100.10 | 100. | 99.91 | 100. | 100. | 100. | 99. | 99. | 101. |
| Less O | .10 | N.d. | .05 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 99.90 | 100. | 99.86 | 100. | 100. | 100. | 99. | 101. | 101. |
| Bulk density | N.d. | N.d. | N.d. | N.d. | N.d. | 2.88 | 2.83 | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | 2.88 | 2.83 | N.d. | N.d. |
| | Semiquantitative spectrographic analyses in parts per million | | | | | | | | |
| Ba | 700 | N | 1,500 | N | N | 579 | 626 | 1,400 | 260 |
| Be | N | 3 | N | N | N | 2 | 7 | 6 | 7 |
| Ce | 200 | 700 | N | 500 | 500 | 121 | 95 | 360 | 210 |
| Co | 20 | 30 | 15 | 30 | 30 | 32 | 33 | 18 | 23 |
| Cr | 100 | 150 | 100 | 100 | 200 | 161 | 273 | 46 | 240 |
| Cu | 5 | 5 | 20 | 70 | 5 | 10 | 22 | 240 | 11 |
| Ga | 50 | 30 | 30 | 15 | 30 | 36 | 66 | 44 | 100 |
| Gd | -- | -- | -- | -- | -- | 8 | 9 | 15 | -- |
| La | 100 | 300 | 50 | 150 | 150 | 71 | 36 | 150 | 63 |
| Mo | N | 3 | 7 | 7 | 3 | 2 | 2 | 3 | 4 |
| Nb | 20 | 20 | 10 | 15 | 10 | 7 | 17 | 40 | 33 |
| Nd | <100 | 300 | N | 150 | 150 | 37 | N | 190 | 50 |
| Ni | 70 | 100 | 50 | 70 | 150 | 78 | 85 | 28 | 64 |
| Pb | N | 10 | N | 10 | 20 | 25 | 16 | 28 | 21 |
| Pr | -- | -- | -- | -- | -- | 10 | 8 | -- | -- |
| Rb | -- | -- | -- | -- | -- | 150 | 100 | -- | -- |
| Sc | 30 | 30 | 30 | 20 | 30 | 17 | 13 | 18 | 20 |
| Sn | 100 | 15 | -- | N | N | 13 | 12 | N | 27 |
| Sr | 150 | 20 | 200 | 10 | 30 | 151 | 239 | 580 | 30 |
| V | 150 | 100 | 150 | 70 | 150 | 145 | >215 | 120 | 150 |
| Y | 50 | 100 | 50 | 50 | 50 | 26 | 18 | 34 | 29 |
| Yb | 5 | 10 | 7 | 5 | 5 | 3 | 2 | 5 | 6 |
| Zn | N | N | N | N | N | 176 | 338 | 160 | 250 |
| Zr | 300 | 500 | 200 | 300 | 500 | 181 | 252 | 690 | 230 |

**Table 27**. Chemical and spectrographic analyses and modes for thermal cordierite-sillimanite-magnetite-biotite gneiss and thermal biotite-gneiss hornfels, central Front Range, Colorado.--Continued

| | Thermal cordierite-magnetite-sillimanite-biotite gneiss | | | | | | | Thermal biotite-gneiss hornfels | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. -- | 212 | 222 | 223 | 192 | 200 | 141 | 147 | 21 | 28 |
| Sample No. ------- | N69a-64 | N196a-64 | N206-64 | N146-65 | N236-65 | W256-70 | W281-70 | GH175a-75 | GH294-75 |
| Lab No. ----------- | D100744 | W168100 | D100743 | W168101 | W168102 | W178092 | W178093 | W192422 | W192425 |
| | Modes in volume percent | | | | | | | | |
| K-feldspar --------- | 5 | 12 | 17 | 1 | 40.6 | 12.9 | 7.3 | -- | 13.6 |
| Plagioclase--------- | 10 | 2 | 9 | 1 | 5.3 | 7.0 | 5.4 | 38.4 | 16.6 |
| Quartz ------------- | 45 | 17 | 50 | 11 | 2.4 | 14.4 | .4 | 26.1 | 29.8 |
| Cordierite --------- | 25 | 33 | 1 | 27 | 26.0 | 26.7 | 58.5 | -- | -- |
| Biotite ------------- | 6 | 10 | 18 | 44 | 9.7 | 9.7 | 7.0 | 29.6 | 25.4 |
| Garnet ------------- | Tr | -- | Tr | -- | -- | -- | -- | -- | -- |
| Sillimanite--------- | 5 | 15 | 3 | 14 | 2.0 | 20.0 | 4.0 | -- | 11.1 |
| Opaque minerals-- | 3 | 6 | 1 | Tr | 7.7 | 7.0 | 14.0 | 3.9 | 2.8 |
| Zircon ------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite --------- | Tr | -- | -- | 1 | 3.0 | -- | .8 | -- | -- |
| Chlorite ------------ | Tr | Tr | Tr | -- | .1 | -- | .9 | -- | -- |
| Muscovite-sericite[1] | Tr | 5 | Tr | 1 | 3.2 | 2.3 | -- | .2 | .7 |
| Spinel-högbomite- | -- | -- | -- | Tr | Tr | -- | 1.2 | -- | -- |
| Rutile--------------- | Tr | -- | Tr | Tr | Tr | -- | -- | -- | -- |
| Corundum --------- | -- | -- | -- | -- | -- | -- | .5 | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | Tr | -- | Tr |
| Apatite ------------ | -- | -- | -- | -- | -- | -- | -- | 1.0 | -- |
| Allanite ------------ | -- | -- | -- | Tr | -- | -- | -- | .1 | -- |
| Epidote------------- | -- | -- | -- | -- | -- | -- | -- | 7 | -- |

[1]Muscovite-sericite replaces plagioclase and sillimanite.

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 260, 268, 346, E.S. Daniels. Analysts for rapid-rock analyses for samples with map locality numbers 193, 198, 245, P.D.L. Elmore; 103, 108, 116, Leonard Shapiro; 13, 1, 2, 279, Deborah Kobilis. Analysts for spectrographic analyses for samples with map numbers 260 and 346, Joseph Haffty; 103, 108, 116, 198, 245, 268, J.L. Harris; 1, 2, 13, 279, Leung Mei. Normative minerals calculated using the USGS graphic analysis program. N.d., not determined; N, not detected; --, not looked for; <, less than; >, greater than; Tr, trace]

| | Lens or layers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | In or adjacent to the Phoenix layer | | | | | Ward | Mount Audubon | | Central City |
| Map locality No. | 260 | 268 | 198 | 245 | 193 | 116 | 103 | 108 | 346 |
| Sample No. | N-321a | N-400b | N227a-65 | N602a-64 | N169a-65 | W281c-71 | W222b-71 | W256b-71 | D245a |
| Lab No. | D100279 | W175655 | W175650 | W175653 | W175649 | W178083 | W178079 | W178077 | D100277 |
| **Chemical Analyses in weight percent** | | | | | | | | | |
| $SiO_2$ | 47.44 | 53.6 | 54.1 | 52.5 | 63.4 | 47.6 | 53.0 | 62.4 | 62.77 |
| $Al_2O_3$ | 15.07 | 12.2 | 16.2 | 13.0 | 14.4 | 13.3 | 5.5 | 9.2 | 14.68 |
| $Fe_2O_3$ | 4.60 | 6.0 | 3.6 | 6.1 | 5.0 | 3.2 | 1.7 | 3.1 | 5.30 |
| FeO | 4.32 | 2.9 | 3.1 | 4.4 | 1.7 | 6.3 | 5.1 | 3.6 | .54 |
| MgO | 4.15 | 2.8 | 2.7 | 3.5 | .4 | 9.3 | 13.1 | 7.7 | .42 |
| CaO | 16.70 | 17.0 | 15.2 | 14.8 | 11.5 | 15.8 | 19.2 | 11.7 | 13.38 |
| $Na_2O$ | 1.62 | .33 | 1.7 | .56 | .45 | 1.2 | .41 | .24 | .04 |
| $K_2O$ | 1.13 | .72 | .44 | .41 | .45 | 1.2 | .41 | .32 | .06 |
| $H_2O+$ | 1.53 | 1.1 | 1.0 | 1.6 | .88 | 1.4 | 1.1 | 1.2 | 1.18 |
| $H_2O$ | .09 | .38 | .29 | .13 | .22 | .10 | .38 | .18 | .06 |
| $TiO_2$ | .77 | .85 | .63 | .97 | .65 | .51 | .21 | .34 | .96 |
| $P_2O_5$ | .19 | .23 | .23 | .32 | .59 | .31 | .07 | .10 | .23 |
| MnO | .15 | .21 | .17 | .21 | .10 | .19 | .17 | .20 | .22 |
| $CO_2$ | 2.15 | 1.3 | .72 | .71 | <.05 | .08 | .10 | .04 | .00 |
| F | .07 | .024 | .03 | .07 | .94 | .33 | .21 | .30 | .04 |
| Cl | .03 | .032 | .034 | .03 | .02 | .027 | .013 | .012 | .03 |
| S (total) | N.d. | N.d | N.d. | N.d. | N.d. | 0 | 0 | .00 | N.d. |
| Subtotal | 100.01 | 100. | 100. | 99. | 100. | 100. | 100. | 100. | 99.91 |
| Less O | .04 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .03 |
| Total | 99.97 | 100. | 100. | 99. | 100. | 100. | 100. | 100. | 99.88 |
| Bulk density | N.d | N.d. | N.d. | N.d. | N.d. | 3.09 | 3.09 | 2.76 | N.d. |
| Powder density sink/float | N.d | N.d | N.d. | N.d. | N.d. | 3.16 | 3.12 | 3.00 | N.d |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | |
| Ba | 300 | 200 | 100 | 150 | 70 | 305 | 87 | 97 | 30 |
| Be | N | 1 | 1 | N | N | 31 | 20 | 4 | N |
| Ce | N | N | N | N | N | 71 | N | 67 | N |
| Co | 70 | 20 | 20 | 15 | 20 | 51 | 43 | 10 | 10 |
| Cr | 105 | 20 | 70 | 150 | 150 | 547 | 549 | 9 | 200 |
| Cu | 15 | 150 | 150 | 20 | 2 | 21 | N | 17 | 70 |
| Ga | 20 | 15 | 15 | 15 | 15 | 7 | N | N | 20 |
| La | N | N | N | N | 50 | 23 | 17 | 21 | 20 |
| Mo | N | N | N | N | N | 3 | 4 | 3 | N |
| Nb | N | N | 3 | N | N | N | 2 | 7 | N |
| Ni | 50 | 50 | 30 | 30 | 15 | 148 | 209 | 11 | 15 |
| Pb | 15 | 30 | 10 | 7 | N | 7 | 4 | 24 | N |
| Rb | -- | -- | -- | -- | -- | 50 | 20 | 20 | -- |
| Sc | 30 | 20 | 15 | 70 | 20 | >68 | 23 | 9 | 20 |
| Sn | N | N | N | N | N | N | N | N | N |
| Sr | 700 | 500 | 700 | 700 | 2,000 | 442 | 105 | 372 | 100 |
| V | 150 | 70 | 70 | 300 | 150 | >215 | 126 | 41 | 100 |
| Y | 15 | 50 | 50 | 50 | 30 | 11 | 7 | 34 | 50 |
| Yb | 2 | 5 | 5 | 5 | 5 | 2 | 2 | 4 | 5 |
| Zn | N | N | N | N | N | 151 | 325 | 258 | N |
| Zr | 30 | 150 | 50 | 70 | 150 | 48 | 29 | 212 | 200 |

Footnotes follow at end of table.

**Table 33**. Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Lens or layers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | In or adjacent to the Phoenix layer | | | | | Ward | Mount Audubon | | Central City |
| Map locality No. ---- | 260 | 268 | 198 | 245 | 193 | 116 | 103 | 108 | 346 |
| Sample No. ---------- | N-321a | N-400b | N227a-65 | N602a-64 | N169a-65 | W281c-71 | W222b-71 | W256b-71 | D245a |
| Lab No. -------------- | D100279 | W175655 | W175650 | W175653 | W175649 | W178083 | W178079 | W178077 | D100277 |
| | [1]Modes in volume percent | | | | | | | | |
| K-feldspar ----------- | 1.0 | -- | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase----------- | 8 | Tr | 58.6 | 14.4 | 24.4 | 9 | -- | -- | -- |
| Quartz ---------------- | 5 | 21 | 4.7 | 24.1 | 44.4 | 2 | Tr | 28 | 43 |
| Biotite ---------------- | -- | -- | -- | -- | .1 | Tr | -- | -- | -- |
| Hornblende ---------- | 1 | 5 | 7.9 | .7 | .6 | 44 | 13 | 9 | -- |
| Pyroxene[2] ----------- | 21 | 25 | 22.7 | -- | -- | 26 | 83 | 27 | -- |
| Opaque minerals---- | Tr | Tr | 1.3 | .1 | 2.6 | Tr | -- | -- | Tr |
| Apatite --------------- | Tr | Tr | Tr | -- | .8 | 1 | Tr | Tr | -- |
| Zircon ---------------- | -- | Tr | -- | -- | -- | -- | -- | Tr | -- |
| Calcite---------------- | 26 | 4 | .9 | 1.0 | .1 | -- | Tr | -- | -- |
| Epidote --------------- | 36 | 23 | 2.5 | 41.8 | 11.4 | 8 | 4 | 36 | 45 |
| Muscovite-sericite[3] - | -- | Tr | -- | -- | 1.1 | 10 | -- | -- | -- |
| Sphene --------------- | 2 | 2 | 1.4 | 3.3 | 1.2 | -- | Tr | Tr | 2 |
| Scapolite ------------- | -- | 15 | -- | -- | -- | -- | -- | -- | -- |
| Garnet ---------------- | -- | 5 | Tr | -- | 13.3 | -- | -- | -- | Tr |
| Tremolite-actinolite | -- | -- | -- | 11.9 | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | -- | -- | 2.7 | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Cummingtonite ----- | -- | -- | -- | -- | -- | -- | -- | -- | 10 |
| | Normative minerals | | | | | | | | |
| Q --------------------- | 5.020 | 22.604 | 15.211 | 20.728 | 39.559 | -- | 3.361 | 29.651 | 39.347 |
| Or --------------------- | 6.691 | 4.302 | 2.612 | 2.447 | 2.677 | 7.056 | 2.427 | 1.886 | .355 |
| Ab--------------------- | 13.514 | 2.599 | 14.228 | 4.562 | 3.684 | 9.882 | 3.401 | 1.952 | .117 |
| An -------------------- | 30.692 | 30.132 | 35.554 | 32.182 | 36.261 | 27.340 | 12.017 | 23.064 | 39.910 |
| Hl --------------------- | .050 | .050 | .050 | .050 | .033 | .049 | .017 | .016 | .050 |
| Wo-------------------- | 15.481 | 18.922 | 14.217 | 14.623 | 7.219 | 19.178 | 33.746 | 13.282 | 10.265 |
| En--------------------- | 10.357 | 7.051 | 6.755 | 8.804 | 1.003 | 14.294 | 32.685 | 19.131 | 1.048 |
| Fs --------------------- | 3.146 | -- | 2.003 | 1.847 | -- | 5.206 | 7.944 | 3.851 | -- |
| Fo --------------------- | -- | -- | -- | -- | -- | 6.133 | -- | -- | -- |
| Fa --------------------- | -- | -- | -- | -- | -- | 2.462 | -- | -- | -- |
| Mt--------------------- | 6.683 | 7.653 | 5.244 | 8.933 | 3.947 | 4.616 | 2.469 | 4.484 | -- |
| Hm-------------------- | -- | .789 | -- | -- | 2.311 | -- | -- | -- | 5.312 |
| Il ---------------------- | 1.465 | 1.632 | 1.202 | 1.861 | 1.243 | .964 | .400 | .644 | 1.615 |
| Tn--------------------- | -- | -- | -- | -- | -- | -- | -- | -- | .275 |
| Ap--------------------- | .451 | .551 | .547 | .765 | 1.407 | .731 | .166 | .236 | .546 |
| Fr --------------------- | .109 | -- | .020 | .086 | -- | .618 | .419 | .597 | .040 |
| Cc--------------------- | 4.900 | 2.990 | 1.645 | 1.631 | -- | .181 | .228 | .091 | -- |

Footnotes follow at end of table.

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Gold Hill area | | | | | | | Idaho Springs area |
|---|---|---|---|---|---|---|---|---|
| | Calc-silicate coarsely inter-layered with hornblende gneiss | | Calc-silicate interlayered with pyroxene-rich hornblende-bearing gneiss | | Calc-silicate finely interlayered with hornblende gneiss | | | Lens in biotite gneiss |
| Map locality No. ---- | 13 | 13 | 1 | 1 | 2 | 2 | 2 | 279 |
| Sample No. ---------- | GH281-3-76 | GH281-4-76 | GH1-5-77 | GH1-6-77 | GH2-1-77 | GH2-2-77 | GH2-6-77 | IS3-80 |
| Lab. No.------------- | W211743 | W211744 | W211745 | W211746 | W211747 | W211748 | W211749 | W211776 |
| | Chemical analyses in weight percent | | | | | | | |
| $SiO_2$ ----------------- | 67.4 | 50.6 | 52.2 | 48.7 | 49.2 | 57.8 | 48.3 | 51.1 |
| $Al_2O_3$---------------- | 9.4 | 12.7 | 3.1 | 14.0 | 13.7 | 16.4 | 13.2 | 17.0 |
| $Fe_2O_3$---------------- | 1.7 | 2.3 | 1.7 | 2.5 | 3.0 | 1.8 | 2.1 | 3.2 |
| FeO ------------------ | 2.7 | 4.9 | 3.9 | 5.2 | 6.0 | 4.8 | 7.0 | 5.6 |
| MgO------------------ | 4.4 | 7.8 | 13.8 | 8.5 | 6.0 | 1.9 | 8.6 | 2.8 |
| CaO------------------ | 10.3 | 15.5 | 22.6 | 15.5 | 16.1 | 11.0 | 15.0 | 12.0 |
| $Na_2O$ ---------------- | 1.8 | 1.4 | .17 | 1.8 | 1.7 | 3.3 | 1.5 | 3.4 |
| $K_2O$------------------ | .53 | .58 | .16 | .62 | .91 | .85 | .72 | .63 |
| $H_2O+$ --------------- | .65 | .79 | .37 | .68 | 1.1 | .74 | .99 | .78 |
| $H_2O-$----------------- | .33 | .35 | .10 | .20 | .18 | .26 | .10 | .14 |
| $TiO_2$ ---------------- | .39 | .73 | .05 | 1.3 | 1.9 | .98 | 1.8 | 2.5 |
| $P_2O_5$ ---------------- | .15 | .10 | .04 | .14 | .25 | .22 | .21 | .38 |
| MnO------------------ | .16 | .22 | .21 | .14 | .20 | .13 | .16 | .11 |
| $CO_2$----------------- | .04 | .55 | .36 | .10 | .19 | .22 | .06 | .53 |
| F--------------------- | .06 | .14 | .06 | .4 | .09 | .07 | .3 | .05 |
| Cl -------------------- | .008 | .01 | .008 | .032 | .009 | .010 | .010 | .013 |
| S (total)-------------- | .01 | .01 | .01 | .05 | .07 | .01 | .01 | .01 |
| Subtotal------------ | 100. | 99. | 99. | 99. | 100. | 100. | 100. | 100. |
| Less O --------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total --------------- | 100. | 99. | 99. | 99. | 100. | 100. | 100. | 100. |
| Bulk density --------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ---------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| | Semiquantitative spectrographic analyses in parts per million | | | | | | | |
| Ba -------------------- | 110 | 360 | 62 | 230 | 240 | 260 | 290 | 130 |
| Be -------------------- | 4 | 2 | 6 | N | 22 | 2 | 4 | 1 |
| Ce -------------------- | N | N | N | N | N | N | N | N |
| Co -------------------- | 17 | 39 | 5 | 48 | 54 | 22 | 49 | 33 |
| Cr -------------------- | 35 | 470 | 2 | 670 | 410 | 14 | 430 | 110 |
| Cu -------------------- | 17 | 6 | 5 | 26 | 1,300 | 30 | 35 | 41 |
| Ga -------------------- | 10 | 10 | 5 | 8 | 13 | 20 | 14 | 19 |
| La -------------------- | 42 | N | N | N | N | 34 | N | 25 |
| Mo -------------------- | N | 2 | 3 | 1 | 2 | 2 | 2 | N |
| Nb -------------------- | 7 | 5 | 6 | 6 | 8 | 8 | 6 | 15 |
| Ni -------------------- | 28 | 130 | 6 | 200 | 150 | 16 | 130 | 49 |
| Pb -------------------- | 17 | 15 | 11 | 28 | 61 | 22 | 17 | 12 |
| Rb -------------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sc -------------------- | 11 | 41 | 2 | 38 | 44 | 25 | 37 | 30 |
| Sn -------------------- | 3 | N | 4 | N | 5 | 3 | 3 | -- |
| Sr -------------------- | 290 | 280 | 230 | 300 | 420 | 870 | 360 | 400 |
| V --------------------- | 77 | 160 | 19 | 140 | 170 | 110 | 170 | 140 |
| Y --------------------- | 47 | 11 | 7 | 14 | 11 | 21 | 9 | 26 |
| Yb -------------------- | 5 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| Zn -------------------- | 130 | 190 | 190 | 80 | 200 | 130 | 130 | 130 |
| Zr -------------------- | 150 | 35 | 90 | 41 | 47 | 100 | 31 | 260 |

Footnotes follow at end of table

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Gold Hill area | | | | | | | Idaho Springs area |
|---|---|---|---|---|---|---|---|---|
| | Calc-silicate coarsely inter-layered with hornblende gneiss | | Calc-silicate interlayered with pyroxene-rich hornblende-bearing gneiss | | Calc-silicate finely interlayered with hornblende gneiss | | | Lens in biotite gneiss |
| Map locality No. ---- | 13 | 13 | 1 | 1 | 2 | 2 | 2 | 279 |
| Sample No. --------- | GH281-3-76 | GH281-4-76 | GH1-5-77 | GH1-6-77 | GH2-1-77 | GH2-2-77 | GH2-6-77 | IS3-80 |
| Lab. No. ------------- | W211743 | W211744 | W211745 | W211746 | W211747 | W211748 | W211749 | W211776 |
| | | | | [1]Modes in volume percent | | | | |
| K-feldspar ---------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase---------- | 35. | 34. | -- | 26.3 | 34.4 | 59.7 | 27.4 | 51.1 |
| Quartz --------------- | 30. | -- | -- | 1.4 | -- | 7.4 | .1 | 5.8 |
| Biotite --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende --------- | 3. | 12. | -- | 28.0 | 12.4 | 7.8 | 41.0 | 11.4 |
| Pyroxene[2] ----------- | 25. | 42. | 83. | 31.6 | 42.8 | 17.8 | 29.6 | 16.0 |
| Opaque minerals---- | Tr | Tr | -- | Tr | .2 | Tr | -- | .9 |
| Apatite -------------- | Tr | Tr | -- | -- | .5 | .3 | .4 | .5 |
| Zircon --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Calcite--------------- | -- | 1. | 5. | -- | -- | -- | -- | 1.2 |
| Epidote -------------- | 7. | 10. | Tr | 1.1 | 7.5 | 5.6 | .6 | 10.9 |
| Muscovite-sericite[3] - | -- | -- | 2. | -- | -- | -- | -- | -- |
| Sphene -------------- | Tr | 1. | -- | 1.5 | 2.2 | 1.4 | .9 | 2.2 |
| Scapolite ------------ | -- | -- | -- | 10.5 | -- | -- | -- | -- |
| Garnet --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tremolite-actinolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite ------------- | Tr | -- | 10. | -- | -- | -- | -- | -- |
| Allanite ------------- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Cummingtonite ----- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | Normative minerals | | | | |
| Q --------------------- | 33.000 | 4.625 | 2.213 | -- | 1.985 | 12.851 | -- | 5.210 |
| Or -------------------- | 3.153 | 3.500 | .959 | 3.690 | 5.367 | 5.026 | 4.266 | 3.725 |
| Ab -------------------- | 15.257 | 12.023 | 1.384 | 15.117 | 14.282 | 27.867 | 12.653 | 28.714 |
| An -------------------- | 16.149 | 27.262 | 7.364 | 28.612 | 27.048 | 27.482 | 27.270 | 29.321 |
| Hl --------------------- | .017 | .017 | .017 | .050 | .016 | .016 | .017 | .016 |
| Wo ------------------- | 14.072 | 19.236 | 43.149 | 18.548 | 20.602 | 9.989 | 18.173 | 10.144 |
| En -------------------- | 11.031 | 19.839 | 34.853 | 18.632 | 14.913 | 4.735 | 19.138 | 6.978 |
| Fs -------------------- | 3.208 | 6.414 | 6.130 | 4.836 | 5.619 | 5.934 | 7.527 | 3.698 |
| Fo -------------------- | -- | -- | -- | 1.885 | -- | -- | 1.638 | -- |
| Fa -------------------- | -- | -- | -- | .539 | -- | -- | .710 | -- |
| Mt -------------------- | 2.481 | 3.406 | 2.500 | 3.651 | 4.341 | 2.611 | 3.053 | 4.643 |
| Il --------------------- | .746 | 1.416 | .096 | 2.487 | 3.601 | 1.862 | 3.428 | 4.751 |
| Ap -------------------- | .358 | .242 | .096 | .334 | .591 | .521 | .499 | .901 |
| Fr --------------------- | .096 | .275 | .118 | .802 | .139 | .104 | .579 | .033 |
| Pr --------------------- | .019 | .019 | .019 | .094 | .131 | .019 | .019 | .019 |
| Cc -------------------- | .092 | 1.277 | .830 | .229 | .431 | .501 | .137 | 1.206 |

[1]Modes estimated for samples D245a, GH281-3-76, GH-281-4-76, and GH1-5-77.
[2]Pyroxene undifferentiated, but mostly diposide.
[3]Muscovite-sericite is replacement of plagioclase.

**Table 34.** Chemical and spectrographic analyses and modes for garnet-magnetite-hornblende-quartz gneiss, Central City quadrangle, central Front Range, Colorado.

[Analysts for all rapid-rock analyses, H.F. Phillip, P.D.L. Elmore, P.W. Scott, K.E. White. Analyst for all spectrographic analyses, R.G. Havens. N.d., not determined; N, not detected; N.A., not available; --, not found; <, less than; Tr, trace]

| Map locality No. --- | 327 | 328 | 332 | 342 | 330 | 331 |
|---|---|---|---|---|---|---|
| Sample No. --------- | A125-55 | A126-55 | GO-51A-55 | GO-51B-55 | Mary 1 | Mary 2 |
| Lab No. ------------- | 140572 | 140573 | 140577 | 140578 | 140579 | 140580 |
| Chemical analyses in weight percent | | | | | | |
| $SiO_2$ ---------------- | 52.8 | 49.7 | 52.4 | 51.4 | 49.7 | 43.1 |
| $Al_2O$---------------- | 11.1 | 10.5 | 8.2 | 9.4 | 7.8 | 9.7 |
| $Fe_2O_3$--------------- | 3.4 | 4.9 | 11.7 | 10.9 | 11.0 | 7.6 |
| FeO ----------------- | 16.5 | 16.8 | 13.9 | 15.0 | 13.9 | 17.9 |
| MgO ---------------- | 2.0 | 2.0 | 2.8 | 3.8 | 1.9 | 2.4 |
| CaO----------------- | 2.4 | 2.3 | 5.4 | 3.0 | 2.4 | 2.4 |
| $Na_2O$ --------------- | .05 | .09 | .10 | .09 | .06 | .06 |
| $K_2O$---------------- | .21 | .31 | .49 | 1.8 | 1.2 | .91 |
| $H_2O+$ -------------- | 1.2 | 1.4 | .74 | .87 | 1.3 | 1.3 |
| $H_2O-$ --------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| $TiO_2$ ---------------- | .42 | .38 | .32 | .52 | .30 | 42 |
| $P_2O_5$ ---------------- | .89 | .52 | .70 | .59 | .94 | .76 |
| MnO---------------- | 3.5 | 3.5 | 3.5 | 3.2 | 3.0 | 3.7 |
| $CO_2$---------------- | 5.6 | 8.0 | .25 | .13 | 6.4 | 9.6 |
| F--------------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Cl ------------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| S (total) ------------ | 1.3 | 1.2 | 1.2 | .94 | 1.2 | .86 |
| Total -------------- | 100. | 100. | 101. | 100. | 100. | 100. |
| Semiquantitative spectrographic analyses in parts per million | | | | | | |
| Ba ------------------ | 30 | 150 | 150 | 700 | 150 | 150 |
| Be ------------------ | N | N | 1 | N | 1 | N |
| Co------------------ | 30 | 30 | 15 | 30 | 30 | 30 |
| Cr ------------------ | 70 | 70 | 30 | 70 | 70 | 70 |
| Cu------------------ | 300 | 300 | 150 | 300 | 300 | 150 |
| Ga------------------ | N | N | <30 | <30 | <30 | <30 |
| La ------------------ | 30 | 30 | 30 | 30 | 30 | 30 |
| Mo ----------------- | 30 | 70 | 15 | 15 | 30 | 30 |
| Ni ------------------ | 70 | 70 | 30 | 70 | 70 | 70 |
| Pb ------------------ | 15 | 15 | N | N | 15 | 15 |
| Sc ------------------ | 15 | 15 | 7 | 15 | 7 | 15 |
| Sr ------------------ | 7 | 15 | 15 | 30 | 15 | 15 |
| V ------------------- | 150 | 150 | 70 | 150 | 150 | 150 |
| Y ------------------- | 70 | 30 | 30 | 70 | 70 | 70 |
| Yb------------------ | <10 | <10 | <10 | <10 | <10 | <10 |
| Zn------------------ | 300 | 300 | 300 | 300 | 300 | 300 |
| Zr ------------------ | 150 | 150 | 70 | 150 | 70 | 70 |
| Modes in volume percent | | | | | | |
| K-feldspar --------- | N.A. | N.A. | -- | -- | N.A. | N.A. |
| Plagioclase--------- | N.A. | N.A. | -- | -- | N.A. | N.A. |
| Quartz -------------- | N.A. | N.A. | 37 | 20 | N.A. | N.A. |
| Biotite -------------- | N.A. | N.A. | 11 | 7.5 | N.A. | N.A. |
| Hornblende --------- | N.A. | N.A. | 11 | 28.5 | N.A. | N.A. |
| Garnet -------------- | N.A. | N.A. | 32 | 30 | N.A. | N.A. |
| Opaque minerals--- | N.A. | N.A. | [1]8.5 | 12 | N.A. | N.A. |
| Apatite ------------- | N.A. | N.A. | .5 | 2 | N.A. | N.A. |
| Sphene ------------- | N.A. | N.A. | -- | Tr | N.A. | N.A. |

[1]Pyrite 0.5 percent.

**Table 35.** Average chemical composition for calc-silicate gneiss by area, central Front Range, Colorado.

| | | | | | | Gold Hill | |
|---|---|---|---|---|---|---|---|
| Oxide | Nederland | Central City | Ward Mt. Audubon | Ward excluding Mt. Audubon | Idaho Springs | Interlayered with hornblende gneiss | Interlayered with pyroxene-rich gneiss |
| $SiO_2$----- | 54.2 | 62.8 | 57.7 | 47.6 | 51.1 | 54.7 | 50.4 |
| $Al_2O_3$---- | 14.2 | 14.7 | 7.4 | 13.3 | 17.0 | 13.1 | 8.6 |
| $Fe_2O_3$---- | 5.1 | 5.3 | 2.4 | 3.2 | 3.2 | 2.2 | 2.1 |
| FeO------ | 3.3 | .54 | 4.4 | 6.3 | 5.6 | 5.1 | 4.6 |
| MgO----- | 2.7 | .42 | 10.4 | 9.3 | 2.8 | 5.8 | 11.2 |
| CaO------ | 15.0 | 13.4 | 15.5 | 15.8 | 12.0 | 13.6 | 19.1 |
| $Na_2O$---- | .9 | .04 | .33 | 1.2 | 3.4 | 1.9 | 1.0 |
| $K_2O$------ | .6 | .06 | .37 | 1.2 | .63 | .8 | 0.39 |
| $TiO_2$----- | .58 | .96 | .28 | .51 | 2.50 | 1.06 | .90 |
| $P_2O_5$----- | .31 | .23 | .09 | .31 | .38 | .18 | .90 |
| MnO----- | .17 | .22 | .19 | .19 | .11 | .17 | .18 |

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples from map locality numbers 206, 228, 390, G.O. Riddle; 261, 366, 367, 369, E.S. Daniels, 339, 341, 347, D.F. Powers and P.R. Barnett; 348, L.N. Tarrant; 350, Jean Theobold. Analysts for rapid rock chemical analyses for samples from map locality numbers 98, 114, 116, 145, Leonard Shapiro; 193, 198, 245, 268, P.D.L. Elmore; 302, 303, Z.A. Hamlin; 33, Kay Coates and Hezekiah Smith; 270, Deborah Kobilis; 199, 310, 311, 312, 313, 361, 362, 363, 364, P.D.L. Elmore, S.D. Botts, Gillison Chloe, Lowell Artis, Hezekiah Smith, James Kelsey, J.L. Glenn, Joseph Budinsky. Analysts for spectrographic analyses for samples from locality numbers 206, 228, 390, Barbara Tobin; 366, 367, J.L. Sutton, Jr.; 33, Norma Rait; 261, J.G. Haffty; 369, H.G. Neiman; 270, Leung Mei; 339, 341, 347, P.R. Barnett; 310, 311, 312, 313, 361, W.B. Crandell; 98, 114, 116, 193, 198, 199, 245, 268, 302, 303, 304, 362, 363, J.L. Harris. Normative minerals calculated using the USGS graphic analysis program. N.d., not determined; N, not detected; --, not looked for; Tr, trace; <, less than; x, present but quantity unknown]

| | Phoenix layer | | | | | | [1]Inclusion in Caribou stock | [1]Baltimore layer | [1]Lens northeast of Cardinal |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 268 | 198 | 245 | 261 | 228 | 199 | 193 | 390 | 306 |
| Sample No. ------ | N-400a | N227-65 | N602-64 | N322a | N278-64 | N233-65 | N169-65 | N-126 | N354a-65 |
| Lab. No.---------- | W175654 | W175651 | W175652 | D100280 | D101256 | W171837 | W175648 | D101254 | D101255 |
| **Chemical analyses in weight percent** | | | | | | | | | |
| $SiO_2$ ------------- | 50.4 | 48.2 | 52.8 | 44.75 | 49.15 | 46.3 | 52.5 | 49.35 | 46.49 |
| $Al_2O_3$------------ | 13.8 | 13.4 | 15.4 | 14.34 | 16.07 | 16.3 | 15.2 | 14.58 | 13.16 |
| $Fe_2O_3$------------ | 4.6 | 4.2 | 3.4 | 3.70 | 3.28 | 4.7 | 4.1 | 4.66 | 3.63 |
| FeO --------------- | 4.7 | 7.6 | 6.7 | 8.30 | 7.16 | 5.7 | 6.0 | 8.01 | 9.27 |
| MgO -------------- | 3.0 | 7.6 | 5.5 | 8.50 | 6.54 | 6.1 | 6.8 | 6.96 | 7.34 |
| CaO--------------- | 17.4 | 11.0 | 8.2 | 13.63 | 11.16 | 18.1 | 6.8 | 10.37 | 14.16 |
| $Na_2O$ ------------ | .74 | 1.7 | 3.2 | 1.74 | 2.83 | .94 | 2.5 | 2.69 | 1.86 |
| $K_2O$-------------- | .55 | 2.1 | .82 | 1.24 | .87 | .05 | 2.1 | .64 | .59 |
| $H_2O+$ ----------- | 1.2 | 1.5 | 1.0 | 1.78 | 1.11 | .72 | 1.6 | 1.28 | 1.02 |
| $H_2O-$ ------------ | .19 | .25 | .11 | .07 | .04 | .13 | .20 | .06 | .05 |
| $TiO_2$ ------------- | 1.9 | 1.1 | 1.2 | .95 | .84 | .63 | .97 | .95 | 1.16 |
| $P_2O_5$ ------------ | .27 | .30 | .29 | .20 | .13 | .21 | .13 | .11 | .16 |
| MnO -------------- | .24 | .28 | .26 | .22 | .19 | .20 | .23 | .22 | .27 |
| $CO_2$-------------- | 1.3 | .21 | .22 | .40 | .42 | <.05 | <.05 | .00 | .74 |
| F------------------ | .027 | .23 | .14 | .12 | .23 | <.01 | .21 | .15 | .13 |
| Cl ---------------- | .021 | .16 | .01 | .02 | .02 | .01 | .05 | .03 | .03 |
| S (total) --------- | N.d. | N.d. | N.d. | N.d. | N.d. | .00 | N.d. | N.d. | N.d. |
| Subtotal--------- | 100 | 99. | 99. | 99.96 | 100.04 | 100 | 99. | 100.06 | 100.06 |
| Less O ----------- | N.d. | N.d. | N.d. | .05 | .10 | N.d. | N.d. | .07 | .06 |
| Total ----------- | 100 | 99. | 99. | 99.91 | 99.94 | 100. | 99. | 99.99 | 100.00 |
| Bulk density ----- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ------- | N.d. | N.d. | N.d. | N.d. | 3.00 | 3.32 | N.d. | 3.02 | 3.13 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | |
| Ba---------------- | 200 | 1,000 | 100 | 500 | 200 | 20 | 200 | 200 | 150 |
| Be---------------- | 1 | 1 | N | 0 | 0 | 3 | N | 0 | 0 |
| Ce---------------- | N | N | N | 0 | 0 | N | 500 | 0 | 0 |
| Co---------------- | 20 | 50 | 50 | 50 | 30 | 20 | 15 | 70 | 50 |
| Cr ---------------- | 50 | 300 | 100 | 150 | 300 | 500 | 300 | 700 | 200 |
| Cu---------------- | 2 | 50 | 15 | 70 | 70 | 7 | 10 | 100 | 15 |
| Ga---------------- | 15 | 15 | 10 | 15 | 20 | 15 | 15 | 30 | 20 |
| Gd---------------- | N | -- | -- | -- | -- | -- | -- | -- | -- |
| La ---------------- | N | N | N | 0 | 0 | N | 150 | 0 | 0 |
| Mo --------------- | N | N | N | 0 | 0 | 5 | 3 | 0 | 0 |
| Nb---------------- | N | N | N | 0 | 0 | N | N | 0 | 0 |
| Nd---------------- | N | N | N | N | N | N | N | N | 0 |
| Ni ---------------- | 30 | 150 | 50 | 150 | 70 | 70 | 100 | 70 | 100 |
| Pb ---------------- | 15 | 10 | N | 15 | 0 | N | N | 0 | 0 |
| Pr ---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rb---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sc ---------------- | 30 | 30 | 50 | 30 | 50 | 50 | 20 | 70 | 70 |
| Sn ---------------- | N | N | N | N | N | N | N | N | -- |
| Sr ---------------- | 300 | 700 | 200 | 1,500 | 200 | 2,000 | 1,000 | 300 | 200 |
| V ----------------- | 100 | 150 | 150 | 200 | 300 | 300 | 100 | 500 | 700 |
| Y ----------------- | 30 | 30 | 50 | 20 | 2 | 50 | 50 | 30 | 20 |
| Yb---------------- | 3 | 3 | 5 | 2 | N | 5 | 5 | N | -- |
| Zn---------------- | -- | N | N | N | 0 | N | N | 0 | 0 |
| Zr ---------------- | 100 | 70 | 70 | 30 | 30 | 30 | 200 | 30 | 50 |

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Phoenix layer | | | | | | [1]Inclusion in Caribou stock | [1]Baltimore layer | [1]Lens northeast of Cardinal |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 268 | 198 | 245 | 261 | 228 | 199 | 193 | 390 | 206 |
| Sample No. ------ | N-400a | N227-65 | N602-64 | N322a | N278-64 | N233-65 | N169-65 | N-126 | N354a-65 |
| Lab. No.---------- | W175654 | W175651 | W175652 | D100280 | D101256 | W171837 | W175648 | D101254 | D101255 |
| | Modes of volume percent | | | | | | | | |
| K-feldspar ------- | 5 -- | .9 | -- | -- | -- | -- | Tr | -- | -- |
| Plagioclase------- | 7 | 34.6 | 47.3 | 4.4 | [6]46.6 | 35.2 | 33.0 | 38.5 | 25.6 |
| Quartz------------ | 21 | .8 | 8.0 | .2 | 1.9 | .2 | 11.3 | 1.0 | 13.0 |
| Biotite------------ | -- | Tr | 5.6 | -- | -- | -- | 29.2 | -- | -- |
| Sericite----------- | -- | -- | -- | 15.5 | -- | -- | -- | -- | -- |
| Hornblende ------ | 26 | 48.2 | 34.3 | 65.1 | 39.6 | -- | 19.8 | 56.6 | 44.9 |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Clinopyroxene[7] - | 5 | 9.3 | Tr | 14.4 | 10.1 | 45.5 | .3 | 1.2 | 5.2 |
| Orthophyroxene- | Tr | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Apatite ---------- | Tr | .6 | .5 | .4 | .4 | .4 | 2.1 | Tr | .4 |
| Opaque minerals | 2 | 2.3 | 2.8 | Tr | -- | 4.0 | 3.9 | 2.7 | 4.9 |
| Allanite ---------- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Sphene ----------- | 2 | .6 | .1 | -- | .1 | -- | -- | Tr | -- |
| Zircon ------------ | Tr | -- | .1 | -- | -- | -- | -- | Tr | -- |
| Calcite------------ | 2 | .5 | 1. | Tr | -- | Tr | -- | -- | .2 |
| Chlorite ---------- | -- | .5 | .3 | -- | .2 | -- | -- | -- | .3 |
| Epidote----------- | 35 | 1.7 | -- | -- | 1.1 | 14.7 | .4 | -- | 5.5 |
| | Normative minerals | | | | | | | | |
| Q ----------------- | 46.578 | -- | 5.968 | -- | -- | 1.104 | 39.559 | -- | -- |
| C ----------------- | 14.232 | -- | -- | -- | -- | -- | -- | -- | -- |
| Or ---------------- | 3.849 | 12.510 | 4.896 | 7.478 | 5.206 | .298 | 2.677 | 3.838 | 3.527 |
| Ab---------------- | 7.241 | 13.308 | 27.285 | 9.212 | 24.250 | 8.015 | 3.684 | 23.097 | 15.923 |
| An --------------- | -- | 23.547 | 25.537 | 28.225 | 29.214 | 40.418 | 36.261 | 26.198 | 26.119 |
| Hl ---------------- | .039 | .266 | .017 | -- | -- | -- | .033 | -- | -- |
| Ne---------------- | -- | -- | -- | 3.150 | -- | -- | -- | -- | -- |
| Wo --------------- | -- | 11.128 | 4.761 | 15.395 | 9.730 | 20.327 | 7.219 | 10.554 | 16.352 |
| En---------------- | 7.503 | 18.531 | 13.841 | 9.529 | 11.552 | 15.308 | 1.003 | 17.426 | 12.329 |
| Fs ---------------- | 2.534 | 8.998 | 8.080 | 4.963 | 6.670 | 5.961 | -- | 9.751 | 8.505 |
| Fo ---------------- | -- | .386 | -- | 8.462 | 3.464 | -- | -- | .114 | 4.321 |
| Fa ---------------- | -- | .206 | -- | 4.857 | 2.204 | -- | -- | .071 | 3.285 |
| Mt---------------- | 7.899 | 6.139 | 4.981 | 5.475 | 4.816 | 6.867 | 3.947 | 6.856 | 5.325 |
| Hm--------------- | -- | -- | -- | -- | -- | -- | 2.311 | -- | -- |
| Il ----------------- | 4.274 | 2.106 | 2.303 | 1.841 | 1.616 | 1.831 | 1.243 | 1.831 | 2.229 |
| Ap---------------- | .757 | .716 | .694 | .483 | .312 | .264 | 1.407 | .264 | .383 |
| Fr ---------------- | .598 | .421 | .237 | -- | -- | -- | -- | -- | -- |
| Cc---------------- | 2.159 | .481 | .506 | .928 | .967 | -- | -- | -- | 1.703 |
| Mg--------------- | 1.131 | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Golden Gate layer | | | | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Map locality No- | [8]310 | [8]311 | 312 | [8]313 | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. ------ | GG-1 | GG-2 | GG-3 | GG-4 | SP-1-80 | SP-1a-80 | M-250a | M-276a | M-279a | M-300 | M-488a |
| Lab. No.---------- | W170057 | W170058 | W170059 | W170060 | W211750 | W211751 | W170053 | W170054 | W170055 | W170056 | D101105 |
| **Chemical analyses in weight percent** | | | | | | | | | | | |
| $SiO_2$ ------------- | 52.3 | 53.1 | 61.4 | 51.2 | 47.6 | 45.5 | 51.1 | 48.9 | 49.6 | 48.5 | 50.74 |
| $Al_2O$------------- | 13.4 | 14.5 | 11.3 | 13.7 | 13.4 | 15.6 | 15.0 | 13.8 | 15.9 | 15.7 | 13.93 |
| $Fe_2O_3$------------ | 3.7 | 2.7 | 2.5 | 2.7 | 1.9 | 3.8 | 2.7 | 2.7 | 2.1 | 2.1 | 3.02 |
| FeO -------------- | 11.5 | 10.6 | 6.6 | 8.1 | 9.1 | 7.2 | 9.2 | 9.7 | 9.5 | 9.9 | 9.23 |
| MgO------------- | 4.4 | 3.7 | 3.9 | 7.7 | 5.1 | 4.4 | 4.8 | 7.1 | 5.6 | 6.8 | 7.33 |
| CaO-------------- | 8.7 | 8.5 | 9.0 | 9.6 | 12.3 | 15.2 | 9.4 | 11.0 | 10.9 | 11.0 | 8.78 |
| $Na_2O$ ------------ | 2.6 | 3.1 | 2.2 | 3.0 | 2.5 | 1.8 | 3.7 | 2.2 | 2.4 | 2.3 | 1.51 |
| $K_2O$-------------- | .28 | .45 | .59 | .91 | 1.3 | .63 | .58 | 1.4 | .49 | .68 | 1.19 |
| $H_2O+$ ----------- | .87 | .81 | .69 | .77 | 1.5 | 1.3 | .90 | 1.0 | 1.0 | .77 | 2.45 |
| $H_2O-$ ------------ | .13 | .09 | .09 | .07 | .20 | .07 | .07 | .08 | .09 | .06 | .18 |
| $TiO_2$ ------------- | 1.4 | 1.6 | .82 | 1.0 | 4.5 | 4.2 | .96 | .92 | .95 | .98 | .95 |
| $P_2O_5$------------- | .17 | .24 | .52 | .18 | .48 | .43 | .17 | .12 | .15 | .17 | .09 |
| MnO------------- | .27 | .26 | .18 | .22 | .18 | .21 | .32 | .26 | .23 | .21 | .23 |
| $CO_2$-------------- | <.05 | <.05 | .30 | .06 | .68 | 1.1 | .31 | .08 | .40 | <.05 | .35 |
| F------------------ | N.d. | N.d. | N.d. | N.d. | .1 | .05 | N.d. | N.d. | N.d. | N.d. | .07 |
| Cl ---------------- | N.d. | N.d. | N.d. | N.d. | .024 | .014 | N.d. | N.d. | N.d. | N.d. | .04 |
| S (total) --------- | N.d. | N.d. | N.d. | N.d. | .01 | .19 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Subtotal ------- | 100. | 100. | 100. | 99. | 101. | 101. | 99. | 99. | 99. | 99. | 100.09 |
| Less O----------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .05 |
| Total ---------- | 100. | 100. | 100. | 99. | 101. | 101. | 99. | 99. | 99. | 99. | 100.04 |
| Bulk density ----- | 3.02 | 2.96 | 2.86 | 2.97 | N.d. | N.d. | 2.90 | N.d. | N.d. | 2.98 | N.d. |
| Powder density sink/float ------ | 3.08 | 3.08 | 2.98 | 3.05 | N.d. | N.d. | 3.03 | 3.10 | 3.05 | 3.10 | 3.03 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | | | |
| Ba---------------- | 500 | 200 | 700 | 300 | 150 | 120 | 70 | 200 | 150 | 200 | 100 |
| Be---------------- | N | N | 2 | 1 | N | 1 | 1 | N | N | N | N |
| Ce---------------- | N | N | N | N | N | N | N | N | N | N | N |
| Co---------------- | 30 | 30 | 30 | 50 | 38 | 47 | 50 | 30 | 50 | 50 | 50 |
| Cr ---------------- | N | 10 | 150 | 300 | 180 | 230 | 70 | 70 | 50 | 150 | 100 |
| Cu---------------- | 50 | 2 | 15 | 20 | 32 | 80 | 500 | 20 | 30 | 7 | 20 |
| Ga---------------- | 20 | 20 | 10 | 15 | 21 | 19 | 20 | 15 | 15 | 15 | <30 |
| Gd---------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| La ---------------- | N | N | 100 | N | N | N | N | N | N | N | N |
| Mo --------------- | 5 | 3 | 3 | 3 | N | 1 | 3 | 3 | 3 | 3 | N |
| Nb---------------- | N | N | 3 | N | 6 | 13 | N | N | N | N | -- |
| Nd---------------- | N | N | N | 100 | N | N | -- | N | N | N | -- |
| Ni ---------------- | 10 | 15 | 50 | 70 | 57 | 70 | 70 | 50 | 30 | 7 | 70 |
| Pb ---------------- | N | N | N | N | 13 | 11 | N | N | N | N | 20 |
| Pr ---------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| Rb---------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| Sc ---------------- | 20 | 30 | 20 | 50 | 22 | 31 | 50 | 50 | 50 | 30 | 50 |
| Sn ---------------- | N | N | N | N | N | N | N | N | N | N | N |
| Sr ---------------- | 150 | 200 | 500 | 300 | 290 | 530 | 700 | 300 | 300 | 300 | 70 |
| V----------------- | 150 | 200 | 150 | 200 | 140 | 150 | 200 | 150 | 300 | 150 | 500 |
| Y ----------------- | 30 | 50 | 30 | 30 | 12 | 17 | 30 | 20 | 30 | 30 | 20 |
| Yb---------------- | 3 | 5 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | <3 |
| Zn ---------------- | N | N | N | N | 150 | 170 | N | N | N | N | N |
| Zr ---------------- | 50 | 70 | 150 | 70 | 57 | 150 | 70 | 30 | 50 | 7 | 50 |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Golden Gate layer | | | | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Map locality No- | [8] 310 | [8]311 | 312 | [8]313 | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. ------ | GG-1 | GG-2 | GG-3 | GG-4 | SP-1-80 | SP-1a-80 | M-250a | M-276a | M-279a | M-300 | M-488a |
| Lab. No.---------- | W170057 | W170058 | W170059 | W170060 | W211750 | W211751 | W170053 | W170054 | W170055 | W170056 | D101105 |
| | | | | | Modes in volume percent | | | | | | |
| K-feldspar ------- | -- | -- | -- | -- | Tr | 5 | -- | -- | -- | -- | -- |
| Plagioclase------- | 26.8 | 35.4 | 12.6 | 34.9 | 36.0 | 25. | 51.9 | 35.6 | 40.7 | 34.9 | .7 |
| Quartz ----------- | 10.9 | 9.9 | 44.0 | 3.1 | 1.5 | .5 | .8 | Tr | .9 | 1.0 | 12.1 |
| Biotite ----------- | .5 | .1 | .4 | 2.5 | 1.0 | -- | -- | -- | -- | -- | -- |
| Sericite ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 34.3 |
| Hornblende ------ | 60.6 | 52.3 | 30.8 | 56.9 | 49.4 | 25. | 44.2 | 56.6 | 56.5 | 62.3 | 25.8 |
| Cummingtonite - | -- | -- | -- | -- | 1.8 | Tr | -- | -- | -- | -- | 20.4 |
| Clinopyroxene[7] - | -- | -- | 2.0 | -- | 5.3 | 36. | .1 | 7.4 | -- | 1.1 | -- |
| Orthopyroxene -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite ---------- | .4 | .4 | .7 | .1 | -- | 1. | .2 | .2 | Tr | Tr | .1 |
| Opaque minerals | .8 | 1.2 | Tr | .3 | .2 | .5 | .5 | Tr | .1 | -- | 5.8 |
| Allanite --------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .3 |
| Sphene ---------- | -- | .7 | 1.9 | 1.1 | 3.4 | 8. | .4 | .1 | .7 | .7 | -- |
| Zircon ----------- | -- | -- | -- | -- | -- | -- | .2 | -- | -- | -- | -- |
| Calcite----------- | Tr | 4.1 | 1.1 | .1 | 1.4 | 4. | -- | .8 | Tr | -- | -- |
| Chlorite --------- | -- | -- | -- | -- | -- | -- | .2 | -- | -- | -- | Tr |
| Epidote ---------- | -- | -- | .7 | -- | -- | -- | 1.5 | -- | .3 | -- | .5 |
| | | | | | Normative minerals | | | | | | |
| Q ----------------- | 7.968 | 7.032 | 23.927 | -- | 0.825 | 3.413 | 0.194 | -- | 1.152 | -- | 5.779 |
| Or ---------------- | 1.676 | 2.692 | 3.510 | 5.466 | 7.649 | 3.666 | 3.475 | 8.426 | 2.948 | 4.086 | 7.223 |
| Ab---------------- | 22.283 | 26.559 | 18.740 | 25.803 | 20.843 | 14.926 | 31.746 | 18.959 | 20.674 | 19.788 | 13.124 |
| An --------------- | 24.374 | 24.624 | 19.343 | 21.577 | 21.527 | 32.167 | 22.923 | 24.081 | 31.726 | 31.018 | 28.469 |
| Hl ---------------- | -- | -- | -- | -- | .049 | .016 | -- | -- | -- | -- | -- |
| Wo --------------- | 7.606 | 6.883 | 8.465 | 10.543 | 13.116 | 13.526 | 7.882 | 12.603 | 8.247 | 9.745 | 5.593 |
| En---------------- | 11.100 | 9.330 | 9.778 | 17.303 | 12.647 | 10.791 | 12.121 | 11.572 | 14.198 | 11.810 | 18.751 |
| Fs ---------------- | 16.460 | 15.264 | 9.095 | 10.287 | 7.990 | 3.099 | 13.864 | 9.519 | 14.831 | 10.612 | 13.674 |
| Fo ---------------- | -- | -- | -- | 1.534 | -- | -- | -- | 4.511 | -- | 3.791 | -- |
| Fa ---------------- | -- | -- | -- | 1.005 | -- | -- | -- | 4.089 | -- | 3.753 | -- |
| Mt---------------- | 5.434 | 3.964 | 3.649 | 3.979 | 2.743 | 5.426 | 3.969 | 3.990 | 3.100 | 3.096 | 4.498 |
| Il ----------------- | 2.693 | 3.077 | 1.568 | 1.930 | 8.510 | 7.855 | 1.849 | 1.780 | 1.837 | 1.892 | 1.853 |
| Ap---------------- | .408 | .576 | 1.240 | .433 | 1.132 | 1.003 | .408 | .290 | .362 | .409 | .219 |
| Fr ---------------- | -- | -- | -- | -- | .117 | .024 | -- | -- | -- | -- | -- |
| Pr ---------------- | -- | -- | -- | -- | .019 | .350 | -- | -- | -- | -- | -- |
| Cc---------------- | -- | -- | .687 | .139 | 1.540 | 2.464 | 1.568 | .185 | .926 | -- | .818 |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Lens in cordierite gneiss--Morrison | | Lens and layers near Ward | | [2]Lens upper Green Lakes | [2]Layers, Lake Isabelle area | |
|---|---|---|---|---|---|---|---|
| Map locality No- | [8]369 | 367 | 114 | [8]116 | 145 | [8]98 | 98 |
| Sample No------- | M532-C2 | M-497c | W266a-1-71 | W281b-71 | W275b-70 | W151-71 | W151a-71 |
| Lab. No.--------- | D100505 | D101106 | W178074 | W178082 | W178080 | W178075 | W178076 |
| **Chemical analyses in weight percent** | | | | | | | |
| $SiO_2$ ------------- | 49.34 | 51.10 | 54.6 | 44.5 | 54.6 | 45.5 | 61.5 |
| $Al_2O_3$------------ | 14.52 | 13.14 | 17.8 | 14.4 | 14.1 | 12.7 | 14.4 |
| $Fe_2O_3$------------ | 3.89 | 5.53 | 5.9 | 3.7 | 6.2 | 3.3 | 2.0 |
| FeO --------------- | 9.0 | 10.46 | 3.7 | 6.1 | 7.3 | 7.9 | 4.1 |
| MgO -------------- | 7.43 | 5.68 | 3.3 | 9.8 | 5.2 | 9.7 | 5.5 |
| CaO--------------- | 9.68 | 8.35 | 8.3 | 16.4 | 7.7 | 13.6 | 5.9 |
| $Na_2O$ ------------ | 2.04 | 1.07 | 2.2 | 1.0 | .65 | .69 | 2.5 |
| $K_2O$-------------- | .65 | .70 | 1.4 | 1.4 | 1.8 | 2.2 | 1.8 |
| $H_2O+$ ----------- | 1.70 | 1.72 | 1.9 | 2.0 | 1.0 | 1.7 | 1.2 |
| $H_2O-$ ------------ | .06 | .22 | .20 | .15 | .06 | .26 | .11 |
| $TiO_2$ ------------- | 1.17 | 1.53 | .54 | .57 | 1.6 | .54 | .37 |
| $P_2O_5$------------- | .12 | .21 | .24 | .35 | .29 | .12 | .07 |
| MnO -------------- | .25 | .24 | .22 | .19 | .16 | .29 | .18 |
| $CO_2$-------------- | .04 | .06 | .08 | .02 | .00 | .01 | .01 |
| F------------------ | .06 | .12 | .18 | .83 | .18 | .33 | .34 |
| Cl ----------------- | .04 | .01 | .02 | .02 | .01 | .03 | .03 |
| S (total)---------- | N.d. | N.d. | .01 | .00 | .05 | .19 | .00 |
| Subtotal--------- | 99.99 | 100.14 | 100. | 100. | 100. | 99. | 99. |
| Less O ----------- | .04 | .05 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total ----------- | 99.95 | 100.09 | 100. | 100. | 100. | 99. | 99. |
| Bulk density ----- | N.d. | N.d. | 2.91 | 3.02 | 3.04 | 3.00 | 2.75 |
| Powder density sink/float ------- | 3.03 | 3.08 | 2.92 | 3.16 | 3.04 | 3.08 | 2.80 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | |
| Ba ---------------- | 70 | 70 | 392 | 570 | 397 | 173 | 302 |
| Be ---------------- | 0 | 2 | N | 2 | 1 | 1 | 5 |
| Ce ---------------- | -- | -- | N | 122 | 88 | N | 66 |
| Co ---------------- | 30 | 50 | 20 | 24 | 35 | 48 | 3 |
| Cr ---------------- | 150 | 50 | 4 | 126 | 13 | 481 | 8 |
| Cu ---------------- | 70 | 30 | 21 | 14 | 27 | 47 | 23 |
| Ga ---------------- | 20 | <50 | 9 | 33 | 15 | 2 | 21 |
| Gd ---------------- | -- | -- | N | N | 12 | N | 14 |
| La ---------------- | 0 | 0 | N | 67 | 16 | N | 34 |
| Mo --------------- | 0 | 0 | 3 | 2 | 3 | 3 | 2 |
| Nb ---------------- | 0 | 0 | N | 10 | 3 | -- | 13 |
| Nd ---------------- | -- | 0 | N | 45 | 76 | -- | 69 |
| Ni ---------------- | 50 | 50 | 4 | 66 | 44 | 251 | 5 |
| Pb ---------------- | 10 | 0 | 13 | 21 | 11 | 4 | 42 |
| Pr ---------------- | -- | -- | 4 | 9 | 5 | -5 | 7 |
| Rb ---------------- | -- | -- | 70 | 150 | 100 | 100 | 70 |
| Sc ---------------- | 100 | 50 | 31 | 15 | >68 | 43 | 26 |
| Sn ---------------- | -- | -- | 2 | 8 | <3 | .7 | 4 |
| Sr ---------------- | 300 | 100 | 486 | 156 | 457 | 200 | 534 |
| V ----------------- | 200 | 500 | 215 | 161 | >215 | >215 | 21 |
| Y ----------------- | 30 | 30 | 13 | 25 | 27 | 9 | 122 |
| Yb ---------------- | 5 | <5 | 2 | 3 | 3 | 2 | 9 |
| Zn ---------------- | 0 | 0 | 109 | 126 | 126 | 196 | 282 |
| Zr ---------------- | 50 | 50 | 39 | 149 | 56 | 22 | 499 |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Lens in cordierite gneiss-- Morrison | | Lens and layers near Ward | | [2]Lens upper Green Lakes | [2]Layers, Lake Isabelle area | |
|---|---|---|---|---|---|---|---|
| Map locality No. | [8]369 | 367 | 114 | [8]116 | 145 | [8]98 | 98 |
| Sample No. ------ | M532-C2 | M-497c | W266a-1-71 | W281b-71 | W275b-70 | W151-71 | W151a-71 |
| Lab. No.---------- | D100505 | D101106 | W178074 | W178082 | W178080 | W178075 | W178076 |
| | | | Modes in volume percent | | | | |
| K-feldspar ------- | -- | -- | 5 | -- | -- | -- | .1 |
| Plagioclase------- | 21.5 | 1.7 | 60 | -- | 33 | 31.0 | 33. |
| Quartz------------ | 2.7 | 23.4 | 10 | -- | 23 | -- | 37. |
| Biotite ------------ | 6.3 | -- | -- | -- | 19 | 25.5 | 10. |
| Sericite ----------- | -- | 22.1 | -- | 3 | -- | Tr | -- |
| Hornblende ------ | 68.2 | 49.0 | 25 | 77 | 16 | 3.2 | 19. |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- |
| Clinopyroxene[7] - | -- | -- | -- | 3 | -- | 37.1 | -- |
| Orthopyroxene -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite ----------- | .1 | .5 | x | 1 | 1 | -- | Tr |
| Opaque minerals | 1.2 | 3.3 | x | 1 | 8 | 3.2 | Tr |
| Allanite ---------- | -- | -- | -- | -- | Tr | -- | -- |
| Sphene ----------- | -- | -- | -- | -- | -- | -- | -- |
| Zircon ------------ | Tr | -- | -- | -- | Tr | -- | Tr |
| Calcite------------ | Tr | Tr | -- | -- | -- | -- | -- |
| Chlorite- --------- | -- | -- | x | -- | -- | -- | -- |
| Epidote----------- | -- | -- | x | 15 | -- | -- | -- |
| | | | Normative minerals | | | | |
| Q------------------ | 2.247 | 13.441 | 15.292 | -- | 19.301 | -- | 18.921 |
| Or----------------- | 3.914 | 4.217 | 8.264 | 8.209 | 10.563 | 13.213 | 10.675 |
| Ab----------------- | 17.589 | 9.231 | 18.448 | 2.625 | 5.388 | 5.561 | 21.008 |
| An ---------------- | 29.084 | 29.550 | 34.599 | 30.510 | 30.068 | 25.587 | 22.954 |
| Ne----------------- | -- | -- | -- | 3.047 | -- | .080 | -- |
| Hl ----------------- | -- | -- | .033 | .033 | .016 | .050 | .050 |
| Wo---------------- | 7.847 | 4.551 | 1.378 | 17.547 | 2.031 | 16.596 | 1.439 |
| En----------------- | 18.855 | 14.423 | 8.210 | 12.274 | 12.860 | 10.643 | 13.747 |
| Fs ----------------- | 12.071 | 12.804 | 1.415 | 3.800 | 5.795 | 4.862 | 5.621 |
| Fo ----------------- | -- | -- | -- | 8.371 | -- | 9.747 | -- |
| Fa ----------------- | -- | -- | -- | 2.856 | -- | 4.908 | -- |
| Mt----------------- | 5.747 | 8.175 | 8.545 | 5.323 | 8.927 | 4.863 | 2.910 |
| Il ------------------ | 2.264 | 2.963 | 1.024 | 1.074 | 3.018 | 1.042 | .705 |
| Ap----------------- | .290 | .507 | .568 | .823 | .682 | .289 | .166 |
| Fr ----------------- | -- | -- | .326 | 1.629 | .314 | .667 | .688 |
| Pr ----------------- | -- | -- | .019 | -- | .093 | .361 | -- |
| Cc----------------- | .093 | .139 | .182 | .045 | -- | .023 | .023 |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | [3]Layer James of 4th Creek area | [4]Southeast July mine | | Lens and layers Central City area | | | | |
|---|---|---|---|---|---|---|---|---|
| Map locality No- | 33 | 302 | 303 | 339 | 341 | 347 | 348 | 350 |
| Sample No. ------ | GH350-75 | ML-7a | ML-8a | CC-309b | CC-730 | S472c-53 | EWT10-54 | EWT281-54 |
| Lab. No.---------- | W194508 | W197381 | W197382 | G-3102 | G-3103 | G-3104 | A-4 | A1-72 |
| | | | Chemical analyses in weight percent | | | | | |
| $SiO_2$ -------------- | 57.9 | 50.8 | 47.7 | 50.01 | 49.43 | 48.54 | 48.19 | 55.27 |
| $Al_2O_3$------------ | 16.1 | 14.7 | 12.0 | 13.86 | 15.02 | 17.18 | 15.66 | 16.17 |
| $Fe_2O_3$------------ | 2.4 | 2.6 | 3.6 | 2.95 | 3.11 | 3.61 | 3.86 | 2.27 |
| FeO -------------- | 4.8 | 6.7 | 9.2 | 10.35 | 8.73 | 10.61 | 9.08 | 6.30 |
| MgO------------- | 3.8 | 7.5 | 5.6 | 5.99 | 5.88 | 5.42 | 7.17 | 3.42 |
| CaO-------------- | 7.8 | 13.5 | 18.4 | 10.33 | 10.18 | 7.87 | 8.68 | 7.49 |
| $Na_2O$ ------------ | 2.0 | 1.4 | .46 | 2.57 | 3.38 | 3.14 | .92 | 4.65 |
| $K_2O$-------------- | 1.4 | .76 | .37 | .57 | 1.06 | .34 | 1.07 | 1.31 |
| $H_2O+$ ----------- | 1.0 | .71 | 1.2 | 1.18 | .95 | 1.46 | 3.17 | .99 |
| $H_2O-$ ------------ | .38 | .12 | .11 | .08 | .06 | .10 | .67 | .03 |
| $TiO_2$ ------------- | .84 | .56 | .91 | 1.19 | 1.33 | 1.05 | .75 | .98 |
| $P_2O_5$ ------------- | .14 | .18 | .12 | .12 | .20 | .13 | .12 | .24 |
| MnO------------- | .10 | .16 | .30 | .22 | .21 | .29 | .26 | .19 |
| $CO_2$-------------- | .01 | .26 | .33 | .33 | .27 | .27 | .01 | .48 |
| F----------------- | .06 | .12 | .05 | .07 | .09 | .09 | N.d. | .17 |
| Cl ---------------- | .01 | .02 | .02 | .02 | .05 | .01 | N.d. | N.d. |
| S (total)--------- | N.d. | .00 | .20 | .10 | .01 | .04 | N.d. | .01 |
| Subtotal-------- | 99. | 100. | 101. | 99.94 | 99.96 | 100.15 | 99.61 | 99.98 |
| Less O----------- | N.d. | N.d. | N.d. | .08 | .06 | .06 | N.d. | N.d. |
| Total ----------- | 99. | 100. | 101. | 99.86 | 99.90 | 100.09 | 99.61 | 99.98 |
| Bulk density ----- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ------- | N.d. | N.d. | N.d. | 3.06 | 3.04 | 3.01 | N.d. | N.d. |
| | | | Semiquantitative spectrographic analyses in parts per million | | | | | |
| B ----------------- | 7 | 9 | 19 | N | N | N | N | N |
| Ba---------------- | 220 | 120 | 41 | 70 | 211 | 70 | -- | 200 |
| Be---------------- | 2 | 2 | 8 | 0 | 0 | 0 | -- | -- |
| Ce---------------- | N | N | N | -- | -- | -- | -- | -- |
| Co---------------- | 26 | 34 | 29 | 50 | 50 | 34 | -- | -- |
| Cr---------------- | 68 | 600 | 37 | 60 | 200 | 16 | -- | -- |
| Cu---------------- | 24 | 4 | 84 | 73 | 5 | 16 | -- | -- |
| Ga---------------- | 21 | 12 | 17 | 23 | 20 | 23 | -- | -- |
| Gd---------------- | 13 | N | N | -- | -- | -- | -- | -- |
| La---------------- | 19 | 14 | N | <100 | <50 | <100 | -- | -- |
| Mo---------------- | N | N | N | 0 | 2 | 0 | -- | -- |
| Nb---------------- | 10 | 6 | 7 | 0 | 0 | 0 | -- | -- |
| Nd---------------- | N | N | N | 0 | 0 | 0 | -- | -- |
| Ni ---------------- | 33 | 140 | 32 | 44 | 70 | 12 | -- | -- |
| Pb ---------------- | 17 | 16 | N | <30 | 10 | <30 | -- | -- |
| Pr ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Rb---------------- | N | N | N | -- | -- | -- | -- | -- |
| Sc ---------------- | 33 | 33 | >9 | 77 | 30 | 67 | -- | -- |
| Sn ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Sr ---------------- | 210 | 130 | 130 | 150 | 311 | 180 | -- | -- |
| V----------------- | 180 | 150 | 190 | 410 | 500 | 410 | -- | -- |
| Y----------------- | 30 | 12 | 15 | 50 | 30 | 40 | -- | -- |
| Yb---------------- | 4 | 1 | 3 | 5 | 4 | 4 | -- | -- |
| Zn---------------- | 140 | 98 | 190 | 0 | 0 | 0 | -- | -- |
| Zr ---------------- | 67 | 24 | 62 | 90 | 200 | 100 | -- | -- |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | [3]Layer James of 4th Creek area | [4]Southeast July mine | Lens and layers Central City area | | | | | |
|---|---|---|---|---|---|---|---|---|
| Map locality No.-- | 33 | 302 | 303 | 339 | 341 | 347 | 348 | 350 |
| Sample No.-------- | GH350-75 | ML-7a | ML-8a | CC-309b | CC-730 | S472c-53 | EWT10-54 | EWT281-54 |
| Lab. No.---------- | W194508 | W197381 | W197382 | G-3102 | G-3103 | G-3104 | A-4 | A1-72 |
| | | | Modes in volume percent | | | | | |
| K-feldspar ------- | -- | -- | -- | -- | .6 | -- | -- | N.d. |
| Plagioclase------- | 52.0 | 29.2 | 23.5 | 30.5 | 36.1 | 40.4 | 38.3 | N.d. |
| Quartz ----------- | 18.2 | 5.9 | 2.1 | 6.5 | 7.1 | 9.0 | 12.9 | N.d/ |
| Biotite ----------- | 4.9 | .4 | -- | .3 | 1.0 | -- | -- | N.d. |
| Sericite ---------- | -- | .3 | .3 | -- | -- | -- | -- | N.d. |
| Hornblende ------ | 23.7 | 50.9 | 23.2 | 58.9 | 51.7 | 40.3 | 48.8 | N.d. |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Clino-pyroxene[7] | -- | 9.6 | 41.9 | 1.9 | 2.2 | -- | -- | N.d. |
| Ortho-pyroxene - | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Apatite ---------- | -- | .5 | .4 | .3 | .5 | .3 | -- | N.d. |
| Opaque minerals | .2 | Tr | -- | .4 | Tr | 3.0 | -- | N.d. |
| Allanite --------- | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Sphene ---------- | .5 | .4 | 3.4 | -- | .6 | -- | -- | N.d. |
| Zircon- ---------- | -- | -- | -- | -- | .1 | -- | -- | N.d. |
| Calcite----------- | -- | 1.4 | -- | -- | .1 | 2.6 | -- | N.d. |
| Chlorite --------- | .5 | -- | -- | .9 | -- | 4.4 | -- | N.d. |
| Epidote---------- | -- | 1.4 | 5.2 | -- | Tr | -- | -- | N.d. |
| | | | Normative minerals | | | | | |
| Q ---------------- | 18.058 | 3.811 | 4.188 | 1.630 | -- | -- | 55.85 | 3.307 |
| Or --------------- | 8.420 | 4.500 | 2.179 | 3.377 | 6.277 | 2.011 | 6.434 | 7.754 |
| Ab---------------- | 17.149 | 11.723 | 3.732 | 21.654 | 28.290 | 26.520 | 7.922 | 39.411 |
| An --------------- | 31.406 | 31.725 | 29.562 | 24.740 | 22.925 | 31.846 | 36.064 | 19.411 |
| Hl ---------------- | .017 | .033 | .033 | .033 | .083 | .016 | -- | -- |
| Wo --------------- | 2.768 | 13.277 | 24.326 | 9.739 | 10.077 | 1.712 | 2.878 | 5.055 |
| En---------------- | 9.632 | 18.717 | 13.899 | 14.956 | 8.041 | 12.405 | 18.171 | 8.531 |
| Fs ---------------- | 6.298 | 9.548 | 12.520 | 14.845 | 6.389 | 13.991 | 12.954 | 8.421 |
| Fo ---------------- | -- | -- | -- | -- | 4.649 | .755 | -- | -- |
| Fa ---------------- | -- | -- | -- | -- | 4.071 | .963 | -- | -- |
| Mt---------------- | 3.542 | 3.777 | 5.202 | 4.288 | 4.519 | 5.239 | 5.695 | 3.297 |
| Il ----------------- | 1.624 | 1.066 | 1.722 | 2.266 | 2.531 | 1.996 | 1.449 | 1.864 |
| Ap---------------- | .338 | .427 | .283 | .285 | .475 | .308 | .289 | .569 |
| Fr- --------------- | .099 | .214 | .080 | .122 | .149 | .161 | -- | .309 |
| Pr ---------------- | -- | -- | .373 | .188 | .019 | .075 | -- | .019 |
| Cc---------------- | .023 | .593 | .748 | .752 | .615 | .615 | .023 | 1.093 |

[1]Nederland quadrangle.
[2]Ward quadrangle.
[3]Gold Hill quadrangle.
[4]Monarch Lake quadrangle.
[5]Estimated mode.
[6]Includes some sericite.
[7]Mostly diopside.
[8]Amphibolite

## APPENDIX III

### TABLES 28-32, 36, AND 38-40

## GENERAL INFORMATION

**Table 28.**--Averaged modes and chemical analyses for biotite gneiss north and south of the Idaho Springs-Ralston shear zone, central Front Range, Colorado.

[Tr, trace]

| Mineral | Modes south of shear zone (volume percent) | | | |
|---|---|---|---|---|
| | Biotite gneiss | Garnet-biotite gneiss | Sillimanite-biotite gneiss | Garnet-sillimanite-biotite gneiss |
| K-feldspar ---------- | 6.5 | 10.4 | 4.7 | 2.3 |
| Plagioclase---------- | 22.4 | 25.8 | 13.3 | 12.1 |
| Quartz --------------- | 45.6 | 36.5 | 44.2 | 45.8 |
| Biotite --------------- | 15.9 | 16.5 | 20.0 | 17.9 |
| Garnet --------------- | 0 | .8 | 0 | 1.1 |
| Sillimanite ---------- | 0 | 0 | 8.4 | 3.9 |
| Opaque minerals---- | .7 | 1.0 | .8 | 1.3 |
| Muscovite-sericite -- | 7.5 | 6.7 | 8.1 | 9.6 |
| Chlorite ------------- | .1 | 0 | Tr | .1 |

| Mineral | Modes north of shear zone (volume percent) | | | |
|---|---|---|---|---|
| | Biotite gneiss | Garnet-biotite gneiss | Sillimanite-biotite gneiss | Garnet-sillimanite-biotite gneiss |
| K-feldspar ---------- | 9.6 | 9.6 | 6.6 | 8.8 |
| Plagioclase---------- | 30.8 | 31.0 | 14.2 | 10.5 |
| Quartz --------------- | 37.5 | 40.7 | 38.0 | 39.7 |
| Biotite --------------- | 16.2 | 13.2 | 21.1 | 21.7 |
| Garnet --------------- | 0 | 3.3 | 0 | 3.8 |
| Sillimanite ---------- | 0 | 0 | 8.8 | 8.6 |
| Opaque minerals---- | 1.7 | .6 | 1.4 | .8 |
| Muscovite-sericite -- | 3.5 | .4 | 8.1 | 5.4 |
| Chlorite ------------- | .2 | Tr | Tr | .2 |

| Mineral | Major Oxides (weight percent) | |
|---|---|---|
| | South of shear zone (34 analyses) | North of shear zone (62 analyses) |
| $SiO_2$ | 68.4 | 60.6 |
| $Al_2O_3$ | 15.7 | 19.2 |
| $Fe_2O_3$ | 2.7 | 3.0 |
| FeO | 4.1 | 5.9 |
| MgO | 1.8 | 2.5 |
| CaO | .9 | 1.2 |
| $Na_2O$ | 1.4 | 1.1 |
| $K_2O$ | 3.5 | 3.3 |

Note: Cordierite not shown in garnet-sillimanite-biotite gneiss for either of the areas. It is common in the northern area and sparse in the southern area.

**Table 29.** Summary of oxides in central Front Range biotite-gneiss assemblages.

[N.d., not determined]

| Number of analyses | 12 | 5 | 2 | 29 | 14 | 3 | 5 |
|---|---|---|---|---|---|---|---|
| Oxide | Biotite gneiss | Garnet-biotite gneiss | Garnet-hornblende-biotite gneiss | Sillimanite-biotite gneiss | Garnet-sillimanite-biotite gneiss | Magnetite-sillimanite-biotite gneiss | Cordierite-magnetite-sillimanite-biotite gneiss |
| $SiO_2$ ---- | 70.6 | 61.9 | 66.5 | 65.9 | 61.5 | 66.4 | 50.9 |
| $Al_2O_3$--- | 13.2 | 15.1 | 12.6 | 17.5 | 17.2 | 16.4 | 24.4 |
| $Fe_2O_3$--- | 2.4 | 1.8 | 3.6 | 2.7 | 2.3 | 4.6 | 5.9 |
| FeO ----- | 3.0 | 6.3 | 4.3 | 4.1 | 5.4 | 3.3 | 6.4 |
| MgO ---- | 1.7 | 2.2 | 1.9 | 1.9 | 2.3 | 1.7 | 3.3 |
| CaO ----- | 1.9 | 2.0 | 3.0 | .7 | 1.3 | .29 | .7 |
| $Na_2O$ --- | 2.1 | 2.2 | 1.3 | 1.2 | 1.8 | .84 | 1.3 |
| $K_2O$----- | 2.8 | 3.1 | 3.8 | 3.6 | 3.6 | 3.0 | 3.7 |
| $TiO_2$ ---- | .95 | .73 | 1.2 | 1.2 | .95 | .97 | 1.4 |
| $P_2O_5$---- | .21 | .13 | .37 | .11 | .10 | .09 | .08 |
| MnO---- | .07 | .12 | .13 | .08 | .10 | .05 | .11 |
| $CO_2$----- | .02 | .28 | .41 | .03 | .03 | .02 | .01 |
| F--------- | .13 | .08 | .03 | .10 | .11 | .06 | N.d. |
| S (total) | .06 | .02 | .10 | .01 | .01 | .01 | .2 |
| $K_2O/Na_2O$ (weight percent) | | | | | | | |
| | 1.3 | 1.4 | 2.9 | 3.0 | 2.0 | 3.6 | 3.3 |
| CaO/MgO (weight percent) | | | | | | | |
| | 1.12 | .91 | 1.58 | .37 | .56 | .17 | .20 |

| Number of analyses | 1 | 15 | 1 | 9 | 7 | 5 |
|---|---|---|---|---|---|---|
| | | | | | Thermal | |
| Oxide | Cordierite-garnet-biotite gneiss | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | Cordierite-garnet-sillimanite-biotite gneiss | Cordierite-sillimanite-biotite gneiss | Cordierite-magnetite-biotite gneiss | Biotite gneiss |
| $SiO_2$ ---- | 75.8 | 63.1 | 72.4 | 60.7 | 55.1 | 51.4 |
| $Al_2O_3$--- | 10.2 | 18.0 | 13.3 | 20.0 | 22.6 | 23.9 |
| $Fe_2O_3$--- | 1.7 | 1.7 | .9 | 3.4 | 3.9 | 4.8 |
| FeO ----- | 4.0 | 6.3 | 5.3 | 5.1 | 6.2 | 6.2 |
| MgO ---- | 2.8 | 2.3 | 2.3 | 2.7 | 2.9 | 3.1 |
| CaO ----- | .52 | .7 | .17 | .59 | .40 | 1.8 |
| $Na_2O$ --- | .57 | 1.1 | 1.7 | 1.2 | 1.1 | 1.6 |
| $K_2O$----- | 2.2 | 3.7 | 1.6 | 3.2 | 4.2 | 3.8 |
| $TiO_2$ ---- | .37 | .93 | .20 | .90 | 1.1 | 1.4 |
| $P_2O_5$---- | .05 | .07 | .02 | .07 | .08 | .41 |
| MnO---- | .09 | .17 | .10 | .08 | .11 | .07 |
| $CO_2$----- | N.d. | .02 | .02 | .01 | .02 | .02 |
| F--------- | N.d. | .07 | .09 | .07 | .15 | .36 |
| S (total) | N.d. | .10 | N.d. | .04 | N.d. | .02 |
| $K_2O/Na_2O$ (weight percent) | | | | | | |
| | 3.8 | 3.4 | .9 | 2.7 | 3.8 | 2.4 |
| CaO/MgO (weight percent) | | | | | | |
| | .19 | .30 | .07 | .22 | .14 | .58 |

**Table 30.** Comparison of the average chemical composition of Archean and Early Proterozoic clastic sedimentary rocks with average Front Range biotite gneiss.

[--, nothing reported]

| Oxides in weight percent | | | |
|---|---|---|---|
| Oxides | [1]Archean | [1]Early Proterozoic | Front Range biotite gneiss |
| $SiO_2$ -------- | 65.9 | 70.9 | 65.1 |
| $Al_2O_3$------- | 14.9 | 14.0 | 16.2 |
| [2]$FeO_t$ ------- | 6.4 | 6.1 | 7.4 |
| MgO ------- | 3.6 | 2.4 | 2.3 |
| CaO -------- | 3.3 | 1.3 | 1.3 |
| $Na_2O$ ------- | 2.9 | 1.3 | 1.4 |
| $K_2O$ -------- | 2.3 | 3.0 | 3.4 |
| $TiO_2$ -------- | .6 | .6 | .9 |
| MnO ------- | -- | -- | .12 |
| $P_2O_5$-------- | -- | -- | .7 |

[1]McLennan, 1982.
[2]$FeO_t$, represents total iron.

**Table 31.** Spectrographic analyses for selected trace elements in central Front Range biotite gneiss by area

[X-ray spectrographic analyses for Nb, Rb, Sr, Y, Zr, analysts: R.G. Johnson, and K.O. Dennen. Quantitative optical spectrographic analyses for Ba, Ce, Cr, Sc, V; analyst: P.H. Briggs, <, less than]

| Area and map locality No. | Trace elements in parts per million | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
| **Central City** | | | | | | | | | | |
| 340 | 1,200 | 74 | 199 | 17 | 233 | 23 | 148 | 137 | 18 | 216 |
| 345 | 605 | 112 | 130 | 15 | 118 | 41 | 77 | 112 | 67 | 228 |
| 349 | 485 | 286 | 162 | 14 | 135 | 23 | 98 | 111 | 46 | 212 |
| **Idaho Springs** | | | | | | | | | | |
| 277 | 1,950 | 249 | 29 | 14 | 145 | 9 | 686 | 68 | 33 | 276 |
| 280 | 492 | 99 | 103 | 15 | 144 | 13 | 94 | 66 | 26 | 288 |
| 281 | 329 | 111 | 27 | 13 | 121 | 10 | 196 | 27 | 43 | 377 |
| 282 | 1,010 | 87 | 3 | 13 | 83 | 10 | 54 | 4 | 44 | 268 |
| 284 | 369 | 88 | 156 | 10 | 86 | 10 | 185 | 64 | 34 | 225 |
| 285 | 1,010 | 121 | 35 | 11 | 134 | 11 | 162 | 22 | 61 | 555 |
| **Ralston Buttes** | | | | | | | | | | |
| 351 | 477 | 96 | 217 | 15 | 167 | 16 | 86 | 93 | 31 | 232 |
| 352 | 392 | 109 | 217 | 71 | 126 | 11 | 90 | 72 | 36 | 248 |
| 353 | 713 | 124 | 267 | 11 | 134 | 8 | 31 | 84 | 38 | 317 |
| 354 | 509 | 71 | 177 | 26 | 164 | 12 | 122 | 79 | 27 | 204 |
| 355 | 349 | 76 | 176 | 14 | 182 | 13 | 19 | 74 | 36 | 246 |
| 356 | 349 | 113 | 134 | 13 | 185 | 9 | 51 | 68 | 40 | 230 |
| 357 | 517 | 236 | 283 | 30 | 307 | 32 | 59 | 157 | 80 | 368 |
| 358 | 516 | 80 | 173 | 22 | 113 | 10 | 139 | 67 | 31 | 222 |
| **Morrison** | | | | | | | | | | |
| 367 | 441 | 90 | 3 | 11 | 20 | 4 | 33 | <2 | 50 | 250 |
| 368A[1] | 495 | 91 | 2 | 13 | 69 | 11 | 11 | <2 | 69 | 278 |
| 368B[1] | 549 | 54 | 3 | 17 | 97 | 8 | 13 | <2 | 51 | 253 |
| **Indian Hills** | | | | | | | | | | |
| 315 | 1,140 | 79 | 79 | 13 | 197 | 18 | 195 | 92 | 23 | 179 |
| 317 | 565 | 77 | 56 | 17 | 180 | 12 | 168 | 45 | 34 | 201 |
| 319 | 592 | 73 | 82 | 11 | 78 | 8 | 125 | 48 | 23 | 223 |
| 320 | 311 | 108 | 94 | 9 | 69 | 6 | 225 | 32 | 39 | 398 |
| **Evergreen** | | | | | | | | | | |
| 322 | 1,100 | 126 | 85 | 15 | 161 | 11 | 436 | 56 | 39 | 222 |
| **Squaw Pass** | | | | | | | | | | |
| 271 | 471 | 91 | 76 | 8 | 79 | 6 | 89 | 37 | 29 | 396 |
| 272 | 649 | 82 | 83 | 15 | 219 | 15 | 118 | 68 | 46 | 216 |
| 274 | 817 | 109 | 111 | 12 | 167 | 19 | 66 | 101 | 41 | 185 |
| 275 | 374 | 55 | 163 | 7 | 107 | 10 | 144 | 74 | 24 | 200 |
| 276 | 576 | 123 | 90 | 18 | 138 | 12 | 138 | 64 | 38 | 226 |
| **Tungsten** | | | | | | | | | | |
| 161 | 765 | 89 | 167 | 8 | 110 | 10 | 214 | 74 | 27 | 245 |
| 174 | 882 | 162 | 161 | 20 | 136 | 19 | 130 | 116 | 41 | 298 |
| 177 | 744 | 117 | 165 | 20 | 157 | 33 | 19 | 146 | 55 | 278 |
| **Nederland** | | | | | | | | | | |
| 200 | 1,320 | 142 | 243 | 21 | 166 | 28 | 206 | 169 | 44 | 279 |
| 230 | 312 | 99 | 37 | 23 | 132 | 9 | 46 | 33 | 49 | 249 |
| 255 | 977 | 121 | 181 | 10 | 92 | 23 | 321 | 134 | 66 | 341 |
| 257 | 892 | 100 | 172 | 15 | 246 | 26 | 130 | 136 | 39 | 212 |
| 263 | 586 | 106 | 227 | 16 | 149 | 26 | 52 | 127 | 43 | 212 |
| **East Portal** | | | | | | | | | | |
| 325 | 851 | 142 | 132 | 15 | 226 | 15 | 91 | 83 | 24 | 228 |
| **Monarch Lake** | | | | | | | | | | |
| 300 | 785 | 88 | 98 | 13 | 165 | 12 | 332 | 54 | 28 | 196 |
| 301 | 700 | 124 | 109 | 20 | 198 | 12 | 206 | 83 | 37 | 188 |
| 303 | 546 | 86 | 94 | 15 | 132 | 18 | 145 | 86 | 36 | 179 |
| 305 | 443 | 84 | 96 | 11 | 125 | 18 | 139 | 82 | 33 | 175 |
| 309 | 347 | 218 | 212 | 15 | 112 | 8 | 141 | 99 | 23 | 317 |
| **Allens Park** | | | | | | | | | | |
| 323 | 368 | 84 | 80 | 19 | 150 | 12 | 160 | 44 | 30 | 241 |

Footnote follows at end of table.

**Table 31.** Spectrographic analyses for selected trace elements in central Front Range biotite gneiss by area.--Continued

| Area and map locality No. | Trace elements in parts per million | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
| **Ward** | | | | | | | | | | |
| 88 | 397 | 167 | 27 | 18 | 219 | 8 | 47 | 28 | 52 | 342 |
| 90 | 730 | 107 | 127 | 15 | 217 | 17 | 62 | 100 | 33 | 231 |
| 109 | 218 | 78 | 115 | 10 | 93 | 9 | 149 | 71 | 26 | 245 |
| 122 | 778 | 83 | 108 | 17 | 185 | 19 | 160 | 99 | 34 | 331 |
| 137 | 414 | 61 | 50 | 9 | 142 | 14 | 487 | 93 | 17 | 162 |
| 141 | 946 | 156 | 179 | 17 | 200 | 24 | 158 | 131 | 43 | 263 |
| 154 | 823 | 113 | 133 | 14 | 202 | 18 | 103 | 101 | 25 | 209 |
| 155 | 1,230 | 154 | 85 | 17 | 153 | 15 | 200 | 63 | 31 | 273 |
| 156 | 698 | 91 | 123 | 16 | 100 | 14 | 201 | 86 | 26 | 223 |
| 158 | 607 | 177 | 228 | 17 | 180 | 33 | 127 | 177 | 27 | 312 |
| **Gold Hill** | | | | | | | | | | |
| 18 | 1,010 | 113 | 103 | 19 | 182 | 19 | 270 | 97 | 17 | 251 |
| 19 | 180 | 112 | 141 | 53 | 268 | 16 | 11 | 99 | 17 | 253 |
| 26 | 334 | 127 | 171 | 16 | 176 | 19 | 13 | 121 | 19 | 294 |
| 31 | 260 | 98 | 144 | 13 | 46 | 14 | 36 | 98 | 20 | 380 |
| 35 | 981 | 84 | 70 | 13 | 118 | 16 | 309 | 65 | 27 | 206 |
| 51 | 885 | 98 | 113 | 11 | 91 | 10 | 138 | 74 | 34 | 258 |
| 58 | 47 | 30 | 596 | 10 | 35 | 2 | <05 | 29 | 08 | 163 |
| 73 | 903 | 142 | 174 | 18 | 278 | 30 | 95 | 116 | 29 | 205 |

[1]Two distinct layers of biotite gneiss same location.

**Table 32.** Comparison of averaged amounts of trace elements in biotite geneiss of the central Front Range, Colorado, with those in an average shale.

| Trace element (in parts per million) | Ba | Ce | Co | Cr | Cu | Ga | La | Mo | Nb | Ni | Pb | Rb | Sc | Sr | V | Y | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Front Range biotite gneiss | 666 | 114 | 19 | 134 | 35 | 28 | 50 | 4 | 17 | 56 | 28 | 149 | 16 | 145 | 80 | 37 | 85 | 261 |
| [1]Average shale | [2]580 | 50 | 20 | 100 | 57 | [2]19 | 40 | 2 | 20 | 95 | 20 | [2]140 | 10 | 450 | 130 | 30 | 80 | 200 |

[1]Includes Holocene shales (Krauskopf, 1967).

[2]Turekian and Wedpohl, 1964, p. 186.

**Table 36.** Comparison of trace elements in average calc-silicate gneiss, central Front Range, with average carbonate rock, average deep-sea carbonate rock, and average basalt given in parts per million, as reported by Turekian and Wedepohl (1964).

[--, no data; <, less than; * from Krauskopf, 1967]

| Trace element | Calc-silicate gneiss | Carbonate rock | Deep-sea carbonate rock | Basalt |
|---|---|---|---|---|
| Ba ---------- | 239 | 10 | 190 | *330 |
| Ce ---------- | 20 | < 1 | < 1 | * 1 |
| Cr ---------- | 412 | 11 | 11 | *170 |
| Nb ---------- | 8 | -- | -- | 20 |
| Rb ---------- | 35 | -- | -- | 30 |
| Sc ---------- | 39 | 1 | 2 | * 30 |
| Sr ---------- | 423 | | | 465 |
| V ---------- | 236 | 20 | 20 | *250 |
| Y ---------- | 18 | | | 25 |
| Zr ---------- | 70 | | | 150 |

**Table 38.** Average chemical composition of central Front Range hornblende gneiss and amphibolite, and that of several types of basalt.

| | Front Range hornblende gneiss and amphibolite | | | | | | | Typical basalts | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oxide | Phoenix layer | Morrison layer | Central City lenses | Golden Gate layer | Clear Creek layer | Other lenses and layers | [1]Average for Front Range | [2]Tholeiitic basalt | [3]Icelandic basalt | [4]Hawaii basalt | [2]Normal alkali basalt |
| $SiO_2$ | 48.6 | 49.8 | 50.3 | 54.5 | 46.6 | 51.2 | 50.2 | 50.83 | 47.96 | 49.8 | 45.78 |
| $Al_2O_3$ | 14.9 | 14.9 | 15.6 | 13.2 | 14.5 | 14.4 | 14.6 | 14.07 | 15.53 | 14.0 | 14.64 |
| $Fe_2O_3$ | 4.0 | 2.5 | 3.2 | 2.9 | 2.9 | 4.0 | 3.3 | 2.88 | 2.06 | 2.5 | 3.16 |
| FeO | 6.7 | 9.5 | 9.0 | 9.2 | 8.2 | 6.5 | 8.2 | 9.0 | 8.34 | 8.5 | 8.73 |
| MgO | 6.2 | 6.3 | 5.6 | 4.9 | 4.8 | 6.5 | 5.7 | 6.34 | 9.70 | 7.2 | 9.39 |
| CaO | 13.2 | 10.2 | 8.9 | 9.0 | 13.8 | 10.8 | 11.0 | 10.42 | 13.32 | 11.3 | 10.74 |
| $Na_2O_3$ | 1.9 | 2.4 | 2.9 | 2.7 | 2.2 | 1.6 | 2.3 | 2.23 | 1.82 | 2.2 | .95 |
| $K_2O$ | .94 | .87 | .87 | .56 | 1.0 | 1.2 | .91 | .82 | .30 | .62 | .95 |
| $TiO_2$ | 1.10 | .95 | 1.10 | 1.20 | 4.3 | .90 | 1.59 | 2.03 | .96 | 2.60 | 2.63 |
| $P_2O_5$ | .23 | .14 | .16 | .28 | .45 | .17 | .24 | .23 | .21 | .32 | .39 |
| MnO | .23 | .25 | .23 | .23 | .19 | .25 | .23 | .18 | .18 | .18 | .20 |

[1]Average of table 37.
[2]Nockolds (1954).
[3]Flanagan (1984).
[4]Brenner and Harel (1976).

**Table 39**. Spectrographic analyses for selected trace elements in parts per million in hornblende gneiss, amphibolite, and calc-silicate gneiss by area, central Front Range, Colorado.

[Quantitative optical spectrographic analyses for the elements Ba, Ce, Cr, Sc, V; analyst, P.H. Briggs. X-ray spectrographic analyses for the elements Nb, Rb, Sr, Zr, Y; analysts R.R. Larson, R.G. Johnson, and K.O. Dennen; <, less than]

| Area and map locality No. | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
|---|---|---|---|---|---|---|---|---|---|---|
| Idaho Springs | | | | | | | | | | |
| [1]279 | 96 | 33 | 114 | 11 | 10 | 25 | 502 | 131 | 23 | 200 |
| Morrison | | | | | | | | | | |
| 364 | 220 | 11 | 254 | 7 | 13 | 39 | 254 | 262 | 24 | 70 |
| 367 | 51 | 18 | 97 | 9 | 7 | 53 | 233 | 355 | 32 | 87 |
| Squaw Pass | | | | | | | | | | |
| 270 | 77 | 26 | 257 | 12 | 16 | 31 | 159 | 218 | 31 | 134 |
| Nederland | | | | | | | | | | |
| 198 | 676 | 35 | 421 | 8 | 64 | 34 | 1,710 | 208 | 27 | 74 |
| 199 | 25 | 15 | 407 | 5 | 34 | 44 | 258 | 286 | 17 | 37 |
| 228 | 290 | 17 | 130 | 8 | 12 | 39 | 301 | 285 | 25 | 44 |
| [1]260 | 470 | 14 | 4 | 5 | 45 | <2 | 213 | 74 | 11 | 43 |
| 261 | 461 | 24 | 301 | 8 | 45 | 31 | 635 | 259 | 33 | 58 |
| 390 | 118 | 10 | 237 | 9 | 15 | 53 | 635 | 302 | 33 | 58 |
| Monarch Lake | | | | | | | | | | |
| 302 | 180 | 19 | 836 | 10 | 12 | 35 | 149 | 179 | 20 | 43 |
| 303 | 204 | 18 | 118 | 8 | 21 | 53 | 139 | 368 | 34 | 75 |
| Ward | | | | | | | | | | |
| 98 | 268 | 13 | 1,150 | 8 | 112 | 37 | 575 | 206 | 18 | 29 |
| 114 | 466 | 26 | 14 | 6 | 92 | 26 | 402 | 170 | 17 | 41 |
| 116 | 290 | 33 | 698 | 6 | 51 | 50 | 254 | 264 | 18 | 45 |
| Gold Hill | | | | | | | | | | |
| [1]01 | 435 | 30 | 683 | 6 | 59 | 42 | 435 | 206 | 19 | 46 |
| [1]01 | 58 | 12 | 2 | 6 | 4 | <2 | 228 | 14 | 12 | 52 |
| 01 | 170 | 9 | 1,150 | 10 | 14 | 37 | 146 | 193 | 18 | 44 |

[1]Calc-silicate gneiss.

**Table 40.** Frequency distribution for trace elements that occur above their mean in biotite gneiss, central Front Range, Colorado.

7½' Quadrangles

| | |
|---|---|
| CC, Central City | M, Morrison |
| EV-SP, Evergreen and Squaw Pass | N, Nederland |
| GH, Gold Hill | T, Tungsten |
| IH, Indian Hills | RB, Ralston Buttes |
| IS, Idaho Springs | W, Ward |
| ML, Monarch Lake | |

| | Quadrangles | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | M | IH | EV-SP | CC | IS | N | T | RB | W | GH | ML |
| Ba | | | x | x | x | x | x | | | | |
| Be | | | | | | | | | x | x | x |
| Ce | | x | x | x | x | x | | x | x | x | x |
| Cu | x | x | | x | | | | | | | |
| Cr | | | | x | | x | x | x | x | x | |
| Ga | x | | | x | | x | x | | x | x | |
| La | | x | x | x | x | x | x | x | x | x | x |
| Mo | x | | | x | | x | x | x | x | x | |
| Nb | | | | | | | | x | | | |
| Ni | | | x | x | | x | x | x | x | x | x |
| Pb | | x | x | x | x | | | | | | |
| Rb | | | x | x | | | | x | x | | |
| Sc | x | | | x | | x | x | x | x | x | x |
| Sn | | | | | | x | x | | x | x | |
| V | | | | x | | x | x | | | | |
| Y | x | x | x | x | x | x | x | x | x | | x |
| Zr | x | x | x | x | x | x | x | x | x | x | x |

**Table 1.** Modes (volume percent) for biotite gneiss, central Front Range, Colorado.
(--, not found; Tr, trace)

| Locality No. | 160 | 165 | 287 | 295 | 209 | 214 | 215 | 221 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | T-74 | T-141 | J-174 | J-452 | N1a-64 | N104-64 | N118a-64 | N155-64 |
| K-feldspar | 32.4 | 8.3 | 7.0 | -- | 18.6 | Tr | 7.8 | 10.7 |
| Plagioclase | 20.9 | 22.1 | 6.1 | 8.4 | 26.4 | 19.8 | 45.6 | 26.2 |
| Quartz | 35.0 | 48.8 | 52.2 | 38.2 | 36.4 | 72.0 | 44.0 | 45.8 |
| Biotite | 8.0 | 17.6 | 31.3 | 21.1 | 15.7 | 5.8 | 4 | [1]10.0 |
| Opaque minerals | .4 | 1.6 | .1 | 1.1 | 2.6 | 1.6 | 1.5 | 1.0 |
| Zircon | .3 | Tr | .1 | Tr | Tr | .2 | Tr | Tr |
| Muscovite-sericite[3] | 3.0 | 1.6 | 3.2 | 30.9 | -- | -- | .1 | 5.4 |
| Apatite | -- | -- | -- | Tr | .3 | -- | Tr | -- |
| Chlorite | -- | -- | -- | -- | Tr | .6 | .6 | .9 |
| Sphene | -- | -- | -- | -- | -- | -- | Tr | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Calcite | -- | -- | -- | -- | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- |
| Corundum | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | .3 | -- | -- | -- | -- |

| Locality No. | 224 | 236 | 238 | 242 | 124 | 130 | 131 | 133 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N211-64 | N399-64 | N428-64 | N583-64 | W81-70 | W181-70 | W189-70 | W200-70 |
| K-feldspar | 22. | 2.0 | 30.2 | .2 | 18.2 | -- | 1.5 | 25.7 |
| Plagioclase | 18. | 29.9 | 22.4 | 30.6 | 23.1 | 58.3 | 47.8 | 21.8 |
| Quartz | 49. | 58.4 | 23.9 | 50.7 | 49.6 | 6.7 | .6 | 30.2 |
| Biotite | [1]10. | 7.3 | 13.8 | 13.2 | 7.3 | 26.6 | 37.2 | 18.9 |
| Opaque minerals | .4 | 2.0 | 1.6 | 1.0 | .3 | 6.0 | 7.9 | 2.8 |
| Zircon | Tr | .3 | .2 | Tr | .1 | .2 | Tr | Tr |
| Muscovite-sericite[3] | -- | Tr | 6.6 | 4.2 | .7 | 1.9 | 4.3 | -- |
| Apatite | -- | Tr | 1.3 | -- | .1 | .3 | -- | .3 |
| Chlorite | .6 | Tr | -- | .1 | .6 | -- | -- | -- |
| Sphene | -- | Tr | -- | -- | -- | -- | -- | .2 |
| Xenotime-monazite | -- | Tr | Tr | -- | -- | -- | -- | -- |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | .1 | -- | -- | -- | -- | -- | .1 |
| Epidote | -- | Tr | -- | -- | Tr | -- | .3 | -- |
| Corundum | -- | -- | -- | -- | -- | Tr | .4 | -- |
| Spinel | -- | -- | -- | -- | -- | -- | Tr | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 134 | 135 | 137 | 138 | 139 | 143 | 145 | 97 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W213-70 | W232-70 | W241-70 | W242b-70 | W246-70 | W270-70 | W275a-70 | W150-71 |
| K-feldspar | .2 | 47.3 | .3 | -- | 1.1 | 8.4 | 2.7 | 2.3 |
| Plagioclase | 15.5 | 23.1 | 48.4 | 29. | 33.6 | 35.4 | 40.4 | 82.8 |
| Quartz | 55.1 | 24.8 | 31.2 | 30. | 35.9 | 27.0 | 39.3 | .9 |
| Biotite | 13.3 | 2.8 | 18.4 | 27. | [1]19.2 | 28.6 | 16.3 | 10.8 |
| Opaque minerals | 1.7 | .7 | 1.7 | 1. | .2 | .1 | 1.0 | 2.7 |
| Zircon | Tr | Tr | Tr | Tr | Tr | -- | Tr | Tr |
| Muscovite-sericite[3] | 13.8 | .2 | Tr | 13. | 1.0 | .5 | .4 | -- |
| Apatite | -- | .3 | Tr | -- | -- | Tr | -- | .3 |
| Chlorite | .4 | .8 | -- | -- | -- | Tr | Tr | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | .1 |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | -- | Tr |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | .1 |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- |
| Corundum | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 1**. Modes (volume percent) for biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 107 | 109 | 82 | 83 | 353 | 354 | 359 | 360 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W252a-71 | W257-71 | W56-73 | W64-73 | RB3-80 | RB4-80 | RB9a-80 | RB10-80 |
| K-feldspar ----------- | -- | 2.5 | -- | -- | -- | -- | 3.3 | 19.2 |
| Plagioclase ---------- | 62. | 30.6 | 40.3 | 18. | .5 | 4.1 | 37.2 | 24.2 |
| Quartz---------------- | 14. | 51.4 | 39.5 | 51. | 58.4 | 56.3 | 43.7 | 37.5 |
| Biotite---------------- | 18. | 12.9 | 18.9 | 31. | 19.0 | 17.9 | [2]13.4 | 13.9 |
| | | | | | | | | |
| Opaque minerals --- | 5. | 1.3 | 1.0 | -- | .7 | 1.8 | .1 | Tr |
| Zircon---------------- | Tr | Tr | -- | Tr | Tr | Tr | Tr | .1 |
| Muscovite-sericite[3]-- | -- | 1.3 | -- | -- | 2.1 | 19.6 | -- | 3.7 |
| Apatite------------------ | 1.0 | -- | -- | -- | Tr | .3 | .1 | Tr |
| | | | | | | | | |
| Chlorite -------------- | Tr | -- | -- | -- | -- | Tr | -- | -- |
| Sphene --------------- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | Tr | .1 | -- |
| Calcite --------------- | -- | -- | -- | -- | -- | -- | 1.2 | .1 |
| | | | | | | | | |
| Allanite -------------- | Tr | -- | -- | -- | -- | -- | .1 | Tr |
| Epidote--------------- | Tr | -- | .3 | -- | -- | -- | .8 | 1.3 |
| Corundum ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel ---------------- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline---------- | -- | -- | -- | -- | .3 | Tr | -- | -- |
| Locality No. --------- | 277 | 284 | 314 | 3 | 421 | 424 | 425 | |
| Sample No. ---------- | IS1-80 | IS8-80 | GG-5 | M-57 | C4-87 | P1-87 | P2-87 | |
| K-feldspar ----------- | 19.0 | 1.5 | 2.5 | .3 | 15.5 | 14.1 | 6.0 | |
| Plagioclase ---------- | 30.5 | 30.3 | 30.3 | 49.8 | 49.7 | 40.4 | 46.9 | |
| Quartz---------------- | 32.6 | 52.4 | 38.5 | 31.1 | 17.9 | 31.7 | 30.5 | |
| Biotite---------------- | 15.0 | 11.9 | 20.5 | 17.3 | 14.7 | 12.8 | 14.5 | |
| | | | | | | | | |
| Opaque minerals --- | 1.8 | .8 | Tr | .1 | Tr | .6 | 1.0 | |
| Zircon---------------- | Tr | .3 | Tr | .1 | Tr | Tr | Tr | |
| Muscovite-sericite[3] | -- | 2.1 | 6.1 | .6 | 2.2 | .1 | .8 | |
| Apatite --------------- | .8 | -- | .3 | .3 | Tr | .3 | .3 | |
| | | | | | | | | |
| Chlorite -------------- | -- | .7 | -- | -- | -- | -- | -- | |
| Sphene --------------- | -- | -- | -- | -- | -- | -- | -- | |
| Xenotime-monazite- | -- | -- | -- | -- | Tr | Tr | Tr | |
| Calcite --------------- | -- | -- | 1.1 | .4 | -- | -- | -- | |
| | | | | | | | | |
| Allanite -------------- | .3 | -- | .3 | -- | -- | -- | -- | |
| Epidote--------------- | Tr | -- | .4 | -- | -- | -- | -- | |
| Corundum ----------- | -- | -- | -- | -- | -- | -- | -- | |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- | -- | |
| Tourmaline---------- | -- | -- | -- | -- | -- | -- | -- | |

[1]Includes traces of rutile.
[2]Includes 0.1 percent hornblende.
[3]Muscovite-sericite is mostly sericite after plagioclase.

**Table 2.** Modes (volume percent) for garnet-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 266 | 211 | 215 | 231 | 233 | 247 | 248 | 251 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N-381 | N40a-64 | N118-64 | N360-64 | N363a-64 | N636a-64 | N656-64 | N705-64 |
| K-feldspar | 1.0 | 1.6 | 0.9 | 41.1 | 18.5 | 24.9 | 36.6 | 4.8 |
| Plagioclase | 25.0 | 35.3 | 59.0 | 16.8 | 21.7 | 20.9 | 20.4 | 22.7 |
| Quartz | 51.4 | 46.4 | 31.0 | 23.7 | 45.3 | 37.7 | 38.7 | 60.0 |
| Biotite | 15.6 | 14.8 | 6.0 | 17.0 | 10.0 | 13.2 | 3.1 | 8.1 |
| Garnet | .2 | 1.8 | Tr | Tr | 2.3 | 1.8 | .3 | 4.0 |
| Opaque minerals | .8 | .1 | 2.8 | .9 | 1.4 | .7 | .4 | .1 |
| Zircon | Tr | Tr | .1 | Tr | Tr | Tr | -- | Tr |
| Apatite | -- | Tr | .1 | -- | -- | -- | -- | -- |
| Rutile | -- | Tr | -- | -- | -- | Tr | -- | -- |
| Allanite | -- | -- | Tr | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | -- | .1 | -- | -- | .5 | .1 | .3 |
| Andalusite | -- | -- | -- | Tr | -- | -- | -- | -- |
| Calcite | -- | -- | Tr | Tr | .1 | -- | -- | -- |
| Chlorite | -- | -- | -- | -- | .7 | .3 | .4 | -- |
| Epidote | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende | -- | -- | -- | -- | -- | -- | -- | |
| Sphene | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |
| Locality No. | 121 | 81 | 79 | 303 | 303 | 304 | 305 | 315 |
| Sample No. | W12a-70 | W20-73 | W15-1-73 | ML8-1 | ML8a-1 | ML-9 | ML-10 | IH-1-80 |
| K-feldspar | -- | 12.2 | -- | -- | 1.9 | -- | 1.1 | 9.4 |
| Plagioclase | 31.7 | 51.4 | 33.8 | 60.0 | 27.2 | 4.6 | 34.5 | 21.3 |
| Quartz | 49.3 | 25.2 | 38.0 | 29.8 | 28.1 | 71.3 | 34.5 | 21.7 |
| Biotite | 15.5 | 8.6 | 22.1 | 2.9 | 21.7 | 19.3 | 22.4 | 30.3 |
| Garnet | 3.0 | 2.0 | .2 | 6.4 | 17.7 | 4.3 | 6.1 | 2.7 |
| Opaque minerals | .5 | .3 | .9 | -- | .3 | .1 | -- | 2.7 |
| Zircon | Tr | Tr | -- | -- | -- | Tr | Tr | Tr |
| Apatite | -- | -- | .4 | -- | .2 | -- | Tr | Tr |
| Rutile | -- | -- | -- | -- | .4 | -- | -- | -- |
| Allanite | -- | -- | Tr | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | .3 | 4.1 | -- | .4 | -- | .5 | 11.9 |
| Andalusite | -- | -- | -- | -- | -- | .4 | -- | -- |
| Calcite | -- | -- | -- | -- | -- | -- | .4 | Tr |
| Chlorite | Tr | -- | .1 | .9 | 2.0 | -- | .5 | -- |
| Epidote | -- | Tr | .4 | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | Tr | -- | .1 | -- | -- | Tr |
| Hornblende | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 2.**--Modes (volume percent) for garnet-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 320 | 281 | 359 | 360 | 365 | 391 | 423 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | IH-6-80 | IS5-80 | RB9-80 | RB10a-80 | M-74 | M-77 | C6-87 |
| K-feldspar ----------- | 29.5 | 0.5 | 4.8 | 8.0 | 0.1 | 8.1 | 5.1 |
| Plagioclase----------- | 13.1 | 38.8 | 35.0 | 21.0 | 41.3 | 26.6 | 40.8 |
| Quartz ---------------- | 40.0 | 25.9 | 45.4 | 49.6 | 44.0 | 45.6 | 19.7 |
| Biotite ---------------- | 13.0 | '' | 9.5 | 12.0 | 11.2 | 10.1 | 34.1 |
| Garnet ---------------- | Tr | Tr | .5 | 2.0 | 2.1 | Tr | .2 |
| Opaque minerals---- | 1.0 | 1.3 | .1 | Tr | .6 | 1.3 | Tr |
| Zircon ---------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr |
| Apatite --------------- | Tr | .2 | -- | -- | Tr | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | Tr | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] - | 2.0 | 15.0 | 4.7 | Tr | .6 | 8.3 | .1 |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- |
| Calcite---------------- | -- | .4 | -- | 1.5 | -- | -- | -- |
| Chlorite -------------- | -- | -- | -- | -- | .1 | -- | -- |
| Epidote --------------- | .3 | -- | -- | 5.2 | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | Tr |
| Hornblende ---------- | .7 | -- | -- | .7 | -- | -- | -- |
| Sphene --------------- | .4 | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | Tr | -- | -- | -- | -- | -- | -- |

[1]Includes some chlorite.

[2]Muscovite-sericite mostly retrograde after plagioclase.

**Table 3.** Modes (volume percent) for layers in a metagabbro dike; country rock is hornblende gneiss.

(--, not found; Tr, trace)

| | Host Rock | Altered Mafic Dike | | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. | 219 | 219 | 219 | 219 | 219 | 219 | 219 |
| Sample No. | N132-64 | N132a-64 | N132b-64 | N132c-64 | N132d-64 | N132e-64 | N132f-64 |
| Plagioclase | 31.3 | 8.6 | 39.2 | 13. | 4.4 | 4.0 | 4.5 |
| Quartz | 15.7 | 23.0 | 14.1 | 32. | 13.5 | 23.8 | 8.2 |
| Hornblende | 44.4 | -- | -- | 16. | -- | -- | -- |
| Gedrite | -- | 18.4 | [1]24.4 | -- | [2]27.7 | 3.8 | 18.0 |
| Hypersthene | -- | .4 | -- | -- | -- | -- | 13.8 |
| Pyroxene-(Ortho) | .5 | -- | -- | 2. | -- | -- | -- |
| Opaque minerals | 7.3 | 3.5 | 7.2 | .5 | 3.8 | 1.6 | 3.9 |
| Biotite | .3 | 1.6 | 4.2 | -- | 16.0 | [3]33.6 | [3]15.4 |
| Cordierite | -- | -- | 1.6 | -- | 27.1 | -- | 24.0 |
| Apatite | .1 | .2 | .2 | Tr | .1 | -- | -- |
| Zircon | Tr | Tr | -- | Tr | Tr | Tr | Tr |
| Epidote | -- | -- | -- | 36. | -- | -- | -- |
| Sphene | .4 | -- | -- | .5 | -- | -- | -- |
| Garnet | -- | 44.1 | 9.1 | -- | -- | 33.2 | 4.2 |
| Spinel | -- | Tr | -- | -- | -- | -- | -- |
| Sericite | -- | -- | -- | -- | 7.4 | -- | 8.0 |

[1]Tremolite-actinolite mantles gedrite.
[2]Includes traces of cummingtonite.
[3]Includes traces of rutile.

**Table 4.** Modes (volume percent) for cordierite-biotite gneiss and cordierite-garnet-biotite gneiss ± staurolite, central Front Range, Colorado.

(--, not found; Tr, trace)

| | Cordierite-biotite gneiss | | | | Cordierite-garnet-biotite gneiss ± staurolite | | |
|---|---|---|---|---|---|---|---|
| Locality No. | 10 | 111 | 80 | Locality No. | 230 | 308 | 314 |
| Sample No. | GH232-76 | W259b-71 | W18-73 | Sample No. | N340a-64 | ML-14 | GG5a-80 |
| K-feldspar | 0.9 | 1.6 | 23.1 | K-feldspar | 6.1 | 3.4 | 0.5 |
| Plagioclase | 5.8 | 23.6 | 12.7 | Plagioclase | 4.8 | 25.5 | 13.8 |
| Quartz | 64.0 | 49.9 | 42.3 | Quartz | 59.3 | 49.3 | 63.8 |
| Cordierite | 17.3 | .5 | [1]10.5 | Cordierite | 1.9 | [1]1.5 | 2.3 |
| Biotite | 12.0 | 14.8 | 7.4 | Biotite | 19.5 | Tr | 11.5 |
| Opaque minerals | Tr | 1.0 | 1.4 | Opaque minerals | .3 | 1.0 | .3 |
| Apatite | -- | -- | Tr | Apatite | -- | -- | Tr |
| Zircon | Tr | .3 | Tr | Zircon | Tr | Tr | Tr |
| Xenotime-monazite | Tr | -- | Tr | Xenotime-monazite | -- | .3 | -- |
| Muscovite-sericite[2] | -- | 6.9 | 2.4 | Muscovite-sericite[2] | 5.2 | .1 | .5 |
| Andalusite | -- | .1 | -- | Chlorite | 2.8 | 17.3 | .5 |
| Calcite | -- | -- | .2 | Epidote | -- | 1.5 | -- |
| Isotropic mass | -- | 1.3 | -- | Garnet | .1 | .1 | 6.8 |
| | | | | Rutile | Tr | Tr | -- |
| | | | | Staurolite | -- | -- | Tr |

[1]Includes some pinnite.

[2]Muscovite-sericite mostly retrograde after plagioclase.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. --------- | 161 | 163 | 164 | 167 | 168 | 169 | 170 | 172 | 173 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | T-78 | T-86 | T-109 | T-153 | T-155 | T-163 | T-172 | T-196 | T-208 |
| K-feldspar------------ | 13.9 | 12.9 | 24.0 | 0.9 | 7.9 | 15.5 | 8.2 | 2.5 | 18.3 |
| Plagioclase----------- | 14.4 | 2.5 | 24.0 | 1.2 | 11.4 | 21.1 | 13.5 | 11.0 | 15.3 |
| Quartz ---------------- | 55.4 | 48.2 | 36.6 | 42.0 | 19.4 | 48.5 | 61.9 | 56.9 | 52.5 |
| Biotite ---------------- | 12.6 | 20.6 | 12.9 | 30.7 | 26.6 | 12.2 | 13.2 | 19.6 | 10.9 |
| Sillimanite ----------- | 1.1 | 12.6 | Tr | 21.0 | 27.8 | 2.0 | 1.8 | 5.0 | .2 |
| Opaque minerals---- | 2.5 | 1.3 | .9 | 1.6 | 1.7 | .3 | 1.0 | .5 | 1.9 |
| Zircon ---------------- | Tr | .2 | Tr | .2 | Tr | Tr | .2 | Tr | .2 |
| Muscovite-sericite[7] - | -- | -- | 1.6 | 2.4 | 5.2 | .4 | .2 | 3.9 | -- |
| Chlorite -------------- | .1 | -- | -- | -- | -- | -- | -- | .6 | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | -- | Tr | -- | Tr | -- | Tr | -- | Tr |

| Locality No. --------- | 175 | 176 | 179 | 180 | 182 | 183 | 184 | 213 | 214 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | T-230 | T-248 | T-326 | T-333 | T-364 | T-401 | T-414 | N87-64 | N104a-64 |
| K-feldspar------------ | .2 | .7 | 7.4 | 3.7 | Tr | -- | 2.4 | 35.0 | 5.7 |
| Plagioclase----------- | 18.4 | .7 | 1.8 | 14.0 | 30.3 | 3.7 | 6.4 | 11.8 | 22.9 |
| Quartz ---------------- | 34.1 | 36.7 | 35.9 | 45.9 | 52.9 | 54.5 | 62.7 | 24.5 | 32.4 |
| Biotite ---------------- | 41.5 | 29.5 | 32.6 | 23.6 | 13.6 | 30.5 | 21.4 | 14.1 | 17.2 |
| Sillimanite ----------- | .6 | 27.1 | 16.3 | 11.4 | Tr | 8.7 | 6.3 | 10.3 | 3.5 |
| Opaque minerals---- | 2.5 | 2.7 | 3.7 | .8 | 1.4 | 1.0 | .5 | 4.1 | 3.1 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | .1 | .2 | Tr | .2 | .1 |
| Muscovite-sericite[7] - | 1.8 | 2.6 | 2.3 | .6 | 1.7 | 1.4 | .3 | -- | 12.5 |
| Chlorite -------------- | -- | -- | -- | -- | -- | -- | -- | -- | 2.2 |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | .4 |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | .9 | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | -- | Tr | -- | -- | -- | Tr | Tr |

| Locality No. --------- | 225 | 241 | 185 | 117 | 126 | 132 | 136 | 138 | 140 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | N225a-64 | N555-64 | N18-65 | WC29-70 | W92-70 | W190-70 | W234a-70 | W242a-70 | W250-70 |
| K-feldspar------------ | 7.1 | 2.5 | -- | -- | 1. | 23.2 | 13.2 | 0.1 | -- |
| Plagioclase----------- | 20.6 | [1]19.4 | [2]25.0 | 5.7 | 3. | 20.4 | 19.5 | 42.3 | 2.9 |
| Quartz ---------------- | 48.1 | 69.7 | 37.3 | 64.5 | 20. | 23.2 | 23.0 | 8.3 | 44.8 |
| Biotite ---------------- | 9.9 | 3.6 | 32.5 | 17.6 | 35. | 20.0 | 14.2 | 36.9 | 11.3 |
| Sillimanite ----------- | 1.3 | Tr | 1.0 | 9.3 | 37. | 1.0 | .3 | .2 | 30.2 |
| Opaque minerals---- | 1.0 | 1.4 | Tr | 2.3 | 3. | .2 | 4.4 | 2.4 | 3.8 |
| Zircon ---------------- | .2 | Tr | Tr | .1 | Tr | -- | -- | .1 | Tr |
| Muscovite-sericite[7] - | 11.1 | 1.0 | -- | .5 | 1. | 12.0 | 19.0 | 9.5 | 7.0 |
| Chlorite -------------- | .5 | 2.4 | -- | -- | Tr | -- | -- | .2 | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Andalusite ----------- | .2 | -- | -- | -- | -- | -- | 6.4 | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | Tr | Tr | -- | Tr | -- | -- | -- |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. | 144 | 148 | 89 | 90 | 92 | 94 | 96 | 101 | 106 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W273-70 | W293-70 | W48-71 | W66-71 | W71-71 | W92b-71 | W105-71 | W172-71 | W248-71 |
| K-feldspar | 35.7 | -- | Tr | 3. | Tr | 2. | 1.6 | .6 | -- |
| Plagioclase | 20.3 | 18.3 | 1. | 4. | 7. | 22. | 44.7 | 17.5 | 19.8 |
| Quartz | 26.6 | 52.3 | 27 | 26. | 28. | 39. | [3]8.7 | 56.0 | 1.8 |
| Biotite | 14.0 | 9.1 | 8. | 7. | 1. | 14. | 40.9 | 24.4 | 41.3 |
| Sillimanite | .1 | Tr | 9. | 7. | 1. | 9. | Tr | Tr | 32.1 |
| Opaque minerals | .5 | 2.1 | 4. | 4. | 4. | 3. | [5]3.5 | 1.5 | 3.4 |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] | 2.8 | 16.2 | 43. | 42. | 54. | 11. | .3 | -- | 1.6 |
| Chlorite | -- | 2.0 | 8. | 7. | 5. | -- | -- | -- | Tr |
| Rutile | -- | -- | Tr | Tr | Tr | -- | -- | -- | Tr |
| Andalusite | -- | -- | Tr | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 113 | 84 | 78 | 79 | 73 | 65 | 67 | 54 | 55 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W265-71 | W18-72 | W12-1-73 | W15-2-73 | GH47-71 | GH32-72 | GH54-72 | GH162-73 | GH168-73 |
| K-feldspar | 12.0 | 11.4 | 10.4 | -- | 16.5 | 9.0 | 35.7 | 3.6 | 8.8 |
| Plagioclase | [1]22.0 | 8.2 | 39.1 | [1]45.3 | 4.2 | 9.6 | 30.2 | .9 | 5.5 |
| Quartz | 27.4 | 40.7 | 38.7 | 18.6 | 20.7 | 60.8 | 14.5 | 34.2 | 55.4 |
| Biotite | 14.0 | 25.1 | [4]6.4 | [4]33.5 | 23.5 | 15.9 | 8.4 | 29.1 | 16.5 |
| Sillimanite | 1.3 | 13.6 | .5 | .1 | 31.4 | 4.0 | 2.9 | 25.5 | 11.1 |
| Opaque minerals | [6]3.5 | [6].8 | [6].9 | 1.1 | 3.6 | .7 | [6].9 | 4.5 | 2.6 |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | -- | Tr | Tr |
| Muscovite-sericite[7] | 16.5 | .1 | 3.6 | .6 | .1 | -- | 7.3 | 2.2 | .1 |
| Chlorite | 3.3 | .1 | .2 | -- | -- | -- | -- | -- | -- |
| Rutile | Tr | -- | -- | -- | -- | -- | Tr | -- | -- |
| Andalusite | Tr | -- | .2 | -- | -- | -- | .1 | Tr | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | .5 | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | Tr | Tr | Tr | -- | Tr | Tr | Tr |

| Locality No. | 39 | 43 | 52 | 53 | 372 | 19 | 20 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | GH69-74 | GH158-74 | GH412-74 | GH-413-74 | GHB37-75 | GH153-75 | GH172-75 | GH183-75 | GH192-75 |
| K-feldspar | -- | -- | -- | 13.4 | -- | -- | 14.3 | 7.7 | 22.9 |
| Plagioclase | 22. | 3.7 | 1.9 | 16.7 | 8.7 | 2.2 | 15.9 | 19.2 | 21.4 |
| Quartz | -- | 24.8 | 24.5 | 57.8 | 23.6 | 43.5 | 38.2 | 51.6 | 30.6 |
| Biotite | 17. | 46.0 | 40.5 | 10.0 | 43.3 | 27.5 | 14.9 | 13.6 | 10.6 |
| Sillimanite | 16. | 24.9 | 31.6 | Tr | 16.6 | 22.5 | 10.0 | 1.6 | .9 |
| Opaque minerals | 3. | .3 | 1.0 | 1.1 | .6 | 2.8 | 2.3 | Tr | 1.1 |
| Zircon | Tr | Tr | -- | Tr | -- | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] | 42. | .3 | .5 | -- | 5.7 | 1.5 | .8 | 6.1 | 12.4 |
| Chlorite | -- | -- | -- | 1.0 | 1.5 | -- | 3.5 | .2 | .1 |
| Rutile | -- | -- | -- | Tr | -- | -- | Tr | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | Tr | -- | -- | Tr |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 25 | 26 | 29 | 30 | 6 | 8 | 9 | 11 | 271 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | GH233-75 | GH242-75 | GH305-75 | GH306-75 | GH3-76 | GH142-76 | GH204a-76 | GH262-76 | SP2-80 |
| K-feldspar------------ | -- | -- | -- | -- | 11.2 | 1.1 | -- | 5.0 | 8.5 |
| Plagioclase----------- | 21.9 | 4.8 | .4 | 16.9 | 15.9 | .1 | 21.7 | 19.5 | 15.4 |
| Quartz ---------------- | 32.4 | 43.7 | 13.5 | 42.5 | 35.7 | 21.6 | 57.8 | 42.6 | 58.6 |
| Biotite ---------------- | 8.1 | 25.9 | 47.7 | 16.0 | 26.6 | 51.5 | 15.0 | 25.0 | 14.1 |
| Sillimanite ---------- | .1 | 23.6 | 26.7 | 13.0 | 9.3 | 18.8 | .1 | 1.8 | Tr |
| Opaque minerals---- | .7 | 1.7 | 1.4 | .3 | .5 | 1.1 | .5 | Tr | .4 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] - | 36.6 | .3 | 10.2 | 11.0 | .8 | 5.8 | 4.9 | 6.1 | 3.0 |
| Chlorite -------------- | .2 | -- | -- | .3 | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |

| Locality No. --------- | 272 | 273 | 274 | 275 | 276 | 278 | 278 | 280 | 281 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS2a-80 | IS4-80 | IS5a-80 |
| K-feldspar------------ | 2. | 14.6 | 16.3 | 12.0 | 4.9 | 1.8 | 9.9 | 7.2 | .2 |
| Plagioclase----------- | 8. | 14.8 | 6.8 | 17.4 | 13.8 | 16.4 | 30.4 | 8.7 | 6.1 |
| Quartz ---------------- | 28. | 19.5 | 24.5 | 51.6 | 40.4 | 36.4 | 38.6 | 48.9 | 79.1 |
| Biotite ---------------- | 22. | 25.0 | 27.7 | 16.8 | 14.4 | 24.3 | 13.9 | 20.4 | 2.4 |
| Sillimanite ---------- | 14. | 9.4 | 21.0 | Tr | 14.5 | 16.5 | 3.1 | 11.7 | 1.2 |
| Opaque minerals---- | Tr | 1.8 | 1.3 | 1.1 | 1.2 | 1.4 | .1 | .8 | 1.5 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] - | 26. | 14.9 | 2.4 | 1.1 | 10.8 | 3.2 | 4.0 | 2.3 | 8.8 |
| Chlorite -------------- | Tr | -- | -- | -- | Tr | -- | -- | -- | .1 |
| Rutile ----------------- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | Tr | Tr | -- | -- | -- | -- | -- | Tr |
| Xenotime-monazite- | -- | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |

| Locality No. --------- | 282 | 285 | 317 | 318 | 319 | 351 | 352 | 355 | 356 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | IS6-80 | IS9-80 | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 |
| K-feldspar------------ | 0.7 | 5.0 | 7.1 | 5.8 | 2.2 | -- | -- | -- | -- |
| Plagioclase----------- | 38.5 | 32.4 | 18.3 | 22.2 | 7.8 | 2.2 | 8.1 | .3 | 1.5 |
| Quartz ---------------- | 46.4 | 36.9 | 48.8 | 61.2 | 62.9 | 52.1 | 49.0 | 45.5 | 43.7 |
| Biotite ---------------- | 10.6 | [4]12.4 | 19.9 | -- | 16.3 | 25.4 | 25.7 | 31.0 | 18.5 |
| Sillimanite ---------- | 1.7 | 2.9 | Tr | 3.9 | 5.6 | 11.7 | 7.0 | 15.9 | Tr |
| Opaque minerals---- | .4 | 2.0 | .4 | Tr | Tr | 1.2 | 1.5 | .1 | 1.0 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | .1 | Tr | .1 |
| Muscovite-sericite[7] - | 1.5 | 7.4 | 5.5 | 6.0 | 5.2 | 7.4 | 4.0 | 7.2 | 35.0 |
| Chlorite -------------- | .2 | 1.0 | -- | .9 | -- | -- | -- | -- | .1 |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | 4.5 | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | .1 | Tr | Tr |
| Apatite---------------- | Tr | -- | Tr | -- | Tr | Tr | Tr | Tr | -- |
| Xenotime-monazite- | Tr | -- | Tr | Tr | Tr | -- | -- | -- | Tr |

Footnotes follow at end of table.

**Table 5.** Modes (volume percent) for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 357 | 358 | 4 | 368 | 340 | 289 | 291 | 293 | 294 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | RB7-80 | RB8-80 | M66 | M530b | CC-646 | J-246 | J-282 | J-313 | J-331 |
| K-feldspar------------ | -- | .7 | .3 | -- | 14.3 | -- | 1.4 | 7.3 | 3.7 |
| Plagioclase----------- | 2. | 9.8 | 4.0 | Tr | 5.4 | 25.9 | -- | 3.6 | 19.6 |
| Quartz ---------------- | 1. | 55.6 | 69.4 | 57. | 31.4 | 51.9 | 50.2 | 21.6 | 56.8 |
| Biotite ---------------- | 64. | 15.9 | 22.4 | 22. | 32.1 | 15.0 | 29.8 | 24.4 | 13. |
| Sillimanite ----------- | 31. | 5.3 | 1.7 | 2. | 16.3 | 1.0 | 16.1 | 8.0 | 1.9 |
| Opaque minerals---- | 1. | .3 | Tr | Tr | .7 | 2.7 | 1.2 | 1.9 | .9 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[7] - | 1. | 12.4 | 1.9 | 11. | Tr | 3.5 | 1.3 | 33.2 | 3.2 |
| Chlorite -------------- | -- | -- | .3 | 8. | Tr | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | -- | -- | -- | Tr | Tr | Tr | Tr |

| Locality No. --------- | 296 | 297 | 298 | 322 | 418 | 419 | 422 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | J-455a | J-462a | J-463 | E-1-80 | C1-87 | C2-87 | C5-87 |
| K-feldspar------------ | -- | 0.1 | -- | 7.0 | 8.2 | 15.2 | 15.1 |
| Plagioclase----------- | 4.8 | 10.0 | Tr | 37.9 | 31.2 | 19.7 | 17.6 |
| Quartz ---------------- | 52.3 | 64.4 | 45.4 | 24.4 | 52.2 | 46.0 | 43.7 |
| Biotite ---------------- | 16.4 | 5.0 | 12.3 | 23.3 | 6.2 | 13.5 | 14.8 |
| Sillimanite ----------- | 1.5 | .1 | Tr | 2.1 | .7 | .3 | 5.5 |
| Opaque minerals---- | .8 | 3.2 | 1.4 | Tr | .3 | .1 | -- |
| Zircon ---------------- | Tr | Tr | Tr | Tr | .2 | Tr | .1 |
| Muscovite-sericite[7] - | 23.9 | 16.8 | 36.2 | 5.3 | .9 | 5.2 | 2.9 |
| Chlorite -------------- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | .1 | -- | -- | -- | -- | -- |
| Apatite---------------- | .3 | .3 | .2 | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | -- | Tr | Tr | .1 | Tr | .1 |
| Calcite ---------------- | -- | -- | -- | -- | -- | -- | .2 (in veins) |

[1]Includes traces of calcite. Locality number 79 has 0.3; 281, 0.6; and 422, 0.2 percent calcite in plagioclase.
[2]All kaolinite.
[3]All corundum; no quartz.
[4]Includes traces of epidote in biotite. Locality numbers 78 and 79 have 0.1 percent and 285, 0.5 percent epidote.
[5]Includes traces of sphene.
[6]Includes traces of green spinel.
[7]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 6.** Modes (volume percent) for sillimanite-biotite gneiss and hornfelsic gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No.--------- | 21 | 22 | 32 | 34 | 14 | 28 |
|---|---|---|---|---|---|---|
| Sample No.---------- | GH175a-75 | GH176-75 | GH339-75 | GH353-75 | GH368-76 | GH-294-75 |
| K-feldspar----------- | -- | 0.1 | -- | 4.9 | -- | |
| Plagioclase---------- | 38.4 | 56.3 | 43.9 | 27.3 | 46.0 | 16.6 |
| Quartz--------------- | 26.1 | 21.6 | 28.1 | 47.3 | 30.7 | 29.8 |
| Biotite---------------- | 29.6 | 19.1 | 25.3 | 20.3 | 18.6 | 25.4 |
| | | | | | | |
| Opaque minerals--- | 3.9 | 1.3 | 1.0 | .1 | 3.4 | 2.8 |
| Zircon---------------- | Tr | -- | Tr | Tr | .1 | Tr |
| Muscovite-sericite[2] | .2 | -- | .5 | .1 | -- | .7 |
| Apatite--------------- | 1.0 | .5 | 1.2 | Tr | 1.0 | -- |
| | | | | | | |
| Chlorite-------------- | Tr | Tr | -- | Tr | .1 | -- |
| Xenotime-monazite | Tr | -- | Tr | Tr | .1 | Tr |
| Allanite-------------- | .1 | -- | -- | -- | -- | -- |
| Epidote-------------- | .7 | 1.1 | -- | -- | -- | -- |
| Sillimanite---------- | -- | -- | -- | Tr | -- | 11.1 |

[2]Muscovite-sericite mostly a replacement of plagioclase and sillimanite.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 162 | 166 | 171 | 177 | 178 | 373 | 374 | 375 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | T-80 | T-146 | T-180 | T-251 | T-260a | N-24 | N-43 | N-95 |
| K-feldspar | 11.6 | 20.6 | 1.1 | -- | -- | 1.6 | 6.1 | 4.1 |
| Plagioclase | 20.3 | 23.5 | 3.6 | 2.5 | 8.6 | 5.0 | 5.6 | 3.8 |
| Quartz | 44.6 | 37.8 | 34.2 | 22. | 51.9 | 58.7 | 5.6 | 45.9 |
| Biotite | 15.2 | 11.8 | 32.7 | 40. | 30.6 | 19.4 | 14.2 | 30.0 |
| Garnet | Tr | .1 | .5 | 1. | Tr | 4.0 | 10.0 | 6.1 |
| Sillimanite | 7.2 | 4.7 | 25.6 | 34. | 7.6 | 9.2 | 3.5 | 7.7 |
| Opaque minerals | 1.0 | 1.1 | 1.1 | .5 | .1 | 1.4 | Tr | .5 |
| Zircon | Tr | Tr | Tr | Tr | .1 | Tr | Tr | -- |
| Muscovite-sericite[2] | .1 | .4 | 1.2 | -- | 1.1 | .1 | 54.9 | 1.6 |
| Spinel | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | Tr | -- | -- | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | Tr |
| Chlorite | -- | -- | -- | -- | -- | .6 | .1 | .3 |
| Apatite | -- | -- | -- | -- | -- | -- | Tr | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 376 | 377 | 378 | 255 | 379 | 257 | 257 | 380 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N-101 | N-128 | N-132 | N-167 | N-211 | N-223 | N223a | N377a |
| K-feldspar | 24.2 | -- | 19.4 | 10.3 | 26.0 | 2.2 | 24.6 | 2.5 |
| Plagioclase | 5.3 | 3.4 | 12.4 | 25.0 | 12.5 | 11.6 | 10.5 | 6.6 |
| Quartz | 20.4 | 52.0 | 41.5 | 42.8 | 38.7 | 30.6 | 12.9 | 52.6 |
| Biotite | 28.1 | 22.3 | 15.8 | 14.4 | 15.0 | 22.8 | 28.9 | 20.8 |
| Garnet | 6.5 | 12.7 | 6.7 | 2.2 | .4 | 5.1 | 8.7 | 7.2 |
| Sillimanite | 10.6 | 3.4 | .4 | 1.9 | 2.9 | 9.2 | 7.2 | 8.0 |
| Opaque minerals | .4 | Tr | .3 | 1.4 | 1.6 | .5 | Tr | 1.8 |
| Zircon | Tr | Tr | Tr | Tr | Tr | .1 | Tr | .1 |
| Muscovite-sericite[2] | 4.5 | 6.2 | 3.5 | 1.7 | 2.9 | 17.5 | 6.4 | -- |
| Spinel | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | Tr | Tr | -- | -- | Tr | Tr | Tr |
| Chlorite | -- | -- | Tr | -- | -- | .4 | .8 | .4 |
| Apatite | -- | -- | -- | .3 | -- | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 381 | 382 | 383 | 384 | 385 | 386 | 250 | 186 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N432-64 | N435-64 | N444-64 | N553-64 | N638-64 | N661-64 | N688-64 | N20a-65 |
| K-feldspar | 6.0 | 12.9 | 1.4 | 2.8 | 11.1 | 19.6 | 4.7 | 9.0 |
| Plagioclase | 8.8 | 13.2 | 30.5 | 14.3 | 23.2 | 11.1 | 20.9 | -- |
| Quartz | 58.1 | 34.6 | 49.4 | 56.8 | 45.7 | 51.3 | 57.8 | 44.7 |
| Biotite | 15.1 | 24.9 | 14.4 | 17.2 | 13.7 | 8.4 | 7.7 | 24.4 |
| Garnet | 4.8 | .5 | 1.7 | 1.8 | 6.0 | 7.7 | 6.2 | 5.2 |
| Sillimanite | 6.4 | 7.8 | 1.4 | 5.5 | Tr | .2 | .5 | 5.2 |
| Opaque minerals | .1 | 1.3 | Tr | .9 | .1 | .2 | 1.0 | 5.4 |
| Zircon | Tr | .1 | Tr | .2 | -- | -- | Tr | Tr |
| Muscovite-sericite[2] | .6 | 3.8 | 1.2 | .2 | Tr | 1.2 | 1.2 | 1.1 |
| Spinel | -- | -- | -- | -- | -- | -- | Tr | -- |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile | -- | .1 | -- | -- | -- | -- | Tr | -- |
| Chlorite | .1 | .8 | Tr | .3 | .1 | .3 | -- | -- |
| Apatite | -- | -- | -- | -- | .1 | -- | -- | -- |
| Kaolinite | -- | -- | -- | -- | -- | -- | -- | 5. |
| Andalusite | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | Tr | -- | Tr | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 188 | 189 | 190 | 191 | 202 | 202 | 203 | 204 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | N125-65 | N142a-65 | N143-65 | N144-65 | N335c-65 | N335d-65 | N340-65 | N342-65 |
| K-feldspar ----------- | -- | -- | 2.2 | .4 | 22.7 | 11. | 10.8 | 15.0 |
| Plagioclase----------- | -- | 2.4 | 1.7 | 16.6 | 17.0 | 23. | -- | 13.4 |
| Quartz ---------------- | 15.9 | 57.2 | 55.3 | 18.0 | 47.6 | 50. | 34.0 | 43.8 |
| Biotite ---------------- | 44.7 | 24.5 | 21.0 | 32.5 | 9.2 | 15. | 31.3 | 15.5 |
| Garnet ---------------- | 5.9 | 5.3 | 9.8 | 3.1 | 2.2 | Tr | 8.0 | 7.5 |
| Sillimanite---------- | 20.6 | 1.5 | 5.0 | 20.4 | 1.1 | Tr | 14.9 | 4.0 |
| Opaque minerals---- | 3.1 | Tr | .1 | 1.6 | .2 | Tr | .5 | .8 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2]- | .1 | 9.1 | 4.8 | 7.4 | -- | 1. | .5 | Tr |
| Spinel ---------------- | Tr | -- | Tr | Tr | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | Tr | -- | -- |
| Rutile ----------------- | -- | Tr | Tr | -- | -- | Tr | -- | -- |
| Chlorite -------------- | -- | -- | .1 | -- | -- | -- | -- | -- |
| Apatite --------------- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Kaolinite ------------- | 9.7 | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. --------- | 205 | 118 | 149 | 152 | 88 | 412 | 413 | 414 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | N347-65 | WC31-70 | W295-70 | W321a-70 | W41-71 | SL4-84 | SL5-84 | SL6-84 |
| K-feldspar ----------- | 4.9 | 0.2 | 1. | 4.3 | 5. | 3.6 | 6.4 | 18.3 |
| Plagioclase----------- | 4.6 | 6.5 | 6. | 2.6 | 4. | 2.4 | .6 | 14.1 |
| Quartz ---------------- | 58.0 | 41.0 | 19. | 70.8 | 43. | 59.5 | 33.3 | 36.8 |
| Biotite ---------------- | 10.4 | 26.1 | 15. | 12.7 | 10. | 14.8 | 28.3 | 17.3 |
| Garnet ---------------- | 10.8 | .7 | 4. | Tr | Tr | 7.3 | 5.0 | 2.7 |
| Sillimanite---------- | 7.7 | 8.9 | 7. | 4.3 | Tr | 12.1 | 24.9 | 9.8 |
| Opaque minerals---- | .7 | 1.0 | 4. | .2 | Tr | .3 | 1.5 | 1.0 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | -- | Tr | Tr | Tr |
| Muscovite-sericite[2]- | 2.9 | 15.0 | 43. | 5.1 | 34. | -- | -- | -- |
| Spinel ---------------- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite -------------- | -- | .6 | 1. | -- | 4. | -- | -- | -- |
| Apatite --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | Tr | Tr | Tr | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. --------- | 69 | 60 | 37 | 49 | 18 | 324 | 325 | 325 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | GH15a-71 | GH214-73 | GH34-74 | GH338a-74 | GH91-75 | EP-1 | EP-2 | EP2a |
| K-feldspar ----------- | 12.0 | 4.3 | 9.2 | -- | 2.2 | 2.6 | 37.1 | 13.8 |
| Plagioclase----------- | 5.9 | 19.6 | 10.9 | 4.2 | 25.0 | 21.0 | 5.0 | 5.2 |
| Quartz ---------------- | 1.9 | 22.5 | 22.5 | 41.4 | 25.0 | 25.9 | 48.2 | 59.2 |
| Biotite ---------------- | 37.4 | 34.2 | 26.7 | 32.5 | 34.8 | 28.3 | 6.9 | 15.4 |
| Garnet ---------------- | 3.0 | [1]1.1 | 5.8 | 3.6 | Tr | 4.0 | .9 | Tr |
| Sillimanite---------- | 36.5 | 18.0 | 20.2 | 17.5 | 10.4 | 15.8 | .5 | 4.8 |
| Opaque minerals---- | 1.8 | .3 | .2 | .4 | .2 | .5 | Tr | Tr |
| Zircon ---------------- | -- | Tr | -- | Tr | Tr | -- | -- | Tr |
| Muscovite-sericite[2]- | 1.5 | -- | 4.5 | .4 | 2.1 | .4 | .9 | 1.5 |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Chlorite -------------- | -- | -- | -- | -- | .3 | 1.5 | .5 | .1 |
| Apatite --------------- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | Tr | Tr | Tr | Tr | -- | -- | -- | -- |
| Tourmaline ---------- | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 7.** Modes (volume percent) for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 326 | 283 | 316 | 321 | 387 | 5 | 368 | 389 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | EP-3 | IS-7-80 | IH-2-80 | IH-7-80 | J-184 | M-67 | M530a | CC-871a |
| K-feldspar ----------- | 19.6 | 0.8 | 1.0 | -- | 7.4 | 4.7 | -- | 15.6 |
| Plagioclase----------- | 15.3 | 13.9 | 21.4 | 4.4 | 8.7 | 23.8 | .1 | 7.4 |
| Quartz---------------- | 20.7 | 37.8 | 41.0 | 66.8 | 37.5 | 45.3 | 51.8 | 31.2 |
| Biotite---------------- | 32.3 | 24.7 | 12.7 | 18.2 | 16.0 | 18.4 | 15.5 | 29.1 |
| Garnet---------------- | .1 | 1.1 | Tr | 1.3 | Tr | Tr | Tr | 4.8 |
| Sillimanite----------- | 11.6 | 13.3 | 1.0 | 8.8 | 17.6 | Tr | 3.5 | 10.7 |
| Opaque minerals---- | .1 | .2 | 2.2 | Tr | 2.6 | Tr | .1 | .4 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2]- | .3 | 7.4 | 20.7 | .5 | 9.8 | 7.8 | 17.1 | .8 |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | .6 | -- | -- | -- | -- | 11.9 | -- |
| Apatite --------------- | -- | .2 | -- | Tr | .4 | -- | -- | Tr |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | Tr | -- | Tr | -- | Tr | -- | -- | -- |
| Tourmaline --------- | -- | -- | -- | Tr | -- | -- | -- | -- |

| Locality No. --------- | 393 | 394 | 404 | 405 | 420 | 349 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | S-Sp-30a | S-Sp-30b | S-Sp-64 | DS58-7 | C3-87 | EWT-90b |
| K-feldspar ----------- | 6.4 | 9.8 | -- | -- | -- | 7.0 |
| Plagioclase----------- | 17.7 | 3.1 | .8 | Tr | 7.4 | 7.1 |
| Quartz---------------- | 55.9 | 60.5 | 71.7 | 61.0 | 41.1 | 41.2 |
| Biotite---------------- | 15.3 | 13.4 | 14.0 | 17.2 | 38.0 | 32.0 |
| Garnet---------------- | 2.6 | 1.4 | 4.2 | 6.0 | 1.7 | .5 |
| Sillimanite----------- | 2.1 | 11.8 | 9.1 | 15.8 | 8.6 | 10.3 |
| Opaque minerals---- | Tr | Tr | .2 | Tr | -- | 1.7 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[2]- | -- | -- | -- | -- | 3.2 | .2 |
| Spinel ---------------- | -- | -- | -- | -- | -- | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | -- | -- | -- | -- | -- |
| Apatite- -------------- | -- | -- | -- | -- | -- | Tr |
| Kaolinite ------------- | -- | -- | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | Tr | -- | -- | -- | -- |
| Tourmaline --------- | -- | -- | -- | -- | -- | -- |

[1]Isotropic alteration product of garnet.

[2]Muscovite-sericite mostly a replacement of sillimanite and plagioclase.

**Table 8.** Modes (volume percent) for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. --------- | 252 | 187 | 192 | 201 | 207 | 174 | 181 | 121 | 123 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | N-34 | N121a-65 | N146-65 | N271-65 | N378-65 | T-227 | T-359 | W12b-70 | W64-70 |
| K-feldspar ----------- | 3.1 | 0.5 | 1. | 1.6 | 6.8 | 6.8 | 0.3 | 41.8 | 4.2 |
| Plagioclase----------- | 27.9 | 3.2 | 1. | 11.4 | '' | 4.1 | 15.4 | 11.8 | 14.6 |
| Quartz---------------- | 41.2 | 24.7 | 11. | 31.7 | 45.1 | 30.1 | 72.4 | .9 | 46.8 |
| Cordierite------------ | Tr | 32.3 | 27. | 12.6 | [2].0 | 3.3 | 6.9 | 11.3 | 14.0 |
| Biotite---------------- | 21.1 | 19.6 | [3]44. | 24.7 | 19.7 | 33.0 | 2.1 | 27.5 | 13.4 |
| Sillimanite----------- | .5 | 7.8 | 14. | 6.4 | 2.6 | 19.1 | .3 | 5.0 | 1.6 |
| Opaque minerals---- | 1.0 | 2.9 | Tr | 5.5 | .1 | 3.6 | 2.0 | 1.3 | 2.8 |
| Zircon---------------- | Tr | .1 | Tr | .3 | Tr | Tr | Tr | Tr | .4 |
| Andalusite----------- | .4 | .1 | 1. | -- | Tr | -- | -- | .4 | Tr |
| Rutile----------------- | Tr | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite--- | -- | Tr | Tr | -- | -- | -- | -- | -- | Tr |
| Chlorite -------------- | .9 | .4 | -- | -- | -- | -- | -- | -- | .6 |
| Muscovite-sericite[5] - | 3.9 | 8.4 | 1. | 5.8 | 1.6 | -- | .6 | -- | 1.6 |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. --------- | 125 | 146 | 150 | 156 | 157 | 119 | 95 | 100 | 103 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W89-70 | W278-70 | W317-70 | W330a-70 | W342-70 | WC49a-70 | W103-71 | W156-71 | W222a-71 |
| K-feldspar ----------- | 10.1 | 26. | Tr | 11.7 | 18.8 | 25.5 | 3.2 | 23.3 | 1. |
| Plagioclase----------- | 10.6 | 3. | 1.5 | 25.7 | 10.8 | 13.5 | 27.9 | 7.3 | 20. |
| Quartz---------------- | 18.5 | 11. | 38.8 | 33.3 | 50.4 | 36.2 | 29.2 | 26.6 | 37. |
| Cordierite------------ | .5 | 35. | 18.8 | 4.4 | 7.6 | 4.4 | 7.2 | 13.9 | 1. |
| Biotite---------------- | 38.4 | 7. | 9.3 | 9.7 | 3.4 | 10.8 | 27.8 | 11.2 | 18. |
| Sillimanite----------- | 19.1 | 3. | 14.4 | 9.7 | 1.7 | 4.0 | .7 | 12.8 | 5. |
| Opaque minerals---- | 1.5 | 3. | 4.3 | 4.5 | 2.4 | 3.7 | 2.0 | 1.4 | 2. |
| Zircon---------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite----------- | -- | 7. | Tr | -- | -- | 1.6 | .3 | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite--- | -- | -- | -- | Tr | -- | -- | Tr | Tr | -- |
| Chlorite -------------- | -- | -- | .9 | .1 | .3 | -- | .1 | Tr | Tr |
| Muscovite-sericite[5] - | 1.3 | .5 | 12.0 | .9 | 4.6 | .3 | 1.6 | 3.5 | 17. |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. --------- | 110 | 85 | 86 | 72 | 62 | 63 | 66 | 56 | 58 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W258b-71 | W22-72 | W25-72 | GH40-71 | GH2-72 | GH3a-72 | GH42-72 | GH171-73 | GH190-73 |
| K-feldspar ----------- | 4.4 | 11.2 | 3.4 | -- | 13.1 | 24. | -- | 18.7 | -- |
| Plagioclase----------- | -- | 20. | 4.2 | 7.4 | 38.1 | 8. | 7.7 | 3.1 | -- |
| Quartz---------------- | 30.0 | 44.8 | 55.4 | 11.8 | 13.2 | 25. | 42.6 | 58.0 | 1. |
| Cordierite------------ | 17.3 | 6.6 | 14.5 | 26.0 | 11.0 | 10. | 8.2 | 4.8 | 80. |
| Biotite---------------- | 17.0 | 13.3 | 11.5 | 25.1 | 15.9 | 13. | 12.5 | 8.0 | 13. |
| Sillimanite----------- | 2.6 | 1.3 | 8.8 | 17.2 | 7.8 | 16. | 13.2 | 6.5 | 5. |
| Opaque minerals---- | 2.4 | 2.7 | 1.5 | 2.3 | .9 | 4. | 2.9 | [4].6 | 1. |
| Zircon---------------- | Tr | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |
| Andalusite----------- | -- | .1 | Tr | .8 | Tr | -- | .2 | -- | Tr |
| Rutile----------------- | -- | -- | Tr | -- | -- | -- | -- | -- | -- |
| Spinel-högbomite--- | -- | Tr | Tr | .1 | -- | -- | .1 | -- | -- |
| Chlorite -------------- | -- | -- | Tr | 5.9 | -- | -- | 1.7 | -- | -- |
| Muscovite-sericite[5] - | 26.3 | -- | .7 | 3.4 | -- | Tr | 10.9 | .3 | -- |
| Xenotime-monazite | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr | -- |

Footnotes follow at end of table.

**Table 8**. Modes (volume percent) for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Locality No. --------- | 50 | 31 | 7 | 15 | 301 | 307 | 309 | 399 | 400 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | GH345-74 | GH331-75 | GH92-76 | GH370-76 | ML-6 | ML-12a | ML-15 | S-Sp-267 | S-Sp-268 |
| K-feldspar ----------- | 9.4 | .1 | -- | 21.9 | 25.7 | 1.5 | 1.5 | -- | 28.6 |
| Plagioclase----------- | 5.5 | 69.2 | 7.1 | 8.4 | 14.9 | 11.1 | 22.0 | 13.5 | -- |
| Quartz ---------------- | 35.0 | 2.4 | 35.6 | 29.8 | 37.2 | 44.0 | 41.6 | 46.6 | 44.4 |
| Cordierite ------------ | .4 | 4.4 | 4.7 | 26.7 | 9.1 | 14.7 | 22.0 | 23.4 | 8.8 |
| Biotite ---------------- | 21.8 | 5.5 | 17.3 | -- | 2.4 | 23.1 | 8.9 | 16.2 | 8.7 |
| Sillimanite----------- | 23.4 | 11.9 | 21.1 | 10.3 | 8.2 | 3.8 | 1.6 | .3 | 3.6 |
| Opaque minerals---- | 3.6 | 3.4 | 4.1 | 2.6 | 2.0 | .6 | 1.2 | Tr | Tr |
| Zircon ---------------- | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr | Tr |
| Andalusite ----------- | -- | -- | .2 | .1 | -- | .3 | .3 | -- | -- |
| Rutile ----------------- | Tr | -- | -- | Tr | Tr | -- | -- | -- | -- |
| Spinel-högbomite--- | -- | -- | -- | -- | -- | -- | Tr | -- | -- |
| Chlorite -------------- | -- | -- | 1.0 | .1 | -- | .3 | -- | -- | -- |
| Muscovite-sericite[5] - | .9 | 3.1 | 8.9 | .1 | .4 | .6 | .9 | Tr | 5.9 |
| Xenotime-monazite | Tr | Tr | -- | Tr | Tr | Tr | Tr | Tr | -- |

| Locality No. --------- | 398 | 396 | 401 | 402 | 403 | 406 | 409 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | S-SP-277 | S-SP-348 | S-SP-364 | S-SP-389 | S-SP-392 | DS59-1 | E11-84 |
| K-feldspar ----------- | -- | -- | 15.6 | 2.6 | -- | -- | -- |
| Plagioclase----------- | 2.5 | 1.4 | .3 | 1.3 | 3.0 | -- | 14.7 |
| Quartz ---------------- | 63.0 | 60.4 | 61.3 | 66.6 | 58.8 | 60. | 55.7 |
| Cordierite ------------ | 18.2 | 14.3 | 14.6 | 17.8 | 19.8 | 6. | 6.5 |
| Biotite ---------------- | 6.2 | 17.1 | 2.5 | 4.5 | 16.4 | 28. | 15.9 |
| Sillimanite----------- | 5.8 | 5.2 | 1.7 | .2 | Tr | 6. | 6.7 |
| Opaque minerals---- | -- | Tr | -- | -- | .5 | Tr | .2 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | Tr | -- | -- |
| Spinel-högbomite--- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite- ------------- | -- | -- | -- | -- | 1.5 | -- | .2 |
| Muscovite-sericite[5] - | 4.3 | 1.6 | 4.0 | 7.0 | -- | -- | .1 |
| Xenotime-monazite | -- | Tr | Tr | Tr | Tr | -- | -- |

[1]Includes 1.8 percent kaolinite.

[2]All pinnite added to sericite. Pinnite replaced cordierite.

[3]Includes traces of allanite.

[4]Includes traces of apatite.

[5]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 9.** Modes (volume percent) for cordierite-magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 142 | 159 | 94 | 68 | 70 | 75 | 45 | 12 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W264-70 | W357-70 | W92a-71 | GH3-71 | GH32-71 | GH58-71 | GH180-74 | GH279-76 |
| K-feldspar | -- | 34.8 | -- | 17.4 | 0.5 | -- | 15.5 | 0.5 |
| Plagioclase | 1. | 8.0 | .5 | 13.7 | 2.4 | 6.9 | 7.5 | 10.2 |
| Quartz | 42. | 16.0 | 22.6 | 29.0 | 33.5 | 28.4 | 27.1 | 26.3 |
| Cordierite | 4. | 7.1 | 5.4 | 5.0 | 35.1 | 5.5 | 20.9 | 19.8 |
| Biotite | 11. | 10.8 | 34.8 | 9.3 | 15.1 | 21.2 | 5.3 | 23.6 |
| Sillimanite | 19. | 13.0 | 27.7 | 18.8 | 4.7 | 31.5 | 15.5 | 11.8 |
| Opaque minerals | 6. | 6.9 | 6.2 | 5.6 | 7.0 | 5.9 | 6.2 | 5.6 |
| Zircon | Tr | .1 | Tr | Tr | Tr | .1 | Tr | Tr |
| Chlorite | 2. | -- | Tr | -- | .7 | -- | -- | -- |
| Muscovite-sericite [1] | 25. | 3.3 | 2.8 | 1.2 | 1.0 | .4 | 2.0 | 2.2 |
| Spinel-högbomite | -- | -- | -- | -- | Tr | Tr | -- | -- |
| Xenotime-monazite | -- | Tr | -- | Tr | Tr | .1 | Tr | Tr |

[1]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 10.** Modes (volume percent) for magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 138 | 153 | 154 | 87 | 91 | 93 | 47 | 51 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W242-70 | W323-70 | W326-70 | W25-71 | W68-71 | W90-71 | GH268-74 | GH391-74 |
| K-feldspar | 1.9 | Tr | -- | 17. | 3. | -- | -- | 0.6 |
| Plagioclase | 37.0 | 16. | 5. | 12. | 7. | 6. | -- | 1.3 |
| Quartz | 8.0 | 47. | 37. | 22. | 23. | 29. | 11.2 | 66.3 |
| Biotite | 38.6 | 2. | Tr | 24. | 3. | -- | 43.1 | 12.7 |
| Sillimanite | Tr | 3. | 2. | 20. | 5. | 9. | 39.9 | 14.9 |
| Opaque minerals | 4.0 | 5. | 5. | 5. | 6. | 6. | 5.6 | 3.7 |
| Zircon | Tr | Tr | Tr | Tr | -- | Tr | -- | Tr |
| Muscovite-sericite [1] | 10.5 | 22 | 46. | Tr | 46. | 41. | .2 | .5 |
| Andalusite | Tr | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite | -- | 5. | 5. | Tr | 7. | 9. | -- | Tr |
| Rutile | -- | Tr | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | -- | -- | -- | Tr |

[1]Most muscovite-sericite is a replacement of plagioclase and sillimanite.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.

(--, not found; Tr, trace)

| Locality No. | 253 | 256 | 258 | 259 | 263 | 263 | 264 | 265 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N91 | N179 | N297 | N143 | N338a | N338b | N342 | N361a |
| K-feldspar | 7.5 | 0.9 | 7.8 | 5.9 | 8.2 | 19.0 | 13.7 | 8.2 |
| Plagioclase | 6.6 | .5 | 17.3 | 20.4 | 5.2 | 4.4 | 2.3 | 24.7 |
| Quartz | [2]29.9 | 21.5 | 50.7 | 52.3 | 36.6 | 41.8 | 27.6 | 43.9 |
| Cordierite | 20.9 | 14.2 | 5.4 | 4.4 | 2.7 | .3 | 11.8 | 4.0 |
| Biotite | 18.9 | 32.2 | 13.8 | 13.7 | 27.9 | 22.4 | 18.7 | 15.4 |
| Garnet | 1.1 | 10.8 | Tr | Tr | 11.7 | 7.7 | 7.3 | Tr |
| Sillimanite | [4]6.6 | 12.9 | .3 | .1 | 5.8 | 3.8 | [4]4.4 | 2.0 |
| Opaque minerals | 4.1 | 5.1 | 1.7 | 1.6 | 1.3 | .5 | 2.9 | .4 |
| Zircon | Tr | Tr | Tr | Tr | .1 | Tr | .1 | Tr |
| Andalusite | .2 | Tr | -- | .1 | .3 | -- | -- | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | .9 | 1.1 | 3.0 | 1.5 | .2 | -- | 3.4 | .4 |
| Muscovite-sericite[5] | 3.3 | .8 | -- | -- | .2 | -- | 7.8 | 1.0 |
| Spinel-högbomite | Tr | Tr | Tr | Tr | Tr | Tr | Tr | -- |
| Rutile | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | Tr | -- | -- | -- | -- | -- | -- | -- |
| Apatite | Tr | -- | -- | -- | -- | .1 | -- | -- |

| Locality No. | 211 | 212 | 223 | 237 | 187 | 208 | 120 | 122 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | N40-64 | N69A-64 | N206-64 | N409-64 | N121-65 | N412-65 | W6-70 | W18-70 |
| K feldspar | 19.9 | 5. | 17. | 20.2 | 4.6 | 31.2 | 27.0 | 7.6 |
| Plagioclase | 10.9 | 10. | 9. | [1]12.1 | 1.1 | 7.8 | 3.1 | 11.2 |
| Quartz | 42.1 | 45. | 50. | 23.7 | 10.0 | 1.2 | 26.5 | 47.7 |
| Cordierite | 2.0 | 25. | 1. | Tr | 42.0 | 21.2 | 1.7 | 2.4 |
| Biotite | 16.5 | 6. | 18. | 20.3 | 19.3 | 25.1 | 24.7 | 19.1 |
| Garnet | 1.7 | Tr | Tr | 2.6 | 1.3 | 1.7 | 1.8 | 2.9 |
| Sillimanite- | 6.3 | 5. | 3. | 6.7 | 17.9 | 9.7 | 14.6 | 9.1 |
| Opaque minerals | .5 | 3. | 1. | 3.9 | 3.6 | 1.0 | Tr | Tr |
| Zircon | 1 | Tr | Tr | .2 | -- | Tr | Tr | -- |
| Andalusite | -- | Tr | -- | .3 | Tr | .1 | -- | Tr |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | Tr | Tr | .8 | -- | -- | -- | -- |
| Muscovite-sericite[5]- | -- | Tr | Tr | 9.0 | .2 | 1.0 | .6 | -- |
| Spinel-högbomite | -- | -- | -- | Tr | Tr | Tr | -- | -- |
| Rutile | -- | Tr | Tr | .2 | Tr | -- | -- | -- |
| Xenotime-monazite[6] | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No. | 127 | 128 | 129 | 151 | 152 | 155 | 102 | 108 |
|---|---|---|---|---|---|---|---|---|
| Sample No. | W97-70 | W121-70 | W141-70 | W319-70 | W321-70 | W328-70 | W190-70 | W256c-71 |
| K-feldspar | 7.5 | 16.4 | 6.1 | 7.7 | 20.5 | 34.7 | 15.9 | 3. |
| Plagioclase | 1.4 | 3.1 | 36.0 | .1 | 19.1 | 4.6 | 1.5 | 16. |
| Quartz | 24.0 | 55.8 | 24.5 | 17.7 | 30.6 | 18.8 | 9.7 | 21. |
| Cordierite | 17.1 | [3]8.7 | 7.1 | 23.8 | .3 | 16.2 | 35.0 | Tr |
| Biotite | 21.2 | 6.1 | 18.8 | 15.9 | 12.8 | 9.7 | 19.4 | 20. |
| Garnet | 18.5 | 1.5 | 2.6 | 1.8 | 1.6 | 3.7 | Tr | 1. |
| Sillimanite | 8.9 | 2.0 | 4.6 | 23.2 | 1.7 | 10.2 | 15.0 | [4]Tr |
| Opaque minerals | 1.4 | 1.2 | .3 | 1.2 | .3 | .5 | 2.6 | 2. |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | .3 | Tr |
| Andalusite | Tr | Tr | Tr | -- | Tr | .3 | .6 | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | -- | 1.3 | -- | .3 | .3 | -- | -- | -- |
| Muscovite-sericite[5]- | -- | 3.9 | -- | 8.2 | 12.8 | 1.3 | -- | 37. |
| Spinel-högbomite | Tr | -- | -- | .1 | -- | Tr | Tr | -- |
| Rutile | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.--Continued

| Locality No.---------- | 115 | 116 | 77 | 80 | 343 | 343 | 344 | 349 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W267-71 | W281a-71 | W7-73 | W18-1-73 | CC783a | CC783-1 | CC-887 | EWT-90 |
| K-feldspar----------- | Tr | 11.5 | Tr | .3 | Tr | Tr | 29.7 | 3.3 |
| Plagioclase---------- | .3 | 5.3 | 19.6 | 24.6 | .2 | 6. | 10.6 | 8.0 |
| Quartz --------------- | 23.4 | 20.7 | 16.5 | 40.3 | 22.2 | 53. | 1.2 | 29.6 |
| Cordierite ----------- | 2.5 | 14.0 | 20.0 | [3]27.2 | [3]39.9 | 2. | 10.0 | 4.3 |
| Biotite --------------- | 27.2 | 11.0 | 18.2 | 2.9 | 7.0 | 21. | 20.8 | 28.9 |
| Garnet --------------- | .1 | 9.9 | Tr | Tr | 9.7 | 7. | 1.2 | 20.1 |
| Sillimanite ---------- | [4]27.2 | 16.3 | 12.7 | [4].5 | 17.5 | 10. | 20.1 | 5.7 |
| Opaque minerals---- | 2.5 | 4.2 | 7.1 | 3.4 | 3.3 | 1. | .5 | .1 |
| Zircon --------------- | Tr | Tr | .1 | Tr | .2 | Tr | .3 | Tr |
| Andalusite ---------- | -- | Tr | .6 | -- | -- | -- | -- | -- |
| Staurolite------------ | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite-------------- | 3.5 | 1.5 | .4 | .3 | -- | -- | -- | -- |
| Muscovite-sericite[5]--- | 13.3 | 5.6 | 4.6 | .5 | -- | Tr | 5.6 | Tr |
| Spinel-högbomite------ | -- | Tr | -- | -- | Tr | Tr | Tr | -- |
| Rutile ---------------- | Tr | -- | .1 | -- | Tr | Tr | Tr | -- |
| Xenotime-monazite[6] | -- | -- | .1 | -- | -- | -- | -- | -- |
| Apatite--------------- | -- | -- | .5 | Tr | -- | -- | -- | -- |

| Locality No.---------- | 345 | 71 | 74 | 62 | 64 | 57 | 59 | 61 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | JG-38b | GH35-71 | GH55-71 | GH2-72 | GH4-72 | GH189-73 | GH195-73 | GH232-73 |
| K-feldspar----------- | 1.6 | 2.4 | 4.4 | 14.4 | 31.2 | 5.3 | 11.5 | 17.4 |
| Plagioclase---------- | 2.0 | 2.0 | 3.0 | 11.0 | 2.0 | 2.2 | 11.8 | 6.2 |
| Quartz --------------- | 26.1 | 1.7 | 19.3 | 39.7 | 34.6 | 13.6 | 26.2 | 23.0 |
| Cordierite ----------- | 16.4 | 22.7 | 11.8 | 10.0 | 9.1 | [3]11.8 | 13.5 | 4.3 |
| Biotite --------------- | 23.6 | 30.8 | 23.4 | 16.4 | 9.6 | 30.2 | 18.5 | 32.0 |
| Garnet --------------- | 17.3 | 1.8 | 13.9 | .3 | 3.4 | 4.0 | 2.9 | 1.1 |
| Sillimanite ---------- | 11.7 | 32.8 | 21.6 | 7.7 | 9.4 | 31.7 | 14.3 | 15.5 |
| Opaque minerals---- | 1.3 | 5.8 | .7 | .5 | .6 | 1.2 | .9 | Tr |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | Tr | -- | Tr |
| Andalusite ---------- | Tr | -- | -- | -- | .1 | -- | .1 | .5 |
| Staurolite------------ | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite-------------- | -- | -- | .4 | -- | -- | -- | .2 | -- |
| Muscovite-sericite[5] - | -- | -- | 1.5 | -- | -- | -- | -- | -- |
| Spinel-högbomite--- | Tr | Tr | -- | -- | -- | -- | -- | -- |
| Rutile ---------------- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite[6] | -- | Tr | Tr | Tr | -- | [6].1 | .1 | Tr |
| Apatite--------------- | -- | -- | -- | -- | -- | -- | -- | -- |

| Locality No.---------- | 35 | 36 | 38 | 40 | 41 | 42 | 44 | 46 |
|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | GH12-74 | GH19-74 | GH52-74 | GH85-74 | GH133-74 | GH154-74 | GH177-74 | GH223-74 |
| K-feldspar----------- | 9.4 | .3 | .8 | 6.6 | 19.3 | -- | 18.5 | 10.9 |
| Plagioclase---------- | 10.6 | 10.7 | 1.1 | 6.4 | 6.2 | 11.4 | 10.1 | 2.7 |
| Quartz --------------- | 39.9 | 11.8 | 32.2 | 6.1 | 26.3 | 20.0 | 8.7 | 38.2 |
| Cordierite ----------- | 10.5 | Tr | 1.5 | 10.6 | 14.4 | [3].7 | 1.2 | 16.6 |
| Biotite --------------- | 17.9 | 40.0 | 21.3 | 31.8 | 22.0 | 44.0 | 36.6 | 22.6 |
| Garnet --------------- | 1.7 | .1 | .9 | Tr | 3.3 | 1.6 | Tr | .7 |
| Sillimanite ---------- | 9.7 | [4]25.0 | 21.6 | 34.9 | 8.1 | 16.0 | 23.3 | 4.8 |
| Opaque minerals---- | .3 | 2.6 | .9 | 3.4 | .4 | Tr | .2 | .7 |
| Zircon --------------- | Tr | Tr | -- | Tr | Tr | -- | Tr | Tr |
| Andalusite ---------- | -- | .1 | Tr | -- | -- | -- | -- | 1.1 |
| Staurolite------------ | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite-------------- | -- | 1.4 | 4.7 | -- | -- | 5.9 | .9 | -- |
| Muscovite-sericite[5] - | -- | 8.0 | 15.0 | .1 | -- | .4 | .5 | 1.7 |
| Spinel-högbomite--- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ---------------- | -- | Tr | Tr | -- | -- | Tr | -- | -- |
| Xenotime-monazite[6] | Tr | -- | -- | .1 | Tr | -- | Tr | Tr |
| Apatite--------------- | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 11.** Modes (volume percent) for cordierite-garnet-sillimanite-biotite gneiss±K-feldspar±plagioclase, central Front Range, Colorado.--Continued

| Locality No.---------- | 48 | 27 | 16 | 323 | 324 | 299 | 300 | 303 | 306 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | GH327-74 | GH246-75 | GH372-76 | AP-19 | EP-1 | ML-1 | ML-3 | ML-8 | ML-11 |
| K-feldspar------------ | 3.8 | -- | 10.1 | 15.4 | 2.6 | 17.9 | 26.6 | 9.6 | 5.6 |
| Plagioclase----------- | 10.5 | 34.7 | 10.1 | 28.7 | 20.9 | 19.8 | 23.2 | 27.9 | 11.3 |
| Quartz ---------------- | 16.8 | 30.5 | 70.9 | 46.4 | 25.9 | 31.2 | 26.8 | 48.8 | 25.8 |
| Cordierite ------------ | 7.4 | [3]5.1 | 1.0 | 1.7 | .1 | 8.0 | [3]6.3 | .6 | 4.5 |
| Biotit------------------ | 30.4 | 19.3 | 7.0 | 6.7 | 28.3 | 15.2 | 11.8 | 10.0 | 21.6 |
| Garnet ---------------- | 13.2 | 2.7 | Tr | .6 | 4.0 | 1.4 | 1.2 | 1.1 | 30.3 |
| Sillimanite ----------- | 17.2 | 3.0 | .2 | .2 | 15.8 | 4.1 | 1.9 | 1.3 | Tr |
| Opaque minerals---- | .1 | -- | .7 | .3 | .5 | 1.4 | .8 | .1 | .5 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | -- | .1 | -- | Tr | -- |
| Andalusite ----------- | -- | .2 | -- | -- | -- | .8 | .8 | -- | -- |
| Staurolite------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite--------------- | .3 | .2 | -- | Tr | 1.5 | -- | -- | .3 | .1 |
| Muscovite-sericite[5] - | .4 | 4.3 | -- | -- | .4 | -- | .6 | .3 | .3 |
| Spinel-högbomite --- | -- | -- | Tr | Tr | -- | .1 | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite[6] | .1 | Tr | Tr | Tr | -- | Tr | -- | -- | -- |
| Apatite---------------- | -- | Tr | -- | -- | -- | -- | -- | -- | -- |

| Locality No.---------- | 307 | 395 | 397 | 392 | 407 | 367 | 408 | 410 | 411 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | ML-12 | S-SP-349 | S-SP-450 | S-SP452a | DS59-67a | M-497 | E10-84 | SL2-84 | SL3-84 |
| K-feldspar------------ | .5 | -- | -- | -- | -- | Tr | -- | 18.7 | 14.1 |
| Plagioclase----------- | 15.1 | .8 | .2 | .2 | 2.0 | 9.3 | 1.3 | 4.7 | 1.7 |
| Quartz- --------------- | 45.9 | 58.2 | 51.1 | 47.2 | 66.9 | 51.6 | 63.9 | 8.9 | 24.5 |
| Cordierite ------------ | 9.2 | 5.4 | 21.6 | 25.2 | 10.3 | 1.3 | 5.2 | 1.9 | 13.1 |
| Biotite ---------------- | 23.6 | 23.6 | 22.1 | 15.2 | 14.0 | 13.8 | 17.1 | 34.3 | 15.4 |
| Garnet ---------------- | 2.7 | 8.7 | 1.9 | 5.4 | 2.6 | 2.6 | 5.2 | 1.8 | 18.0 |
| Sillimanite ----------- | 1.6 | 3.3 | 2.8 | 6.6 | 3.9 | 11.6 | 7.2 | 29.3 | 12.6 |
| Opaque minerals---- | .5 | Tr | Tr | .2 | Tr | .3 | .1 | .2 | .5 |
| Zircon ---------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | .1 |
| Andalusite ----------- | .5 | -- | -- | -- | -- | Tr | -- | -- | -- |
| Staurolite------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Chlorite--------------- | .2 | -- | .3 | -- | Tr | 9.5 | -- | -- | -- |
| Muscovite-sericite[5] - | .2 | -- | -- | -- | .3 | -- | -- | .1 | -- |
| Spinel-högbomite --- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rutile ----------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite[6] | -- | Tr | -- | Tr | -- | -- | -- | -- | -- |
| Apatite---------------- | -- | -- | -- | -- | -- | -- | -- | .1 | -- |

[1]Includes 0.8 percent kaolinite.
[2]Includes traces of corundum.
[3]Includes pinnite.
[4]Some or all sillimanite altered to muscovite.
[5]Most muscovite is replacement of plagioclase and sillimanite.
[6]Includes traces of sphene.

**Table 12.** Modes (volume percent) for four hornblende gneiss layers, central Front Range, Colorado.

[--, not found; Tr, trace]

| | Phoenix layer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Locality No. ------ | 390 | 261 | 262 | 267 | 268 | 210 | 216 | 217 | 218 |
| Sample No. ------- | N126 | N322a | N328 | N399 | N400a | N-2-64 | N124-64 | N125-64 | N127-64 |
| K-feldspar -------- | -- | -- | 1.5 | -- | -- | -- | -- | 0.5 | -- |
| Plagioclase-------- | 38.5 | 4.4 | 50.0 | 40.7 | 7. | 13.3 | 26.0 | 52.5 | 35.9 |
| Quartz ------------ | 1.0 | .2 | 11.3 | .1 | 21. | -- | -- | 27.8 | -- |
| Scapolite --------- | -- | -- | 7.1 | -- | -- | -- | -- | -- | -- |
| Hornblende ------- | 56.6 | 65.1 | 15.2 | 56.1 | 26. | 64.1 | 68.9 | 10.8 | 51.1 |
| Clinopyroxene --- | 1.2 | 14.4 | 4.5 | .5 | 5. | 17.9 | 3.7 | 1.1 | 10.8 |
| Orthopyroxene --- | Tr | -- | -- | -- | Tr | -- | -- | -- | -- |
| Opaque minerals- | 2.7 | Tr | 3.0 | -- | 2. | Tr | Tr | .5 | Tr |
| Apatite ----------- | Tr | .4 | .6 | -- | Tr | .6 | -- | .1 | -- |
| Zircon ------------ | Tr | -- | -- | -- | Tr | -- | -- | .1 | -- |
| Biotite ------------ | -- | -- | -- | -- | -- | .8 | -- | 6.6 | -- |
| Allanite ---------- | -- | Tr | -- | -- | -- | .2 | -- | -- | -- |
| Sphene ----------- | Tr | -- | 2.3 | -- | 2. | -- | -- | -- | Tr |
| Calcite------------ | -- | Tr | 3.4 | -- | 2. | .8 | -- | -- | .1 |
| Epidote ----------- | -- | -- | 1.1 | 1.6 | 35. | .3 | .3 | -- | -- |
| Sericite[4] ---------- | -- | 15.5 | -- | 1.0 | -- | 1.4 | 1.1 | -- | 2.1 |
| Chlorite ---------- | -- | -- | -- | -- | -- | .6 | -- | -- | -- |

| | Phoenix layer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Locality No. ------ | 220 | 227 | 227 | 228 | 229 | 234 | 235 | 240 | 243 |
| Sample No. ------- | N151-64 | N246-64 | [1]N246a-64 | N278-64 | N317-64 | N375-64 | N395-64 | N484-64 | N584-64 |
| K-feldspar -------- | -- | 7.7 | Tr | -- | -- | 1.4 | 0.3 | -- | 0.1 |
| Plagioclase-------- | 45.1 | 49.2 | 50.0 | [2]46.6 | 43.9 | 53.0 | 50.2 | 57.1 | 38.7 |
| Quartz ------------ | -- | 23.1 | 11.0 | 1.9 | 27.3 | 11.8 | 16.0 | 1.1 | 3.8 |
| Scapolite --------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende ------- | 38.4 | 7.8 | 29.4 | 39.6 | 18.8 | 8.4 | 27.6 | 28.0 | 45.6 |
| Clinopyroxene --- | 14.1 | -- | .3 | 10.1 | .1 | 19.3 | .6 | 3.0 | 9.8 |
| Orthopyroxene --- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Opaque minerals- | .3 | .7 | 7.5 | -- | 5.3 | 1.4 | 3.1 | 3.0 | .2 |
| Apatite ----------- | .1 | .4 | .1 | .4 | .1 | .7 | -- | -- | .1 |
| Zircon ------------ | -- | Tr | -- | -- | Tr | Tr | -- | -- | -- |
| Biotite ------------ | -- | 11.1 | -- | -- | 2.1 | -- | -- | -- | -- |
| Allanite ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene ----------- | Tr | -- | .1 | .1 | -- | .4 | .4 | -- | -- |
| Calcite------------ | -- | -- | Tr | -- | .3 | 1.9 | .3 | 1.4 | 1.6 |
| Epidote ----------- | 1.3 | Tr | Tr | 1.1 | .1 | 1.2 | .6 | 2.4 | .1 |
| Sericite[4] ---------- | .7 | -- | -- | -- | .4 | .5 | .8 | 1.5 | -- |
| Chlorite ---------- | -- | Tr | 1.6 | .2 | 1.6 | -- | .1 | 2.5 | -- |

Footnotes follow at end of table.

**Table 12.** Modes (volume percent) for four hornblende gneiss layers, central Front Range, Colorado.--Continued

| | Phoenix layer | | | | | | Golden Gate layers | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Locality No. | 245 | 246 | 249 | 193 | 198 | 199 | 310 | 311 | 312 | 313 |
| Sample No. | N602-64 | [1]N625-64 | [1]N675-64 | N169-65 | N227-65 | N233-65 | [1]GG-1 | GG-2 | GG-3 | GG-4 |
| K-feldspar | -- | -- | -- | Tr | 0.9 | -- | -- | -- | -- | -- |
| Plagioclase | 47.3 | 1.6 | 25.1 | 33.0 | 34.6 | 35.2 | 26.8 | 35.4 | 12.6 | 34.9 |
| Quartz | 8.0 | -- | .4 | 11.3 | .8 | .2 | 10.9 | 9.9 | 44.0 | 3.1 |
| Scapolite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende | 34.3 | 51.8 | 67.2 | 19.8 | 48.2 | -- | 60.6 | 52.3 | 30.8 | 56.9 |
| Clinopyroxene | Tr | 44.0 | 5.5 | .3 | 9.3 | 45.5 | -- | -- | 2.0 | -- |
| Orthopyroxene | -- | -- | .3 | -- | -- | -- | -- | -- | -- | -- |
| Opaque minerals | 2.8 | Tr | -- | 3.9 | 2.3 | 4.0 | .8 | 1.2 | Tr | .3 |
| Apatite | .5 | -- | .1 | 2.1 | .6 | .4 | .4 | .4 | .7 | .1 |
| Zircon | .1 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Biotite | 5.6 | -- | -- | 29.2 | Tr | -- | .5 | .1 | .4 | 2.5 |
| Allanite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | .1 | -- | Tr | -- | .6 | -- | -- | .7 | 1.9 | 1.1 |
| Calcite | 1.0 | 1.6 | Tr | -- | .5 | Tr | Tr | 4.1 | 1.1 | .1 |
| Epidote | -- | 1.0 | 1.4 | .4 | 1.7 | [3]14.7 | -- | -- | .7 | -- |
| Sericite[4] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite | .3 | -- | -- | -- | .5 | -- | -- | -- | -- | -- |

| | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. | SP1-80 | SP1a-80 | M250a | M-276a | M279a | M300 | [1]M488a |
| K-feldspar | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase | 36.0 | 25. | 51.9 | 35.6 | 40.7 | 34.9 | .7 |
| Quartz | 1.5 | .5 | .8 | Tr | .9 | 1.0 | 12.1 |
| Scapolite | -- | -- | -- | -- | -- | -- | -- |
| Hornblende | 49.4 | 25. | 44.2 | 56.6 | 56.5 | 62.3 | 25.8 |
| Clinopyroxene | 7.1 | 36. | .1 | 7.4 | -- | 1.1 | 20.4 |
| Orthopyroxene | -- | -- | -- | -- | -- | -- | -- |
| Opaque minerals | .2 | .5 | .5 | Tr | .1 | -- | 5.8 |
| Apatite | -- | 1. | .2 | .2 | Tr | Tr | .1 |
| Zircon | -- | -- | .2 | -- | -- | -- | -- |
| Biotite | 1.0 | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- | .3 |
| Sphene | 3.4 | 8.0 | .4 | .1 | .7 | .7 | -- |
| Calcite | 1.4 | 4.0 | -- | .8 | Tr | -- | -- |
| Epidote | -- | -- | 1.5 | -- | .3 | -- | .5 |
| Sericite[4] | -- | -- | -- | -- | -- | -- | 34.3 |
| Chlorite | -- | -- | .2 | -- | -- | -- | Tr |

[1]Amphibolite lens.
[2]Includes sericite.
[3]Includes some clinozoisite.
[4]Replaces plagioclase.

**Table 13.** Modes (volume percent) for hornblende gneiss and amphibolite layers finely interlayered with biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No.-------- | 302 | 302 | 303 | 333 | 334 | 336 | 335 | 337 | 338 | 206 | 98 | 116 | 366 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. -------- | ML-7 | ML-7A | ML-8A | R056 | R063 | R141 | R126 | R218 | R402 | [1]N354-65 | W151a-71 | W281-b-71 | [1]M488a |
| K-feldspar---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1. | -- | -- |
| Plagioclase--------- | 35.2 | 29.2 | 23.5 | 11.0 | 49.0 | 27.4 | 53.8 | 28.0 | 42.9 | 24.7 | 33. | -- | .7 |
| Quartz -------------- | 12.1 | 5.9 | 2.1 | 11.5 | 11.4 | 21.5 | 7.8 | 22.7 | -- | 1.3 | 37. | -- | 12.1 |
| Hornblende -------- | 38.0 | 50.9 | 23.2 | 62.2 | 23.6 | 32.1 | 34.9 | 32.3 | 48.0 | 48.8 | 19. | 77. | 25.8 |
| Clinopyroxene----- | 11.2 | 9.6 | 41.9 | -- | -- | -- | -- | -- | 7.3 | 22.0 | -- | 3. | 20.4 |
| Tremolite-actinolite | -- | -- | -- | -- | 2.7 | -- | -- | -- | -- | -- | -- | -- | -- |
| Biotite -------------- | .4 | .4 | -- | -- | 4.1 | 17.4 | 1.2 | 14.8 | .3 | -- | 10. | -- | -- |
| Apatite-------------- | .6 | .5 | .4 | Tr | .1 | .1 | .5 | .3 | .2 | -- | Tr | 1. | .1 |
| Opaque minerals -- | Tr | Tr | Tr | -- | .6 | .6 | 1.5 | .7 | .2 | 1.3 | Tr | 1. | 5.8 |
| Sphene-------------- | .2 | .4 | 3.4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote- ------------ | .6 | 1.4 | 5.2 | 3.0 | .5 | .9 | -- | 1.2 | .3 | 1.6 | -- | 15. | .5 |
| Calcite -------------- | 1.3 | 1.4 | -- | -- | 1.3 | -- | -- | -- | .5 | .3 | -- | -- | -- |
| Sericite[2] ------------ | .4 | .3 | .3 | 11.3 | -- | -- | -- | -- | -- | -- | -- | 3. | 34.3 |
| Chlorite------------- | -- | -- | -- | 1.0 | 6.7 | -- | .3 | -- | .3 | -- | -- | -- | Tr |
| Zircon -------------- | -- | -- | -- | -- | -- | -- | Tr | -- | -- | -- | Tr | -- | -- |
| Allanite------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .3 |

[1]Amphibolite layer or lens; all other samples hornblende gneiss.
[2]Sericite replaces plagioclase.

**Table 14.** Modes (volume percent) for scattered mafic lenses in garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 107 | 111 | 99 | 98 | 116 | 76 | 77 | 33 | 369 | 370 | 286 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W252b-71 | W259a-71 | W152-71 | W151-71 | W281b-71 | W-4-73 | W-7a-73 | GH-350-75 | M532c-1 | M-597 | J121a |
| Plagioclase | -- | 26.0 | 27.5 | 31.0 | -- | 41.7 | 36.4 | 52.0 | 27.4 | 23.4 | 35.0 |
| Quartz | 22. | 12.1 | 41.7 | -- | -- | 18.2 | 16.3 | 18.2 | Tr | 44.1 | 13.2 |
| Hornblende | 37. | 36.5 | -- | 3.2 | 77. | 1.4 | 29.3 | 23.7 | 69.2 | 27.6 | 49.2 |
| Orthopyroxene | -- | -- | 6.1 | -- | -- | 17.5 | -- | -- | -- | -- | -- |
| Clinopyroxene | -- | -- | -- | 37.1 | 3. | -- | -- | -- | -- | -- | |
| Biotite | -- | 22.5 | 23.2 | 25.5 | -- | 13.8 | 14.6 | 4.9 | 2.2 | 4.0 | 2.0 |
| Apatite | Tr | .7 | Tr | -- | 1. | Tr | .3 | -- | Tr | Tr | Tr |
| Opaque minerals | 6. | 2.0 | .3 | 3.2 | 1. | 3.3 | 3.0 | .2 | .8 | -- | .5 |
| Allanite | -- | .1 | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Zircon | -- | Tr | Tr | -- | -- | -- | Tr | -- | Tr | .1 | Tr |
| Calcite | -- | -- | -- | -- | -- | -- | -- | -- | .4 | .1 | -- |
| Chlorite | -- | .1 | -- | -- | -- | -- | -- | .5 | -- | -- | -- |
| Muscovite-sericite[1] | 10. | -- | -- | Tr | 3. | 1.8 | .1 | -- | -- | .6 | -- |
| Epidote | 25. | Tr | 1.2 | -- | 15. | 2.3 | -- | -- | -- | .1 | -- |
| Sphene | -- | -- | -- | -- | -- | -- | -- | .5 | -- | -- | .1 |

[1]Muscovite-sericite, a replacement of plagioclase.

**Table 15.** Modes (volume percent) for altered hornblende gneiss and amphibolite, located within Late Cretaceous-early Tertiary aureoles, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 199 | 244 | 244 | 193 | 225 | 226 |
|---|---|---|---|---|---|---|
| Sample No. | N233-65 | [1]N590a-64 | [1]N590a-1-64 | [1]N169-65 | [1]N225-64 | [1]N236-64 |
| K-feldspar | -- | 1.0 | -- | Tr | 0.1 | -- |
| Plagioclase | 35.2 | 43.4 | 37.0 | 33.0 | 45.6 | 2. |
| Quartz | .2 | -- | -- | 11.3 | 5.4 | -- |
| Hornblende | -- | 54.0 | 43.5 | 19.8 | 32.8 | 92. |
| Clinopyroxene | 45.5 | .2 | 16.0 | .3 | 14.9 | 2. |
| Biotite | -- | .5 | -- | 29.2 | -- | 3. |
| Opaque minerals | 4.0 | Tr | 3.1 | 3.9 | 1.1 | -- |
| Apatite | .4 | .2 | .1 | 2.1 | .1 | Tr |
| Zircon | -- | .1 | Tr | -- | -- | -- |
| Calcite | Tr | .4 | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- |
| Epidote-clinozoisite | 14.7 | .1 | .3 | .4 | -- | 1. |
| Chlorite | -- | .1 | -- | -- | -- | -- |
| Sphene | -- | -- | -- | -- | -- | -- |
| Allanite | -- | -- | -- | -- | -- | -- |

| Locality No. | 194 | 197 | 196 | 145 | 104 | 104 |
|---|---|---|---|---|---|---|
| Sample No. | N170-65 | N202-65 | N198-65 | W275b-70 | W223a-71 | W223b-71 |
| K-feldspar | -- | -- | -- | -- | -- | -- |
| Plagioclase | 52.9 | 47.0 | 37.4 | 33. | 42.1 | 35.4 |
| Quartz | 2.5 | 6.1 | 2.6 | 23. | 23.6 | 13.7 |
| Hornblende | 38.6 | 42.9 | 53.0 | 16. | 3.8 | 20.5 |
| Clinopyroxene | .7 | .6 | .6 | -- | -- | 1.3 |
| Tremolite-actinolite | -- | -- | -- | -- | -- | -- |
| Biotite | .6 | -- | -- | 19. | 26.3 | 18.0 |
| Opaque minerals | 3.6 | 1.0 | 2.8 | 8. | 1.0 | .5 |
| Apatite | .3 | .1 | .3 | 1. | .6 | .1 |
| Zircon | .1 | Tr | -- | Tr | -- | -- |
| Calcite | .1 | .8 | .3 | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | 8.1 |
| Epidote-clinozoisite | -- | 1.0 | 2.5 | -- | -- | -- |
| Chlorite | .3 | .5 | .1 | -- | -- | -- |
| Sphene | .3 | Tr | .4 | -- | .4 | 1.4 |
| Allanite | -- | -- | -- | Tr | .1 | -- |

[1]Amphibolite layer or lens. Amphibolite sample N590a-1-64 from contact with Late Cretaceous-early Tertiary intrusive; amphibolite sample N590a-64 is 4 m from a Late Cretaceous-early Tertiary intrusive contact.

**Table 16.** Modes (volume percent) for layers of calc-silicate gneiss and diopsidite in biotite gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| Locality No. | 108 | 112 | 105 | 107 | 116 | 371 | 290 | 279 | 346 | 103 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | W256b-71 | W262b-71 | [1]W235-71 | W252c-71 | W281c-71 | GH-186-76 | J-277 | IS3-80 | D245a | [1]W222b-71 |
| K-feldspar | -- | -- | -- | -- | -- | 30.6 | -- | -- | -- | -- |
| Plagioclase | -- | 6. | -- | 5.0 | 9. | 19.4 | -- | 51.1 | 35. | -- |
| Quartz | 28. | 16. | 3.3 | 29.6 | 2. | -- | 7.4 | 5.8 | 30. | Tr |
| Hornblende | 9. | 13. | 15.4 | -- | 44. | -- | 4.6 | 11.4 | 3. | 13. |
| Biotite | [1]1. | .3 | -- | Tr | Tr | -- | -- | [2].2 | -- | -- |
| Clinopyroxene[3] | 27. | 37. | 73.3 | -- | 26 | 30.0 | 13.3 | 16.0 | 25. | 83. |
| Apatite | Tr | -- | .3 | 1.6 | 1. | -- | .1 | .5 | Tr | Tr |
| Zircon | -- | Tr | -- | -- | -- | -- | -- | -- | -- | -- |
| Sphene | Tr | Tr | -- | -- | -- | 1.2 | 6.7 | 2.2 | Tr | Tr |
| Calcite | Tr | Tr | -- | -- | -- | -- | -- | 1.2 | -- | Tr |
| Epidote-clinozoisite | 36. | 27. | 6.5 | 38.9 | 8. | 16.3 | 66.2 | 10.9 | 7. | 4. |
| Chlorite | -- | -- | .9 | 12.0 | -- | -- | -- | -- | Tr | -- |
| Opaque minerals | -- | -- | -- | 1.4 | Tr | -- | 1.6 | .9 | Tr | -- |
| Muscovite-sericite[4] | -- | -- | -- | 11.5 | 10. | 2.5 | -- | -- | -- | -- |
| Garnet | -- | -- | -- | -- | -- | -- | .1 | -- | -- | -- |
| Scapolite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

[1]Diopsidite

[2]Traces of allanite present.

[3]Predominantly diopside.

[4]Muscovite-sericite an alteration product of plagioclase.

**Table 17.** Modes (volume percent) for interlayered calc-silicate gneiss and more mafic and silicic rocks, especially hornblende gneiss, from map localities 1, 2, and 13, Gold Hill area, and the Phoenix layer, Nederland quadrangle, localities 193, 198, 245, 260, and 268. Only calc-silicate gneiss has been shown here for the Phoenix layer; associated hornblende gneiss is reported in table 12, central Front Range, Colorado.

[--, not found; Tr, trace]

| | Hornblende-pyroxene gneiss | | Pyroxene gneiss | | | Calc-silicate gneiss |
|---|---|---|---|---|---|---|
| Locality No. | 13 | 13 | 13 | 13 | 13 | 13 |
| Sample No. | GH281-1-76 | GH281-4-76 | GH281-2-76 | GH281-2a-76 | GH281-3-76 | GH281-1a-76 |
| K-feldspar | Tr | -- | -- | -- | -- | -- |
| Plagioclase | 38. | 34. | 28. | 45. | 35. | 2.0 |
| Quartz | -- | -- | 10. | 9. | 30. | 5.9 |
| Hornblende | 13. | 12. | 1. | 3. | 3. | .6 |
| Clinopyroxene[1] | 29. | 42. | 38. | 30. | 25. | 30.9 |
| Apatite | 1. | Tr | 1. | 1. | Tr | .7 |
| Opaque minerals | .5 | Tr | Tr | Tr | Tr | .1 |
| Allanite | -- | -- | -- | Tr | Tr | -- |
| Zircon | -- | -- | -- | Tr | -- | -- |
| Scapolite | -- | -- | -- | -- | -- | -- |
| Calcite | Tr | 1. | Tr | -- | -- | -- |
| Chlorite | -- | -- | -- | -- | Tr | -- |
| Muscovite-sericite[2] | 3. | -- | -- | -- | -- | -- |
| Epidote | 11. | 10. | 19. | 8. | 7. | 55.7 |
| Sphene | 4.5 | 1. | 3. | 4. | Tr | 4.1 |
| Garnet | -- | -- | -- | -- | -- | -- |

| | Diopsidite | | | Quartz-feldspar gneiss | Impure quartzite |
|---|---|---|---|---|---|
| Locality No. | 1 | 1 | 1 | 1 | 1 |
| Sample No. | GH1-77 | GH1-3-77 | GH1-5-77 | GH1-1-77 | GH1-4-77 |
| K-feldspar | -- | -- | -- | 31.8 | 1.5 |
| Plagioclase | Tr | -- | -- | 3.2 | 2.3 |
| Quartz | -- | -- | Tr | 58.2 | 88.5 |
| Hornblende | 7. | 1. | -- | 1.0 | 2.7 |
| Clinopyroxene[1] | 52. | 97. | 83. | 3.6 | 4.0 |
| Apatite | -- | -- | -- | Tr | .1 |
| Opaque minerals | 2. | -- | -- | -- | .3 |
| Allanite | -- | -- | -- | -- | -- |
| Zircon | -- | -- | -- | -- | -- |
| Scapolite | -- | 2.0 | -- | -- | -- |
| Calcite | Tr | -- | 5. | -- | -- |
| Chlorite | -- | -- | 10. | -- | -- |
| Muscovite-sericite[2] | -- | -- | 2. | -- | -- |
| Epidote | 34. | -- | Tr | .8 | .5 |
| Sphene | 2. | -- | -- | 1.4 | .1 |
| Garnet | 3. | -- | -- | -- | -- |

Footnotes follow at end of table.

**Table 17.** Modes (volume percent) for interlayered calc-silicate gneiss and more mafic and silicic rocks, especially hornblende gneiss, from map localities 1, 2, and 13, Gold Hill area, and the Phoenix layer, Nederland quadrangle, localities 193, 198, 245, 260, and 268. Only calc-silicate gneiss has been shown here for the Phoenix layer; associated hornblende gneiss is reported in table 12, central Front Range, Colorado.--Continued

| | Calc-silicate gneiss | | | Pyroxene gneiss | Calc- silicate gneiss | | |
|---|---|---|---|---|---|---|---|
| Locality No. -------- | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Sample No. --------- | GH1-2-77 | GH1-6-77 | GH1-6a-77 | GH1-7-77 | GH2-1-77 | GH2-2-77 | GH2-3-77 |
| K-feldspar ---------- | -- | -- | -- | 1.6 | -- | -- | -- |
| Plagioclase---------- | 20.6 | 26.3 | 21.2 | 69.8 | 34.4 | 59.7 | 50.3 |
| Quartz --------------- | 6.9 | 1.4 | .9 | 6.9 | -- | 7.4 | -- |
| Hornblende --------- | 1.5 | 28.0 | 22.2 | 1.5 | 12.4 | 7.8 | 4.4 |
| Clinopyroxene[1] ---- | 49.2 | 31.6 | 39.9 | 17.8 | 42.8 | 17.8 | 40.2 |
| Apatite -------------- | -- | -- | .1 | .1 | .5 | .3 | .3 |
| Opaque minerals--- | Tr | Tr | Tr | .1 | .2 | Tr | Tr |
| Allanite ------------- | -- | -- | -- | -- | -- | -- | -- |
| Zircon --------------- | -- | -- | -- | -- | -- | -- | -- |
| Scapolite ------------ | 15.8 | 10.1 | 13.2 | .2 | -- | -- | -- |
| Calcite--------------- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite ------------- | -- | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[2] | -- | -- | -- | .1 | -- | -- | -- |
| Epidote -------------- | 3.7 | 1.1 | 1.0 | 1.4 | 7.5 | 5.6 | 3.0 |
| Sphene -------------- | 2.2 | 1.5 | 1.5 | .5 | 2.2 | 1.4 | 1.8 |
| Garnet --------------- | .1 | -- | -- | -- | -- | -- | -- |

| | Pyroxene gneiss | Hornblende-pyroxene-gneiss | Calc-silicate gneiss from the Phoenix layer | | | | |
|---|---|---|---|---|---|---|---|
| Locality No. -------- | 2 | 2 | 260 | 268 | 193 | 198 | 245 |
| Sample No. --------- | GH2-4-77 | GH2-6-77 | N321a | N400b | N169a-65 | N227a-65 | N602a-64 |
| K-feldspar ---------- | -- | -- | 1. | -- | -- | -- | -- |
| Plagioclase---------- | 19. | 27.4 | 8. | Tr | 24.4 | 58.6 | 14.4 |
| Quartz --------------- | 22. | .1 | 5. | 21. | 44.4 | 4.7 | 24.1 |
| Hornblende --------- | 2. | 41.0 | 1. | 5. | 6. | 7.9 | .7 |
| Biotite --------------- | -- | -- | -- | -- | .1 | -- | -- |
| Clinopyroxene[1] ---- | 22. | 29.6 | 21. | 21. | -- | 22.7 | -- |
| Apatite -------------- | -- | .4 | Tr | Tr | .8 | Tr | -- |
| Opaque minerals--- | -- | -- | Tr | Tr | 2.6 | 1.3 | .1 |
| Allanite ------------- | -- | -- | -- | -- | -- | -- | -- |
| Zircon --------------- | -- | -- | -- | Tr | -- | -- | -- |
| Scapolite ------------ | -- | -- | -- | 15. | -- | -- | -- |
| Calcite--------------- | -- | -- | 26. | 4. | .1 | .9 | 1.0 |
| Chlorite ------------- | 1. | -- | -- | -- | -- | -- | 2.7 |
| Muscovite-sericite[2] | 1. | -- | -- | Tr | 1.1 | -- | -- |
| Epidote -------------- | 32. | .6 | -- | -- | -- | -- | -- |
| Epidote-clinozoisite | -- | -- | 36. | 23. | 11.4 | 2.5 | 53.7 |
| Sphene -------------- | 1. | .9 | 2. | 2. | 1.2 | 1.4 | 3.3 |
| Garnet --------------- | -- | -- | -- | 5. | 13.3 | Tr | -- |

[1]Predominantly diopside; but there maybe unidentified remnants of other clinopyroxenes.

[2]Muscovite-sericite is an alteration of plagioclase.

**Table 18.** Modes (volume percent) for impure quartzite associated with hornblende gneiss and calc-silicate gneiss, central Front Range, Colorado.

[--, not found; Tr, trace]

| | With hornblende gneiss | | | With cal-silicate gneiss | With sillimanite-biotite gneiss |
|---|---|---|---|---|---|
| Locality No. | 269 | 232 | 233 | 1 | 239 |
| Sample No. | N-408-63 | N361-64 | N363a1-64 | GH1-4-77 | N473-64 |
| K-feldspar | -- | 6.0 | -- | 1.5 | 5.0 |
| Plagioclase | 1.7 | 29.4 | 5.4 | 2.3 | 18.0 |
| Quartz | 85.6 | 56.0 | 67.4 | 88.5 | 51.0 |
| Hornblende | 10.1 | -- | -- | 2.7 | -- |
| Clinopyroxene | .6 | -- | -- | 4.0 | -- |
| Opaque minerals | .1 | .5 | [1]2.6 | .3 | 2.0 |
| Apatite | .1 | -- | Tr | .1 | -- |
| Biotite | -- | .8 | 1.0 | -- | 5.0 |
| Epidote | 1.8 | .5 | -- | .5 | -- |
| Sphene | -- | .3 | -- | .1 | -- |
| Allanite | Tr | -- | -- | -- | -- |
| Chlorite | -- | 6.4 | 16.0 | -- | 2.0 |
| Muscovite-sericite[2] | -- | -- | 1.4 | -- | 14.0 |
| Garnet | -- | -- | 5.2 | -- | -- |
| Sillimanite | -- | -- | -- | -- | 3.0 |
| Calcite | -- | -- | 1.0 | -- | -- |
| Zircon | -- | Tr | -- | -- | -- |
| Rutile | -- | -- | -- | -- | Tr |

[1]Pyrite.

[2]Muscovite-sericite replaces plagioclase.

# APPENDIX II

## TABLES 19-27, 33-35, AND 37

## STANDARD WET CHEMICAL ANALYSES, SEMIQUANTITATIVE, QUANTATIVE, OPTICAL, AND X-RAY SPECTROGRAPHIC ANALYSES, MODES, AND NORMATIVE AND TRACE MINERALS OF EARLY PROTEROZOIC METAMORPHIC ROCKS IN THE CENTRAL FRONT RANGE

[Sample numbers or map locality numbers with the following prefixes indicate the quadrangle where sample was collected: AP, Allens Park; A, A1, CC, D, EWT, JG, GO, Mary, ST, S, Central City; E, DS, Evergreen; EP, East Portal; GG, Golden Gate; GH, Gold Hill; IH, Indian Hills; SP, Squaw Pass; IS, Idaho Springs; M, Morrison; ML, Monarch Lake; N, Nederland; RB, Ralston Buttes; W, WC, Ward.]

**Table 19.** Standard wet chemical analyses and semiquantitative spectrographic analyses for biotite from biotitic, felsic, and hornblende gneisses, and calculated composition of biotite, central Front Range, Colorado.

[N.d., not looked for; N, not detected; L, detected but below limit of determination; bulk chemical analyses by E.L. Munson; semiquantitative spectrographic analyst, L.A. Bradley]

| Rock type | Biotite gneiss | Sillimanite-biotite gneiss | Pegmatite in sillimanite-biotite gneiss | | Felsic gneiss (microcline gneiss) | | Hornblende gneiss |
|---|---|---|---|---|---|---|---|
| | | | All from Central City areea | | | | Golden Gate |
| Map Locality | 503 | 501 | 504 | 505 | 500 | 502 | 313 |
| Sample No. | ST-14 | ST-2 | ST-7 | ST-10 | ST-1 | ST-5 | GG-4 |
| Laboratory No. | D102138 | D102139 | D102140 | D102141 | D102142 | D102143 | D102144 |
| Bulk chemical analyses in weight percent | | | | | | | |
| $SiO_2$ | 36.43 | 35.14 | 34.03 | 36.43 | 35.48 | 35.96 | 37.43 |
| $Al_2O_3$ | 21.19 | 18.64 | 19.21 | 15.97 | 16.36 | 14.90 | 15.77 |
| $Fe_2O_3$ | 2.18 | 2.37 | 3.50 | 3.32 | 2.84 | 3.10 | 2.88 |
| FeO | 18.43 | 19.51 | 20.98 | 18.31 | 21.60 | 21.06 | 14.98 |
| MgO | 6.09 | 7.49 | 5.92 | 9.24 | 7.25 | 8.34 | 12.46 |
| CaO | .00 | .00 | .00 | .00 | .00 | .09 | 1.33 |
| $Na_2O$ | .38 | .21 | .27 | .15 | .20 | .23 | .34 |
| $K_2O$ | 8.42 | 9.39 | 9.45 | 9.53 | 9.28 | 9.33 | 8.01 |
| $H_2O+$ | N.d. | 3.00 | 2.99 | 2.60 | 3.08 | 2.89 | 3.88 |
| $H_2O-$ | .08 | .02 | .03 | .04 | .04 | .05 | .22 |
| $TiO_2$ | 2.37 | 3.47 | 2.78 | 2.91 | 2.08 | 2.73 | 2.13 |
| [1]$P_2O_5$ | N.d. | .01 | .05 | .00 | N.d. | .03 | N.d. |
| MnO | N.d. | .19 | .25 | .48 | .44 | .26 | .20 |
| F | N.d. | .34 | .33 | .99 | 1.36 | .80 | .29 |
| Cl | N.d. | .05 | .13 | .18 | N.d. | .10 | N.d. |
| Subtotal | 95.57 | 99.83 | 99.92 | 100.15 | 100.01 | 99.87 | 99.92 |
| Less O | N.d. | .15 | .17 | .46 | .57 | .36 | .12 |
| Total | 95.57 | 99.68 | 99.75 | 99.69 | 99.44 | 99.51 | 99.80 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | |
| Mn | 1,000 | 1,000 | 1,500 | 3,000 | 3,000 | 3,000 | 1,000 |
| Ba | 700 | 700 | 700 | 700 | 150 | 1,000 | 1,500 |
| Ce | N | N | 200 | N | N | N | N |
| Co | 70 | 100 | 70 | 50 | 10 | 70 | 100 |
| Cr | 300 | 1,000 | 1,000 | 20 | 5 | 50 | 500 |
| Cu | 20 | 50 | 20 | 20 | 5 | 10 | 200 |
| Ga | 70 | 70 | 100 | 100 | 100 | 100 | 50 |
| La | N | N | 200 | N | N | N | N |
| Mo | 10 | 20 | 10 | 10 | 10 | 7 | 7 |
| Nb | 20 | 20 | 20 | 50 | 50 | 20 | N |
| Nd | N | N | 200 | N | N | N | N |
| Ni | 200 | 200 | 200 | 10 | L | 15 | 70 |
| Pb | 20 | 50 | 50 | 50 | N | 20 | N |
| Sc | 70 | 50 | 50 | 50 | 20 | 20 | 10 |
| Sn | N | 20 | 30 | 70 | 70 | N | N |
| Sr | 10 | 10 | 10 | 10 | 10 | 15 | 20 |
| V | 300 | 500 | 700 | 100 | 20 | 150 | 300 |
| Y | 50 | 50 | 1,500 | 10 | 50 | 50 | N |
| Yb | 5 | 2 | 70 | 3 | 5 | 2 | 3 |
| Zn | N | 500 | 500 | N | N | N | N |
| Zr | 200 | 100 | 200 | N | N | 50 | 70 |

Footnotes follow at end of table.

**Table 19.** Standard wet chemical analyses and semiquantitative spectrographic analyses for biotite from biotitic, felsic, and hornblende gneisses, and calculated composition of biotite, central Front Range, Colorado.--Continued

| Rock type --------- | Biotite gneiss | Sillimanite-biotite gneiss | Pegmatite in sillimanite-biotite gneiss | | Felsic gneiss (microcline gneiss) | | Hornblende gneiss |
|---|---|---|---|---|---|---|---|
| Locality ---------- | All from Central City area | | | | | | Golden Gate |
| Map locality No. | ST-14 | ST-2 | ST-7 | ST-10 | ST-1 | ST-5 | GG-4 |
| Laboratory No. -- | D102138 | D102139 | D102140 | D102141 | D102142 | D102143 | D102144 |
| Composition of biotite on the basis of 24 anions | | | | | | | |
| Si------------------ | 5.593 | 5.424 | 5.320 | 5.634 | 5.534 | 5.633 | 5.615 |
| Al ------------------ | 2.407 | 2.576 | 2.680 | 2.366 | 2.466 | 2.367 | 2.385 |
| | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| Al ------------------ | 1.428 | .815 | .859 | .545 | .542 | .383 | .403 |
| Ti ------------------ | .274 | .403 | .327 | .338 | .244 | .322 | .240 |
| $Fe^{+3}$---------------- | .252 | .275 | .412 | .386 | .333 | .365 | .325 |
| $Fe^{+2}$---------------- | 2.367 | 2.519 | 2.743 | 2.368 | 2.818 | 2.759 | 1.879 |
| Mn ----------------- | .025 | .025 | .033 | .063 | .058 | .035 | .025 |
| Mg ----------------- | 1.394 | 1.723 | 1.379 | 2.130 | 1.686 | 1.947 | 2.786 |
| | 5.74 | 5.76 | 5.75 | 5.83 | 5.68 | 5.81 | 5.66 |
| Ca ----------------- | -- | -- | -- | -- | -- | .015 | .214 |
| Na------------------ | .113 | .063 | .082 | .045 | .061 | .070 | .099 |
| K ------------------- | 1.650 | 1.849 | 1.885 | 1.880 | 1.847 | 1.864 | 1.533 |
| | 1.76 | 1.91 | 1.97 | 1.93 | 1.91 | 1.95 | 1.84 |
| F-------------------- | N.d. | .166 | .163 | .484 | .671 | .396 | .138 |
| Cl ------------------ | N.d. | .013 | .034 | .047 | N.d. | .027 | N.d. |
| OH ----------------- | 2.991 | 3.068 | 3.087 | 2.641 | 3.163 | 2.967 | 3.662 |
| | N.d. | 3.25 | 3.28 | 3.17 | 3.83 | 3.39 | 3.80 |

[1]$P_2O_5$ is included in $Al_2O_3$.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.

[Analyst for wet chemical analysis of sample with map locality number 388, L.N. Tarrant. Analysts for rapid-rock analyses with sample for locality numbers 329, H.F. Phillip, P.L.D. Elmore, P.W. Scott, K.E. White; 21 and 292, G.H. Smith; 109, 134, 137, 143, Leonard Shapiro; 277, 284, 353, 354, Deborah Kobilis. Analysts for spectrographic analyses for samples from map locality numbers 21, 109, 134, 137, 143, J.L. Harris; 277, 284, 353, 354, Leung Mei. N.d., not determined; N, not detected; --, not found; <, less than; Tr, trace]

| Map locality No. | 388 | 329 | 292 | 134 | 137 | 143 |
|---|---|---|---|---|---|---|
| Sample No. | EWT5a-54 | A1-278-55 | A1-29-55 | W213-70 | W241-70 | W270-70 |
| Lab No. | A1 | 140575 | 140576 | W178102 | W178103 | W178104 |
| **Chemical analyses in weight percent** | | | | | | |
| $SiO_2$ | 76.33 | 72.0 | 67.9 | 75.4 | 65.1 | 69.8 |
| $Al_2O_3$ | 12.30 | 11.9 | 12.7 | 10.8 | 16.1 | 13.7 |
| $Fe_2O_3$ | 1.08 | 1.9 | 2.4 | 2.9 | 2.3 | 1.1 |
| FeO | 1.75 | 3.2 | 2.9 | 2.4 | 3.4 | 2.9 |
| MgO | .59 | 1.5 | 1.8 | 1.6 | 2.1 | 2.5 |
| CaO | 2.41 | 1.7 | 1.2 | .34 | 3.8 | 2.2 |
| $Na_2O$ | 3.13 | 2.6 | .11 | 1.0 | 3.6 | 2.3 |
| $K_2O$ | 1.02 | 2.2 | 4.8 | 3.1 | 2.0 | 4.3 |
| $H_2O+$ | .42 | 1.0 | 2.5 | 1.5 | .88 | .92 |
| $H_2O-$ | .17 | N.d. | N.d. | .15 | .09 | .11 |
| $TiO_2$ | .27 | .58 | .74 | .80 | .76 | .33 |
| $P_2O_5$ | .03 | .15 | .16 | .06 | .24 | .17 |
| MnO | .03 | .12 | .08 | .03 | .06 | .06 |
| $CO_2$ | .01 | .64 | 2.0 | .02 | .00 | .04 |
| F | N.d. | N.d. | N.d. | .11 | .23 | .24 |
| Cl | N.d. | N.d. | N.d. | <.01 | .01 | .01 |
| S (total) | N.d. | .25 | .21 | .02 | .01 | 04 |
| Total | 99.54 | 101. | 99. | 100. | 100. | 100. |
| Bulk density | 2.65 | N.d. | N.d. | 2.66 | 2.74 | 2.70 |
| Powder density sink/float | 2.69 | N.d. | N.d. | 2.76 | 2.76 | 2.96 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | |
| B | N.d. | N.d. | N.d. | N | N | N |
| Ba | N.d. | N.d. | N.d. | 318 | 279 | 624 |
| Be | N.d. | N.d. | N.d. | 1 | N | 3 |
| Ce | N.d. | N.d. | N.d. | 51 | 54 | 43 |
| Co | N.d. | N.d. | N.d. | 8 | 12 | 5 |
| Cr | N.d. | N.d. | N.d. | 66 | 24 | 2 |
| Cu | N.d. | N.d. | N.d. | N | 24 | 22 |
| Ga | N.d. | N.d. | N.d. | 7 | 15 | 12 |
| Gd | N.d. | N.d. | N.d. | 4 | 4 | 4 |
| La | N.d. | N.d. | N.d. | 17 | 21 | 17 |
| Mo | N.d. | N.d. | N.d. | 1 | 1 | 1 |
| Nb | N.d. | N.d. | N.d. | 18 | 3 | 4 |
| Nd | N.d. | N.d. | N.d. | N | 20 | 19 |
| Ni | N.d. | N.d. | N.d. | 34 | 19 | 1 |
| Pb | N.d. | N.d. | N.d. | 3 | 13 | 17 |
| Rb | N.d. | N.d. | N.d. | 150 | 100 | 200 |
| Sc | N.d. | N.d. | N.d. | 9 | 10 | 8 |
| Sn | N.d. | N.d. | N.d. | 4 | 5 | 3 |
| Sr | N.d. | N.d. | N.d. | 81 | 407 | 141 |
| V | N.d. | N.d. | N.d. | 71 | 93 | 37 |
| Y | N.d. | N.d. | N.d. | 4 | 15 | 8 |
| Yb | N.d. | N.d. | N.d. | N | 1 | N |
| Zn | N.d. | N.d. | N.d. | 45 | 76 | 53 |
| Zr | N.d. | N.d. | N.d. | 111 | 101 | 53 |

Footnote follows at end of table.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.--Continued

| Map locality No. ---- | 388 | 329 | 292 | 134 | 137 | 143 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | EWT5a-54 | A1-278-55 | A1-29-55 | W213-70 | W241-70 | W270-70 |
| Lab No. -------------- | AI | 140575 | 140576 | W178102 | W178103 | W178104 |
| Modes in volume percent | | | | | | |
| K-feldspar ----------- | N.d. | N.d. | N.d. | .2 | .3 | 8.4 |
| Plagioclase----------- | N.d. | N.d. | N.d. | 15.5 | 48.4 | 35.4 |
| Quartz ---------------- | N.d. | N.d. | N.d. | 55.1 | 31.2 | 27.0 |
| Biotite ---------------- | N.d. | N.d. | N.d. | 13.3 | 18.4 | 28.6 |
| Opaque minerals---- | N.d. | N.d. | N.d. | 1.7 | 1.7 | .1 |
| Zircon ---------------- | N.d. | N.d. | N.d. | Tr | Tr | -- |
| Muscovite-sericite[1] - | N.d. | N.d. | N.d. | 13.8 | Tr | .5 |
| Apatite --------------- | N.d. | N.d. | N.d. | -- | Tr | Tr |
| Chlorite -------------- | N.d. | N.d. | N.d. | .4 | -- | Tr |
| Allanite -------------- | N.d. | N.d. | N.d. | -- | -- | -- |
| Epidote --------------- | N.d. | N.d. | N.d. | -- | -- | -- |
| Xenotime-monazite- | N.d. | N.d. | N.d. | -- | -- | -- |
| Tourmaline ---------- | N.d. | N.d. | N.d. | -- | -- | -- |

| Map locality No. ---- | 109 | 21 | 353 | 354 | 277 | 284 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | W257-71 | GH175a-75 | RB3-80 | RB4-80 | IS1-80 | IS8-80 |
| Lab No. -------------- | W178105 | W192422 | W211761 | W211762 | W211774 | W211781 |
| Chemical analyses in weight percent | | | | | | |
| $SiO_2$ ------------------ | 77.1 | 61.4 | 74.9 | 73.5 | 65.6 | 68.0 |
| $Al_2O_3$ ----------------- | 10.9 | 16.1 | 11.0 | 12.5 | 14.5 | 15.4 |
| $Fe_2O_3$ ----------------- | 1.6 | 3.3 | 3.8 | 3.7 | 3.3 | 2.2 |
| FeO ------------------- | 2.7 | 4.5 | 3.1 | 2.4 | 3.3 | 2.8 |
| MgO ------------------ | 1.3 | 2.3 | 1.7 | 1.5 | 1.7 | 1.3 |
| CaO ------------------- | 2.3 | 3.5 | .18 | .77 | 2.9 | 1.2 |
| $Na_2O$ ---------------- | 2.4 | 2.8 | .13 | 1.2 | 2.7 | 3.5 |
| $K_2O$ ------------------ | 1.5 | 2.6 | 3.4 | 3.1 | 3.4 | 2.7 |
| $H_2O+$ --------------- | .91 | 1.3 | 1.5 | 1.3 | .58 | .7 |
| $H_2O-$ ---------------- | .08 | .32 | .14 | .14 | .11 | .13 |
| $TiO_2$ ----------------- | .58 | 1.4 | 1.0 | 1.1 | 2.6 | 1.2 |
| $P_2O_5$ ----------------- | .08 | .66 | .07 | .09 | .69 | .11 |
| MnO ------------------ | .03 | .08 | .08 | .07 | .11 | .05 |
| $CO_2$ ------------------ | .01 | .02 | .02 | .02 | .02 | .03 |
| F ---------------------- | .10 | .04 | .06 | .07 | .21 | .08 |
| Cl --------------------- | <.01 | .27 | .002 | .002 | .026 | .008 |
| S (total) ------------- | .02 | .02 | .01 | .01 | .01 | .01 |
| Total ---------------- | 100. | 100. | 101. | 101. | 100. | 99. |
| Bulk density --------- | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ----------- | 2.96 | N.d. | N.d. | N.d. | N.d. | N.d. |

Footnote follows at end of table.

**Table 20.** Chemical and spectrographic analyses and modes for biotite-quartz-feldspar gneiss (biotite gneiss), central Front Range, Colorado.--Continued

| Map locality No. ---- | 109 | 21 | 353 | 354 | 277 | 284 |
|---|---|---|---|---|---|---|
| Sample No. ---------- | W257-71 | GH175a-75 | RB3-80 | RB4-80 | IS1-80 | IS8-80 |
| Lab No. -------------- | W178105 | W192422 | W211761 | W211762 | W211774 | W211781 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | |
| B ---------------------- | N | N | 190 | 7 | N | N |
| Ba --------------------- | 135 | 1,400 | 740 | 420 | 1,200 | 820 |
| Be --------------------- | N | 6 | N | 2 | 3 | 2 |
| Ce --------------------- | 64 | 360 | N | N | 150 | N |
| Co --------------------- | 6 | 18 | 18 | 14 | 16 | 14 |
| Cr --------------------- | 56 | 46 | 200 | 120 | 26 | 110 |
| Cu --------------------- | N | 240 | 4 | 7 | 30 | 4 |
| Ga --------------------- | 9 | 44 | 14 | 12 | 22 | 18 |
| Gd --------------------- | 4 | 15 | N | N | N | N |
| La --------------------- | 37 | 150 | 56 | 40 | 97 | 48 |
| Mo --------------------- | N | 3 | N | N | N | N |
| Nb --------------------- | 6 | 40 | 11 | 11 | 17 | 9 |
| Nd --------------------- | 8 | 190 | 48 | N | 53 | 58 |
| Ni --------------------- | 20 | 28 | 49 | 42 | 17 | 24 |
| Pb --------------------- | 11 | 28 | 10 | 17 | 42 | 26 |
| Rb --------------------- | 100 | N | N | N | N | N |
| Sc --------------------- | 5 | 18 | 12 | 13 | 18 | 15 |
| Sn --------------------- | N | N | N | N | 2 | N |
| Sr --------------------- | 123 | 580 | 46 | 160 | 760 | 280 |
| V ---------------------- | 61 | 120 | 87 | 80 | 92 | 69 |
| Y ---------------------- | 13 | 34 | 24 | 17 | 28 | 42 |
| Yb --------------------- | 1 | 5 | 3 | 2 | 4 | 6 |
| Zn --------------------- | 79 | 160 | 79 | 66 | 110 | 67 |
| Zr --------------------- | 114 | 690 | 110 | 150 | 150 | 160 |
| Modes in volume percent | | | | | | |
| K-feldspar ----------- | 2.5 | -- | -- | -- | 19.0 | 1.5 |
| Plagioclase ---------- | 30.6 | 38.4 | .5 | 4.1 | 30.5 | 30.3 |
| Quartz --------------- | 51.4 | 26.1 | 58.4 | 56.3 | 32.6 | 52.4 |
| Biotite --------------- | 12.9 | 29.6 | 19.0 | 17.9 | 15.0 | 11.9 |
| Opaque minerals---- | 1.3 | 3.9 | .7 | 1.8 | 1.8 | .8 |
| Zircon --------------- | Tr | Tr | Tr | Tr | Tr | .3 |
| Muscovite-sericite[1] - | 1.3 | .2 | 21.1 | 19.6 | -- | 2.1 |
| Apatite -------------- | -- | 1.0 | Tr | .3 | .8 | -- |
| Chlorite ------------- | -- | -- | -- | Tr | -- | .7 |
| Allanite ------------- | -- | .1 | -- | -- | .3 | -- |
| Epidote -------------- | -- | .7 | -- | -- | Tr | -- |
| Xenotime-monazite-- | -- | -- | -- | Tr | -- | -- |
| Tourmaline ---------- | -- | -- | .3 | Tr | -- | -- |

[1]Muscovite-sericite is primarily an alteration of plagioclase.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 340, C.L. Parker; 368, E.S. Daniels. Analysts for rapid-rock analyses for samples number 90, Leonard Shapiro; 73, Hezekiah Smith; 29, Kay Coates and Hezekiah Smith; all others by Deborah Kobilis. Analysts for spectrographic analyses for samples of map number 340, J.C. Hamilton; 368, A.L. Sutton, Jr.; 29, Norma Rait; 19, 23, 26, 28, 73, 90, J.L. Harris; all others by Leung Mei. N.d., not determined; N, not detected; --, not found; Tr, trace; <, less than]

| Map locality No. | 368 | 340 | 90 | 73 | 19 | 23 | 26 | 28 | 29 | 322 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | M530b | CC-646 | W66-71 | GH-47-71 | GH153-75 | GH183-75 | GH242-75 | GH294-75 | GH-305-75 | E1-80 |
| Lab No. | D101108 | I4155 | W178101 | W192418 | W192421 | W192423 | W192424 | W192425 | W194506 | W211758 |
| **Chemical analyses in weight percent** | | | | | | | | | | |
| $SiO_2$ | 70.65 | 62.67 | 59.3 | 56.9 | 64.0 | 73.5 | 59.3 | 41.4 | 52.4 | 64.6 |
| $Al_2O_3$ | 12.90 | 19.12 | 19.4 | 23.5 | 19.0 | 14.1 | 23.2 | 31.6 | 25.2 | 19.4 |
| $Fe_2O_3$ | 1.08 | 2.11 | 6.3 | 5.2 | 4.5 | 1.9 | 5.3 | 6.2 | 2.8 | 1.1 |
| FeO | 5.02 | 5.13 | 3.0 | 4.3 | 4.0 | 2.0 | 5.0 | 7.9 | 6.3 | 4.2 |
| MgO | 3.10 | 2.44 | 2.0 | 2.4 | 1.9 | .82 | 2.4 | 3.8 | 2.6 | 1.7 |
| CaO | .00 | .29 | .18 | .17 | .03 | .48 | .12 | .18 | 1.4 | .58 |
| $Na_2O$ | .42 | .72 | .86 | .65 | .03 | 1.6 | .27 | .33 | .65 | .63 |
| $K_2O$ | 3.93 | 4.50 | 4.2 | 4.3 | 2.6 | 3.8 | 2.7 | 4.9 | 4.3 | 4.9 |
| $H_2O+$ | 2.10 | 1.48 | 2.8 | .66 | 2.3 | 1.4 | 1.4 | 1.7 | 1.9 | 1.8 |
| $H_2O-$ | .08 | .17 | .20 | .20 | .32 | .25 | .22 | .26 | .40 | .27 |
| $TiO_2$ | .31 | .95 | 1.0 | 1.2 | 1.0 | .50 | 1.1 | 1.4 | 1.1 | 1.3 |
| $P_2O_5$ | .02 | .05 | .15 | .06 | .05 | .04 | .06 | .15 | .85 | .07 |
| MnO | .05 | .04 | .06 | .04 | .03 | .05 | .10 | .06 | .10 | .09 |
| $CO_2$ | .00 | .02 | .01 | .02 | .02 | .02 | .02 | .02 | .01 | .05 |
| F | .14 | .02 | .06 | .21 | .13 | .04 | .07 | .45 | .16 | .10 |
| Cl | .02 | .11 | <.01 | .01 | .03 | .01 | .02 | .04 | .01 | .024 |
| S (total) | -- | -- | .02 | .01 | .00 | .01 | .01 | .00 | N.d. | .01 |
| Subtotal | 99.82 | 99.82 | 99. | 100. | 100. | 100. | 101. | 101. | 100. | 100. |
| Less O | .06 | .03 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d | N.d. | N.d. |
| Total | 99.76 | 99.79 | 99. | 100. | 100. | 100. | 101. | 101. | 100. | 100. |
| Bulk density | N.d. | N.d. | 2.79 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | 2.78 | 2.84 | 2.80 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | | |
| B | N | N | N | N | N | N | N | 15 | N | N |
| Ba | 500 | 1,000 | 529 | 550 | 190 | 730 | 250 | 260 | 220 | 740 |
| Be | 1 | N | 1 | N | 2 | 5 | 10 | 7 | 3 | 2 |
| Ce | N | N | 111 | 100 | 250 | 110 | 140 | 210 | 75 | 88 |
| Co | 3 | 20 | 18 | 26 | 16 | 9 | 22 | 23 | 12 | 18 |
| Cr | N | 300 | 109 | 170 | 120 | 47 | 140 | 240 | 54 | 94 |
| Cu | 2 | 7 | 3 | 9 | 16 | 14 | 4 | 11 | 34 | 13 |
| Er | N | N | N | N | N | N | N | N | N | N |
| Ga | 30 | 50 | 25 | 49 | 68 | 18 | 47 | 100 | 31 | 24 |
| Gd | N | N | 9 | N | N | N | N | N | N | N |
| In | N | N | N | N | N | N | N | N | N | N |
| La | N | 70 | 56 | 34 | 67 | 58 | 49 | 63 | 30 | 69 |
| Mo | N | 7 | N | 4 | 8 | 3 | 4 | 4 | N | N |
| Nb | N | 45 | 6 | 10 | 57 | 11 | 18 | 33 | 10 | 18 |
| Nd | N | N | 44 | N | N | 55 | N | 50 | N | 46 |
| Ni | N | 150 | 43 | 69 | 38 | 17 | 57 | 64 | 29 | 39 |
| Pb | 10 | 15 | 6 | 29 | 16 | 26 | 14 | 21 | N | 34 |
| Pr | N | N | N | N | N | N | N | N | N | N |
| Rb | -- | -- | 200 | -- | -- | -- | -- | -- | -- | -- |
| Sc | 10 | 30 | 17 | 19 | 19 | 10 | 18 | 20 | 10 | 18 |
| Sn | N | N | 5 | N | 15 | N | N | 27 | 11 | N |
| Sr | 10 | 300 | 93 | 78 | 16 | 180 | 32 | 30 | 31 | 180 |
| V | N | 150 | 89 | 120 | 87 | 49 | 120 | 150 | 70 | 88 |
| Y | 50 | 50 | 43 | 15 | 10 | 30 | 11 | 29 | 35 | 19 |
| Yb | <7 | 7 | 5 | 5 | 1 | 4 | 2 | 6 | 6 | 3 |
| Zn | N | N | 80 | 150 | 280 | 33 | 140 | 250 | 93 | 86 |
| Zr | 150 | 150 | 138 | 69 | 340 | 170 | 280 | 230 | 94 | 85 |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. | 368 | 340 | 90 | 73 | 19 | 23 | 26 | 28 | 29 | 322 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | M530b | CC-646 | W66-71 | GH-47-71 | GH153-75 | GH183-75 | GH242-75 | GH294-75 | GH-305-75 | E1-80 |
| Lab No. | D101108 | I4155 | W178101 | W192418 | W192421 | W192423 | W192424 | W192425 | W194506 | W211758 |
| **Modes in volume percent** | | | | | | | | | | |
| K-feldspar | -- | 14.3 | 3.0 | 16.5 | -- | 7.7 | -- | 13.6 | -- | 7.0 |
| Plagioclase | Tr | 5.4 | 4 | 4.2 | 2.2 | 19.2 | 4.8 | 16.6 | .4 | 37.9 |
| Quartz | 57 | 31.4 | 26 | 20.7 | 43.5 | 51.6 | 43.7 | 29.8 | 13.5 | 24.4 |
| Biotite | 22 | 32.1 | 7 | 23.5 | 27.5 | 13.6 | 25.9 | 25.4 | 47.7 | 23.3 |
| Sillimanite | 2 | 16.3 | 7 | 31.4 | 22.5 | 1.6 | 23.6 | 11.1 | 26.7 | 2.1 |
| Opaque minerals | Tr | .7 | 4 | 3.6 | 2.8 | Tr | 1.7 | 2.8 | 1.4 | Tr |
| Zircon | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] | 11 | Tr | 42 | .1 | 1.5 | 6.1 | .3 | .7 | 10.2 | 5.3 |
| Chlorite | 8 | Tr | 7 | -- | -- | .2 | -- | -- | -- | -- |
| Rutile | -- | -- | Tr | -- | -- | -- | Tr | -- | -- | -- |
| Andalusite | Tr | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite | -- | -- | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr |
| Apatite | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Epidote | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| Map locality No. | 271 | 272 | 273 | 274 | 275 | 276 | 278 | 280 | 282 | 285 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | SP2-80 | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS4-80 | IS6-80 | IS9-80 |
| Lab. No. | W211752 | W211753 | W211754 | W211755 | W211756 | W211757 | W211775 | W211777 | W211779 | W211782 |
| **Chemical analyses in weight percent** | | | | | | | | | | |
| $SiO_2$ | 81.3 | 64.3 | 59.1 | 59.4 | 76.0 | 69.5 | 64.8 | 72.2 | 71.9 | 75.3 |
| $Al_2O_3$ | 8.6 | 18.6 | 19.8 | 22.9 | 10.8 | 16.6 | 18.7 | 13.4 | 15.4 | 13.0 |
| $Fe_2O_3$ | 1.7 | 2.4 | 3.5 | 2.9 | 2.3 | 3.4 | 3.2 | 2.3 | .98 | 1.2 |
| FeO | 2.0 | 3.6 | 4.8 | 5.3 | 3.0 | 3.0 | 4.8 | 3.7 | 2.4 | 1.6 |
| MgO | .68 | 1.7 | 2.0 | 1.7 | 1.2 | 1.6 | 1.7 | 1.7 | 1.1 | .88 |
| CaO | 1.4 | .63 | .96 | .57 | 1.2 | .91 | .55 | .63 | 1.7 | 1.1 |
| $Na_2O$ | 1.4 | 1.4 | 1.8 | .8 | 2.3 | 2.0 | 1.3 | .52 | 3.4 | 2.3 |
| $K_2O$ | 2.4 | 4.4 | 5.4 | 4.0 | 2.5 | 2.7 | 3.3 | 2.6 | 1.9 | 3.0 |
| $H_2O+$ | .61 | 1.8 | 1.6 | 1.1 | .65 | .13 | 1.1 | 2.1 | .86 | 1.1 |
| $H_2O-$ | .10 | .10 | .11 | .03 | .07 | .14 | .08 | .37 | .11 | .27 |
| $TiO_2$ | .78 | 1.5 | 1.7 | 1.7 | .78 | 1.2 | 1.7 | 1.7 | .92 | .48 |
| $P_2O_5$ | .04 | .07 | .13 | .13 | .09 | .06 | .06 | .02 | .07 | .06 |
| MnO | .06 | .10 | .12 | .11 | .09 | .11 | .11 | .08 | .06 | .03 |
| $CO_2$ | .02 | .04 | .03 | .03 | .12 | .09 | .01 | .02 | .04 | .03 |
| F | .04 | .16 | .14 | .10 | .04 | .09 | .13 | .09 | .06 | .04 |
| Cl | .01 | .018 | .024 | .004 | .001 | .017 | .028 | .007 | .008 | .007 |
| S (total) | .01 | .01 | .02 | .01 | .02 | .01 | .01 | .01 | .01 | .01 |
| Subtotal | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 100. |
| Less O | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 100. |
| Bulk density | N.d | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No.---- | 271 | 272 | 273 | 274 | 275 | 276 | 278 | 280 | 282 | 285 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | SP2-80 | SP3-80 | SP4-80 | SP5-80 | SP6-80 | SP7-80 | IS2-80 | IS4-80 | IS6-80 | IS9-80 |
| Lab. No. ------------ | W211752 | W211753 | W211754 | W211755 | W211756 | W211757 | W211775 | W211777 | W211779 | W211782 |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | | |
| B -------------------- | N | N | N | N | N | N | N | N | N | N |
| Ba-------------------- | 430 | 500 | 1,100 | 480 | 270 | 450 | 390 | 280 | 380 | 940 |
| Be-------------------- | 1 | 2 | 2 | 2 | N | 2 | 2 | 2 | 2 | 1 |
| Ce-------------------- | N | N | N | N | N | N | N | N | N | N |
| Co-------------------- | 8 | 12 | 22 | 21 | 12 | 16 | 18 | 21 | 9 | 3 |
| Cr-------------------- | 53 | 55 | 120 | 120 | 110 | 95 | 110 | 110 | 49 | 11 |
| Cu -------------------- | 4 | 4 | 5 | 22 | 3 | 6 | 31 | 10 | 6 | 6 |
| Er -------------------- | N | N | N | N | N | N | N | N | N | N |
| Ga -------------------- | 8 | 21 | 25 | 26 | 10 | 25 | 27 | 18 | 15 | 13 |
| Gd -------------------- | N | N | N | N | N | N | N | N | N | N |
| In -------------------- | N | N | N | N | N | N | N | N | N | N |
| La-------------------- | 32 | 43 | 38 | 49 | 41 | 64 | 42 | 60 | 40 | 35 |
| Mo -------------------- | N | N | N | N | N | N | N | N | N | 1 |
| Nb -------------------- | 9 | 15 | 11 | 12 | 10 | 14 | 15 | 18 | 16 | 7 |
| Nd -------------------- | N | 43 | 40 | 43 | 34 | 66 | 32 | 61 | N | 49 |
| Ni -------------------- | 15 | 20 | 44 | 48 | 24 | 22 | 31 | 40 | 15 | 7 |
| Pb-------------------- | 26 | 41 | 48 | 28 | 26 | 26 | 20 | 12 | 30 | 17 |
| Pr -------------------- | N | N | N | N | N | N | N | N | N | N |
| Rb-------------------- | N | N | N | N | N | N | N | N | N | N |
| Sc -------------------- | 8 | 14 | 23 | 22 | 11 | 16 | 16 | 20 | 10 | 12 |
| Sn-------------------- | 5 | 4 | 2 | N | N | 3 | 4 | 2 | 4 | 5 |
| Sr -------------------- | 160 | 190 | 290 | 99 | 240 | 210 | 140 | 93 | 340 | 280 |
| V--------------------- | 48 | 66 | 110 | 120 | 72 | 78 | 75 | 95 | 48 | 18 |
| Y--------------------- | 22 | 62 | 34 | 25 | 23 | 43 | 17 | 18 | 14 | 40 |
| Yb -------------------- | 3 | 5 | 5 | 4 | 2 | 5 | 2 | 3 | 2 | 6 |
| Zn-------------------- | 43 | 100 | 110 | 120 | 74 | 94 | 120 | 130 | 68 | 24 |
| Zr -------------------- | 260 | 170 | 100 | 110 | 290 | 170 | 190 | 200 | 130 | 260 |
| **Modes in volume percent** | | | | | | | | | | |
| K-feldspar ---------- | 8.5 | 2 | 14.6 | 16.3 | 12.0 | 4.9 | 1.8 | 7.2 | .7 | 5.0 |
| Plagioclase --------- | 15.4 | 8 | 14.8 | 6.8 | 17.4 | 13.8 | 16.4 | 8.7 | 38.5 | 32.4 |
| Quartz--------------- | 58.6 | 28 | 19.5 | 24.5 | 51.6 | 40.4 | 36.4 | 48.9 | 46.4 | 36.9 |
| Biotite--------------- | 14.1 | 22 | 25.0 | 27.7 | 16.8 | 14.4 | 24.3 | 20.4 | 10.6 | 11.9 |
| Sillimanite---------- | Tr | 14 | 9.4 | 21.0 | Tr | 14.5 | 16.5 | 11.7 | 1.7 | 2.9 |
| Opaque minerals --- | .4 | Tr | 1.8 | 1.3 | 1.1 | 1.2 | 1.4 | .8 | .4 | 2.0 |
| Zircon--------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1]- | 3.0 | 26 | 14.9 | 2.4 | 1.1 | 10.8 | 3.2 | 2.3 | 1.5 | 7.4 |
| Chlorite ------------- | -- | Tr | -- | -- | -- | Tr | -- | -- | .2 | 1.0 |
| Rutile---------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | -- | Tr | Tr | -- | Tr | Tr | Tr | Tr | -- |
| Apatite- ------------- | -- | -- | Tr | Tr | -- | -- | -- | -- | Tr | -- |
| Epidote--------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .5 |
| Tourmaline--------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No | 317 | 318 | 319 | 351 | 352 | 355 | 356 | 357 | 358 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 | RB7-80 | RB8-80 |
| Lab. No. | W211769 | W211770 | W211771 | W211759 | W211760 | W211763 | W211764 | W211765 | W211766 |
| **Chemical analyses in weight percent** | | | | | | | | | |
| $SiO_2$ | 68.8 | 69.6 | 74.3 | 70.3 | 71.4 | 68.6 | 65.2 | 46.5 | 76.9 |
| $Al_2O_3$ | 14.5 | 15.2 | 13.4 | 13.7 | 14.2 | 15.2 | 15.7 | 28.5 | 12.2 |
| $Fe_2O_3$ | 2.4 | 1.6 | 1.3 | 3.1 | 2.9 | 2.2 | 3.8 | 3.2 | 1.9 |
| FeO | 3.6 | 3.2 | 3.4 | 4.5 | 3.6 | 5.2 | 4.1 | 7.1 | 3.0 |
| MgO | 1.9 | 1.4 | 1.0 | 2.1 | 1.6 | 2.4 | 2.1 | 3.3 | 1.1 |
| CaO | 1.0 | .92 | .69 | .65 | .94 | .24 | .29 | .50 | .71 |
| $Na_2O$ | 2.0 | 2.3 | 1.0 | 1.3 | 1.7 | .14 | .55 | .99 | 1.1 |
| $K_2O$ | 4.3 | 3.7 | 2.9 | 2.9 | 2.4 | 3.4 | 5.2 | 4.3 | 2.2 |
| $H_2O+$ | 1.2 | 1.2 | 1.7 | 1.2 | 1.1 | 2.1 | 2.2 | 3.2 | .89 |
| $H_2O-$ | .09 | .39 | .38 | .10 | .11 | .36 | .30 | .57 | .10 |
| $TiO_2$ | 1.0 | 1.0 | 1.3 | 1.3 | 1.2 | 1.4 | 1.4 | 3.0 | .98 |
| $P_2O_5$ | .07 | .06 | .10 | .14 | .12 | .11 | .12 | .13 | .12 |
| MnO | .11 | .08 | .05 | .09 | .11 | .08 | .08 | .09 | .09 |
| $CO_2$ | .02 | .02 | .04 | .03 | .05 | .03 | .06 | .04 | .05 |
| F | .12 | .07 | .06 | .07 | .05 | .09 | .09 | .13 | .04 |
| Cl | .020 | .019 | .008 | .006 | .004 | .015 | .005 | .013 | .007 |
| S (total) | .01 | .01 | .01 | .01 | .01 | .01 | .01 | .01 | <.01 |
| Subtotal | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. |
| Less O | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. | 101. |
| Bulk density | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | |
| B | N | N | 16 | 7 | 70 | 21 | 30 | 13 | 23 |
| Ba | 810 | 1,100 | 440 | 300 | 360 | 360 | N | 380 | 290 |
| Be | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 |
| Ce | N | N | N | N | N | N | N | N | N |
| Co | 14 | 11 | 14 | 18 | 20 | 21 | 20 | 24 | 11 |
| Cr | 39 | 61 | 75 | 140 | 150 | 140 | N | 230 | 130 |
| Cu | 17 | 3 | 8 | 32 | 10 | 13 | 3 | 4 | 4 |
| Er | N | N | N | N | N | N | N | 12 | N |
| Ga | 19 | 18 | 14 | 13 | 16 | 17 | 17 | 40 | 10 |
| In | N | N | N | N | N | N | 7 | N | N |
| La | 41 | 45 | 42 | 49 | 36 | 38 | N | 45 | 30 |
| Mo | N | N | N | N | N | N | N | N | N |
| Nb | 17 | 17 | 15 | 15 | 16 | 18 | 8 | 11 | 9 |
| Nd | 48 | 55 | 41 | 38 | N | N | N | 38 | 33 |
| Ni | 15 | 18 | 28 | 51 | 60 | 61 | 49 | 73 | 30 |
| Pb | 43 | 49 | 22 | 24 | 23 | 10 | 13 | 20 | 18 |
| Sc | 15 | 12 | 13 | 14 | 13 | 17 | N | 16 | 10 |
| Sn | 5 | N | N | N | N | N | N | 5 | 5 |
| Sr | 270 | 310 | 200 | 210 | 240 | 20 | 73 | 100 | 150 |
| V | 50 | 57 | 72 | 81 | 85 | 90 | 79 | 98 | 58 |
| Y | 44 | 12 | 24 | 19 | 22 | 25 | 21 | 22 | 34 |
| Yb | 7 | 1 | 2 | 2 | 2 | 3 | 2 | 5 | 5 |
| Zn | 95 | 56 | 73 | 130 | 130 | 140 | N | 160 | 64 |
| Zr | 180 | 120 | 180 | 190 | 130 | 160 | 91 | 120 | 150 |

Footnote follows at end of table.

**Table 21.** Chemical and spectrographic analyses and modes for sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No.---- | 317 | 318 | 319 | 351 | 352 | 355 | 356 | 357 | 358 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No.---------- | IH3-80 | IH4-80 | IH5-80 | RB1-80 | RB2-80 | RB5-80 | RB6-80 | RB7-80 | RB8-80 |
| Lab. No. ------------ | W211769 | W211770 | W211771 | W211759 | W211760 | W211763 | W211764 | W211765 | W211766 |
| **Modes in volume percent** | | | | | | | | | |
| K-feldspar ----------- | 7.1 | 5.8 | 2.2 | -- | -- | -- | -- | -- | .7 |
| Plagioclase ---------- | 18.3 | 22.2 | 7.8 | 2.2 | 8.1 | .3 | 1.5 | 2 | 9.8 |
| Quartz---------------- | 48.8 | 61.2 | 62.9 | 52.1 | 49.0 | 45.5 | 43.7 | 1 | 55.6 |
| Biotite---------------- | 19.9 | -- | 16.3 | 25.4 | 25.7 | 31.0 | 18.5 | 64 | 15.9 |
| Sillimanite----------- | Tr | 3.9 | 5.6 | 11.7 | 7.0 | 15.9 | Tr | 31 | 5.3 |
| Opaque minerals --- | .4 | Tr | Tr | 1.2 | 1.5 | .1 | 1.0 | 1 | .3 |
| Zircon---------------- | Tr | Tr | Tr | Tr | .1 | Tr | .1 | Tr | Tr |
| Muscovite-sericite[1]- | 5.5 | 6.0 | 5.2 | 7.4 | 4.0 | 7.2 | 35.0 | 1 | 12.4 |
| Chlorite -------------- | -- | .9 | -- | -- | -- | -- | .1 | -- | -- |
| Rutile----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Andalusite----------- | -- | -- | -- | -- | 4.5 | -- | -- | -- | -- |
| Xenotime-monazite- | Tr | Tr | Tr | -- | -- | -- | Tr | -- | -- |
| Apatite--------------- | Tr | -- | Tr | Tr | Tr | Tr | .1 | -- | Tr |
| Epidote--------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tourmaline---------- | -- | -- | -- | -- | .1 | Tr | Tr | -- | -- |

[1]Muscovite-sericite mostly retrograde after plagioclase and sillimanite.

**Table 22.** Chemical and spectrographic analyses and modes for garnet-biotite gneiss and garnet-hornblende-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 247, P.D.L. Elmore, S.D. Botts, Gillison Chloe, J.L. Glenn, Hezekiah Smith, Lowell Artis, James Kelsey; 17, H.F. Phillip, P.D.L. Elmore, P.W. Scott, K.E. White; all other analyses by Leung Mei. Analysts for spectrographic analyses with map locality number 17, R.G. Havens; all others by J.L. Harris. N.d., not determined; N, not detected; N.A., not available; --, not found; <, less than; Tr, trace]

| | Garnet-biotite gneiss | | | | | Garnet-hornblende-biotite gneiss | |
|---|---|---|---|---|---|---|---|
| Map locality No. | 247 | 303 | 305 | 315 | 281 | 17 | 320 |
| Sample No. | N636-64 | ML8a-1 | ML-10 | IH1-80 | IS5-80 | A1-24a-55 | IH6-80 |
| Lab No. | W173200 | W197383 | W197384 | W211767 | W211778 | 140570 | W211772 |
| Chemical analyses in weight percent | | | | | | | |
| $SiO_2$ | 68.4 | 60.8 | 60.7 | 53.9 | 65.6 | 58.1 | 74.8 |
| $Al_2O_3$ | 12.8 | 15.6 | 15.6 | 13.4 | 18.1 | 14.3 | 10.8 |
| $Fe_2O_3$ | 2.0 | 1.8 | 2.0 | 10.9 | 1.4 | 4.5 | 2.6 |
| FeO | 4.7 | 8.5 | 8.4 | 9.8 | 2.5 | 5.4 | 3.2 |
| MgO | 2.4 | 2.4 | 2.3 | 2.3 | 1.5 | 3.0 | .74 |
| CaO | .83 | 3.0 | 2.4 | 1.7 | 11.8 | 5.2 | .80 |
| $Na_2O$ | 1.8 | 2.0 | 2.0 | 2.2 | 3.1 | 1.2 | 1.4 |
| $K_2O$ | 5.1 | 3.0 | 3.0 | 2.6 | 1.9 | 2.6 | 5.0 |
| $H_2O+$ | .97 | 1.9 | 1.4 | .91 | 1.2 | 1.8 | .62 |
| $H_2O-$ | .13 | .13 | .12 | .13 | .12 | N.d. | .07 |
| $TiO_2$ | .60 | .67 | .67 | 1.1 | .59 | 1.4 | 1.0 |
| $P_2O_5$ | .09 | .15 | .16 | .15 | .10 | .62 | .12 |
| MnO | .07 | .13 | .13 | 1.5 | .14 | .14 | .11 |
| $CO_2$ | <.05 | .34 | .41 | .07 | .31 | .70 | .12 |
| F | .10 | .10 | .10 | .10 | .07 | N.d. | .03 |
| Cl | N.d. | .02 | .02 | .03 | .065 | N.d. | .004 |
| S (total) | N.d. | .02 | .03 | N.d. | .01 | .19 | .01 |
| Total | 100. | 101. | 99. | 101. | 101. | 99. | 101. |
| Bulk density | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d |
| Powder density sink/float | 3.12 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | |
| Ba | 1,000 | 310 | 300 | N | 300 | 300 | 1,500 |
| Be | N | 2 | 2 | 1 | 3 | 1 | 2 |
| Ce | 300 | 97 | 59 | N | N | 150 | 78 |
| Co | 10 | 12 | 13 | 21 | 7 | 70 | 9 |
| Cr | 150 | 67 | 75 | 65 | 22 | 30 | 2 |
| Cu | 7 | 11 | 12 | 440 | 7 | 70 | 10 |
| Eu | N | N | N | N | N | N | 3 |
| Ga | 20 | 22 | 24 | 24 | 23 | 15 | 42 |
| Ge | N | N | N | 2 | N | N | 2 |
| La | 100 | 36 | 22 | 35 | 44 | 150 | 47 |
| Mo | 3 | 3 | 2 | N | N | 15 | N |
| Nb | 10 | 10 | 9 | 7 | 10 | N | 19 |
| Nd | N | N | N | N | N | 150 | 35 |
| Ni | 30 | 20 | 19 | 28 | 10 | 70 | 4 |
| Pb | 30 | 20 | 19 | 31 | 22 | 15 | 49 |
| Pt | N | N | N | 5 | N | N | N |
| Sc | 20 | 16 | 14 | 8 | 15 | 30 | 17 |
| Sn | N | N | N | N | 2 | N | 7 |
| Sr | 150 | 170 | 140 | 160 | 290 | 700 | 160 |
| V | 50 | 75 | 74 | 59 | 35 | 300 | 9 |
| Y | 70 | 22 | 19 | 11 | 47 | 70 | 38 |
| Yb | 7 | 4 | 4 | 1 | 12 | <10 | 9 |
| Zn | N | 230 | 230 | N | 77 | Tr | 140 |
| Zr | 200 | 110 | 65 | 120 | 250 | 300 | 220 |

Footnotes follow at end of table.

**Table 22.** Chemical and spectrographic analyses and modes for garnet-biotite gneiss and garnet-hornblende-biotite gneiss, central Front Range, Colorado.--Continued

| | Garnet-biotite gneiss | | | | | Garnet-hornblende-biotite gneiss | |
|---|---|---|---|---|---|---|---|
| Map locality No. ---- | 247 | 303 | 305 | 315 | 281 | 17 | 320 |
| Sample No. ---------- | N636-64 | ML8a-1 | ML-10 | IH1-80 | IS5-80 | A1-24a-55 | IH6-80 |
| Lab No. -------------- | W173200 | W197383 | W197384 | W211767 | W211778 | 140570 | W211772 |
| | Modes in volume percent | | | | | | |
| K-feldspar ----------- | 24.9 | 1.9 | 1.1 | 9.4 | .5 | N.A. | 29.5 |
| Plagioclase----------- | 20.9 | 27.2 | 34.5 | 21.3 | 38.8 | N.A. | 13.1 |
| Quartz---------------- | 37.7 | 28.1 | 34.5 | 21.7 | 25.9 | N.A. | 40.0 |
| Biotite---------------- | 13.2 | 21.7 | 22.4 | 30.3 | 17.9 | N.A. | 13.0 |
| Garnet---------------- | 1.8 | 17.7 | 6.1 | 2.7 | Tr | N.A. | Tr |
| Opaque minerals---- | .7 | .3 | -- | 2.7 | 1.3 | N.A. | 1.0 |
| Hornblende ---------- | -- | -- | -- | -- | -- | N.A. | .7 |
| Zircon ---------------- | Tr | -- | Tr | Tr | Tr | N.A. | -- |
| Allanite -------------- | -- | -- | -- | -- | -- | N.A. | Tr |
| Rutile----------------- | Tr | .4 | -- | -- | -- | N.A. | -- |
| Muscovite-sericite[1] - | .5 | .4 | .5 | 11.9 | [2]15.0 | N.A. | 2.0 |
| Chlorite -------------- | .3 | 2.0 | .5 | -- | N.d. | N.A. | -- |
| Apatite --------------- | -- | .2 | Tr | Tr | .2 | N.A. | Tr |
| Xenotime-monazite- | -- | .1 | -- | Tr | -- | N.A. | -- |
| Calcite---------------- | -- | -- | .4 | Tr | .4 | N.A. | -- |
| Sphene --------------- | -- | -- | -- | -- | -- | N.A. | .4 |
| Epidote--------------- | -- | -- | -- | -- | -- | N.A. | .3 |

[1]Muscovite-sericite is mostly an alteration of plagioclase.

[2]Included in biotite.

**Table 23.** Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 257, 368, and 389, E.S. Daniels; 349 by C.L. Parker. Analysts for rapid-rock analyses for samples with map locality number 255 by P.L.D. Elmore, Lowell Artis, J.L. Glenn, Gillison Chloe, Hezekiah Smith, James Kelsey, and S.D. Botts; 88, 118, 149, and 152 by Leonard Shapiro; 18, by Kay Coates and Hezekiah Smith; 325, Z.A. Hamlin; 283, 316, 321, by Deborah Kobilis. Analysts for spectrographic analyses of samples from map locality numbers 88, 118, 149, 152, 325, J.L. Harris; 257, 389, Joseph Haffty; 368, A.L. Sutton, Jr.; 18, Norma Rait; 349, J.C. Hamilton; 283, 316, 321, Leung Mei. N.d., not determined; N, not detected; --, not found; <, less than; >, greater than; Tr, trace]

| Map locality No. | 389 | 257 | 368 | 255 | 118 | 149 | 152 |
|---|---|---|---|---|---|---|---|
| Sample No. | CC-871a | N223a | M530a | N-167 | WC31-70 | W295-70 | W321a-70 |
| Lab No. | D100276 | D100278 | D101107 | W173199 | W178097 | W178099 | W178100 |
| Chemical analyses in weight percent | | | | | | | |
| $SiO_2$ | 57.93 | 53.88 | 71.22 | 49.5 | 54.4 | 53.5 | 78.6 |
| $Al_2O_3$ | 21.82 | 23.61 | 12.34 | 19.4 | 22.2 | 25.6 | 11.0 |
| $Fe_2O_3$ | 1.08 | 1.24 | 1.04 | 5.9 | 1.6 | 1.9 | 1.4 |
| FeO | 7.02 | 6.71 | 5.87 | 6.2 | 7.7 | 6.6 | 2.6 |
| MgO | 2.91 | 2.75 | 2.87 | 3.3 | 2.4 | 2.3 | 1.5 |
| CaO | .46 | .39 | .00 | 4.5 | .40 | .33 | .35 |
| $Na_2O$ | .94 | 1.18 | .35 | 4.1 | .86 | .69 | .38 |
| $K_2O$ | 5.17 | 7.39 | 3.06 | 2.2 | 5.1 | 5.3 | 2.1 |
| $H_2O+$ | 1.21 | 1.28 | 2.34 | 1.6 | 2.6 | 3.0 | 1.2 |
| $H_2O-$ | .10 | .09 | .14 | .16 | .15 | .15 | .13 |
| $TiO_2$ | 1.09 | .90 | .30 | 1.7 | 1.2 | 1.0 | .69 |
| $P_2O_5$ | .07 | .08 | .02 | .42 | .11 | .11 | .05 |
| MnO | .05 | .12 | .12 | .07 | .15 | .08 | .02 |
| $CO_2$ | .01 | .04 | .00 | .15 | .01 | .01 | .03 |
| F | .14 | .15 | .13 | .12 | .23 | .10 | .05 |
| Cl | .02 | .05 | .02 | N.d. | .09 | .03 | .03 |
| S (total) | N.d. | N.d. | N.d. | N.d. | .04 | .00 | .01 |
| Subtotal | 100.02 | 99.86 | 99.82 | 99. | 99. | 100. | 100. |
| Less 0 | .06 | .07 | .05 | N.d. | N.d. | N.d. | N.d. |
| Total | 99.96 | 99.79 | 99.77 | 99. | 99. | 100. | 100. |
| Bulk density | N.d. | N.d. | N.d. | 2.86 | 2.81 | 2.80 | 2.52 |
| Powder density sink/float | N.d. | N.d. | 2.79 | 3.12 | 2.92 | 2.88 | 2.72 |
| Spectrographic analyses in parts per million | | | | | | | |
| B | N | N | N | N | N | N | N |
| Ba | 700 | 1,500 | 300 | 300 | 467 | 709 | 254 |
| Be | N | N | 1 | 1 | N | N | N |
| Ce | 300 | 300 | N | 300 | 97 | 135 | 73 |
| Co | 20 | 20 | 3 | 50 | 17 | 16 | 7 |
| Cr | 150 | 150 | N | 500 | 144 | 117 | 50 |
| Cu | 20 | 10 | 30 | 50 | 15 | 11 | N |
| Ga | 30 | 30 | 50 | 30 | 30 | 23 | 9 |
| Gd | -- | -- | -- | N | 7 | 7 | 8 |
| La | 50 | 70 | N | 100 | 44 | 71 | 42 |
| Mo | N | N | 15 | 5 | 2 | 2 | N |
| Nb | N | N | N | 10 | 10 | 8 | 7 |
| Nd | 150 | 200 | -- | N | 27 | 56 | 26 |
| Ni | 100 | 100 | N | 70 | 72 | 53 | 17 |
| Pb | 15 | 30 | 10 | 10 | 6 | 9 | 3 |
| Pr | -- | -- | -- | -- | 8 | 10 | 6 |
| Rb | -- | -- | -- | -- | 200 | 200 | 100 |
| Sc | 30 | 30 | 7 | 20 | 31 | 20 | 5 |
| Sn | N | N | N | N | 6 | 6 | N |
| Sr | 200 | 300 | 7 | 1,000 | 124 | 110 | 41 |
| V | 150 | 150 | N | 300 | 143 | 113 | 54 |
| Y | 30 | 30 | 30 | 70 | 43 | 32 | 14 |
| Yb | 3 | 3 | <5 | 7 | 5 | 4 | 1 |
| Zn | N | N | N | N | 81 | 115 | 43 |
| Zr | 150 | 100 | 150 | 100 | 109 | 109 | 295 |

Footnote follows at end of table.

**Table 23**. Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. ---- | 389 | 257 | 368 | 255 | 118 | 149 | 152 |
|---|---|---|---|---|---|---|---|
| Sample No. ---------- | CC-871a | N223a | M530a | N-167 | WC31-70 | W295-70 | W321a-70 |
| Lab No. -------------- | D100276 | D100278 | D101107 | W173199 | W178097 | W178099 | W178100 |
| | | | | Modes in volume percent | | | |
| K-feldspar ----------- | 15.6 | 24.6 | -- | 10.3 | .2 | 1.0 | 4.3 |
| Plagioclase----------- | 7.4 | 10.5 | .1 | 25.0 | 6.5 | 6 | 2.6 |
| Quartz---------------- | 31.2 | 12.9 | 51.8 | 42.8 | 41.0 | 19 | 70.8 |
| Biotite ---------------- | 29.1 | 28.9 | 15.5 | 14.4 | 26.1 | 15 | 12.7 |
| Garnet---------------- | 4.8 | 8.7 | Tr | 2.2 | .7 | 4 | Tr |
| Sillimanite----------- | 10.7 | 7.2 | 3.5 | 1.9 | 8.9 | 7 | 4.3 |
| Opaque minerals---- | .4 | Tr | .1 | 1.4 | 1.0 | 4 | .2 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] - | .8 | 6.4 | 17.1 | 1.7 | 15.0 | 43 | 5.1 |
| Spinel ---------------- | -- | -- | -- | -- | -- | Tr | -- |
| Andalusite ----------- | -- | -- | -- | -- | -- | Tr | Tr |
| Rutile----------------- | -- | Tr | -- | -- | -- | -- | -- |
| Chlorite -------------- | -- | .8 | 11.9 | -- | .6 | .1 | -- |
| Apatite --------------- | Tr | -- | -- | .3 | -- | -- | -- |
| Monazite-xenotime- | -- | -- | -- | -- | -- | -- | -- |

| Map locality No. ---- | 88 | 18 | 325 | 349 | 283 | 316 | 321 |
|---|---|---|---|---|---|---|---|
| Sample No. --------- | W41-71 | GH91-75 | EP2a | EWT90b | IS7-80 | IH2-80 | IH7-80 |
| Lab No. ------------- | W178098 | W194505 | W197378 | I4158 | W211780 | W211768 | W211773 |
| | | | | Chemical analyses in weight percent | | | |
| $SiO_2$ ----------------- | 68.5 | 55.0 | 47.6 | 63.23 | 67.5 | 69.3 | 70.8 |
| $Al_2O_3$---------------- | 15.1 | 25.0 | 15.3 | 17.39 | 17.4 | 15.1 | 14.1 |
| $Fe_2O_3$---------------- | 1.8 | .92 | 5.7 | 3.03 | 1.1 | 4.0 | 2.1 |
| FeO ------------------ | 3.3 | 6.7 | 7.0 | 5.95 | 4.4 | 2.5 | 3.5 |
| MgO ----------------- | 2.8 | 2.5 | 3.1 | 2.67 | 1.5 | 1.2 | 1.5 |
| CaO------------------ | .42 | 1.0 | 6.8 | 6.36 | 1.0 | 1.0 | 1.8 |
| $Na_2O$ ---------------- | 1.1 | 1.8 | 5.6 | .62 | 1.5 | 2.3 | 3.3 |
| $K_2O$------------------ | 3.6 | 3.7 | 1.3 | 3.69 | 2.6 | 3.4 | 2.0 |
| $H_2O+$ --------------- | 3.1 | 1.9 | 4.3 | 1.30 | 1.5 | 1.2 | .98 |
| $H_2O-$ ---------------- | .12 | .32 | .61 | .20 | .17 | .08 | .19 |
| $TiO_2$ ----------------- | .47 | 1.0 | 2.2 | 1.08 | 1.5 | 1.0 | .9 |
| $P_2O_5$ ----------------- | .10 | .07 | .9 | .06 | .08 | .07 | .05 |
| MnO ----------------- | .05 | .06 | .23 | .09 | .26 | .20 | .11 |
| $CO_2$------------------ | .00 | .01 | .00 | .01 | .04 | .05 | .05 |
| F---------------------- | .17 | .07 | .11 | .01 | .08 | .09 | .07 |
| Cl -------------------- | >.01 | .02 | .01 | .11 | .020 | .013 | .013 |
| S (total) ------------- | .00 | N.d. | .01 | .00 | .01 | .01 | .02 |
| Subtotal------------ | 100. | 100. | 101. | 99.80 | 101. | 101. | 101. |
| Less 0 -------------- | N.d. | N.d. | N.d. | .03 | N.d. | N.d. | N.d. |
| Total --------------- | 100. | 100. | 101. | 99.77 | 101. | 101. | 101. |
| Bulk density -------- | 2.67 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ---------- | 2.72 | N.d. | N.d. | 2.88 | N.d. | N.d. | N.d. |

[1] Footnote follows at end of table.

**Table 23.** Chemical and spectrographic analyses and modes for garnet-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map locality No. | 88 | 18 | 325 | 349 | 283 | 316 | 321 |
|---|---|---|---|---|---|---|---|
| Sample No. | W41-71 | GH91-75 | EP2a | EWT90b | IS7-80 | IH2-80 | IH7-80 |
| Lab No. | W178098 | W194505 | W197378 | I4158 | W211780 | W211768 | W211773 |
| Spectrographic analyses in parts per million | | | | | | | |
| B | N | N | 40 | N | N | N | N |
| Ba | 287 | 550 | 320 | 1,000 | 460 | 840 | 250 |
| Be | 2 | 3 | 2 | N | 2 | 2 | 3 |
| Ce | 111 | 97 | 80 | N | N | N | 100 |
| Co | 4 | 15 | 23 | 30 | 22 | 13 | 11 |
| Cr | 13 | 100 | 6 | 200 | 70 | 63 | N |
| Cu | N | 17 | 27 | 15 | 50 | 5 | 100 |
| Ga | 14 | 40 | 30 | 50 | 18 | 16 | 16 |
| Gd | 7 | N | N | -- | N | N | N |
| La | 67 | 35 | 32 | 70 | 60 | 34 | 71 |
| Mo | N | N | 2 | 7 | N | N | N |
| Nb | 10 | 8 | 12 | 15 | 18 | 15 | 14 |
| Nd | 43 | N | N | N | 51 | 34 | N |
| Ni | 8 | 36 | 11 | 100 | 28 | 14 | 16 |
| Pb | 4 | 26 | 23 | 10 | 28 | 25 | 29 |
| Pr | 9 | N | N | N | N | N | N |
| Rb | 200 | -- | N | -- | N | N | N |
| Sc | 4 | 15 | 9 | 50 | 19 | 11 | N |
| Sn | 5 | N | N | N | N | N | 3 |
| Sr | 34 | 180 | 420 | 300 | 220 | 260 | 300 |
| V | 35 | 96 | 94 | 200 | 79 | 49 | 59 |
| Y | 39 | 96 | 22 | 50 | 28 | 15 | 43 |
| Yb | 3 | 10 | 5 | 7 | 3 | 4 | 4 |
| Zn | 37 | 120 | 140 | 150 | 93 | 79 | 130 |
| Zr | 163 | 66 | 150 | N | 200 | 130 | 160 |
| Modes in volume percent | | | | | | | |
| K-feldspar | 5.0 | 2.2 | 13.8 | 7.0 | .8 | 1.0 | -- |
| Plagioclase | 4 | 25.0 | 5.2 | 7.1 | 13.9 | 21.4 | 4.4 |
| Quartz | 43 | 25.0 | 59.2 | 41.2 | 37.8 | 41.0 | 66.8 |
| Biotite | 10 | 34.8 | 15.4 | 32.0 | 24.7 | 12.7 | 18.2 |
| Garnet | Tr | Tr | Tr | .5 | 1.1 | Tr | 1.3 |
| Sillimanite | Tr | 10.4 | 4.8 | 10.3 | 13.3 | 1.0 | 8.8 |
| Opaque minerals | Tr | .2 | Tr | 1.7 | .2 | 2.2 | Tr |
| Zircon | -- | Tr | Tr | Tr | Tr | Tr | Tr |
| Muscovite-sericite[1] | 34 | 2.1 | 1.5 | .2 | 7.4 | 20.7 | .5 |
| Spinel | -- | -- | -- | -- | -- | -- | -- |
| Andalusite | Tr | -- | -- | -- | -- | -- | -- |
| Rutile | Tr | -- | Tr | -- | -- | -- | -- |
| Chlorite | 4 | .3 | .1 | -- | .6 | -- | -- |
| Apatite | -- | -- | -- | Tr | .2 | -- | Tr |
| Monazite-xenotime | -- | -- | -- | -- | -- | Tr | -- |

[1]Muscovite-sericite replaces plagioclase.

**Table 24.** Chemical and spectrographic analyses and modes for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 121, 123, 156, Leonard Shapiro; 192, P.D.L. Elmore, Hezekiah Smith, Lowell Artis, Gillison Chloe, S.D. Botts, J.L. Glenn; 58, Hezekiah Smith; 31 and 63, Kay Coates, and Hezekiah Smith; 301 and 309, Z.A. Hamlin. Analysts for spectrographic analyses for samples with locality numbers 121, 123, 156, 192, 301, 309, J.L. Harris; 31 and 63, Norma Rait. N.d., not determined; N, not detected; --, not found; <, less than; Tr, trace]

| Map Locality No. --- | 121 | 123 | 156 | 192 | 63 | 58 | 31 | 301 | 309 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W12b-70 | W64-70 | W330a-70 | N146-65 | GH3a-72 | GH190-73 | GH331-75 | ML-6 | ML-15 |
| Lab No. ------------- | W178089 | W178090 | W178091 | W168101 | W194509 | W184717 | W194507 | W197380 | W197386 |
| Chemical analyses in weight percent | | | | | | | | | |
| $SiO_2$ ----------------- | 50.5 | 71.3 | 64.8 | 56.5 | 56.1 | 47.6 | 73.0 | 59.7 | 66.7 |
| $Al_2O_3$ ----------------- | 21.3 | 12.8 | 17.3 | 22.5 | 23.8 | 32.0 | 12.6 | 20.5 | 17.2 |
| $Fe_2O_3$ ----------------- | 2.9 | 2.4 | 5.0 | .72 | 5.6 | 1.0 | 4.9 | 5.3 | 2.5 |
| FeO ------------------ | 8.3 | 3.9 | 2.9 | 8.2 | 4.3 | 9.0 | 3.3 | 2.6 | 3.6 |
| MgO ----------------- | 3.5 | 2.1 | 1.7 | 3.1 | 2.2 | 6.8 | 1.2 | 1.7 | 2.1 |
| CaO ------------------ | .63 | 1.0 | .92 | .65 | .52 | .16 | .13 | .39 | .93 |
| $Na_2O$ ---------------- | 1.7 | 1.8 | 1.7 | .85 | .95 | .29 | .21 | 1.5 | 1.4 |
| $K_2O$ ------------------ | 6.4 | 2.7 | 3.5 | 4.4 | 3.5 | .43 | 1.2 | 4.3 | 2.5 |
| $H_2O+$ ---------------- | 1.6 | 1.4 | 1.2 | 1.4 | .93 | 1.3 | .81 | 1.4 | 1.8 |
| $H_2O-$ ----------------- | .14 | .12 | .15 | .15 | .39 | .12 | .40 | .36 | .36 |
| $TiO_2$ ----------------- | 1.4 | .79 | .98 | 1.0 | 1.1 | .47 | 1.1 | .89 | .40 |
| $P_2O_5$ ----------------- | .13 | .06 | .09 | .08 | .06 | .01 | .03 | .12 | .08 |
| MnO ----------------- | .10 | .03 | .05 | .14 | .06 | .12 | .05 | .63 | .07 |
| $CO_2$ ------------------ | .04 | .01 | .02 | <.05 | .00 | .02 | .01 | .00 | .00 |
| F ---------------------- | .12 | .07 | .05 | N.d. | .04 | .02 | .06 | .13 | .06 |
| Cl -------------------- | .03 | .02 | .02 | N.d. | .02 | N.d. | N.d. | .02 | .01 |
| S (total) ------------- | .10 | .01 | .00 | N.d. | N.d. | .13 | N.d. | .01 | .01 |
| Total --------------- | 99. | 100. | 100. | 100. | 99. | 99. | 100. | 100. | 100. |
| Bulk density --------- | 2.71 | 2.70 | 2.83 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ---------- | 2.84 | 2.72 | 2.83 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | |
| Ba -------------------- | 1,200 | 296 | 458 | N | 440 | N | 70 | 530 | 340 |
| Be -------------------- | 3 | N | N | N | 2 | 67 | N | 5 | 19 |
| Ce -------------------- | 109 | 49 | 75 | 500 | 100 | N | 44 | 75 | 100 |
| Co -------------------- | 24 | 11 | 23 | 30 | 21 | 22 | 12 | 16 | 13 |
| Cr -------------------- | 141 | 81 | 107 | 100 | 130 | 196 | 67 | 110 | 820 |
| Cu -------------------- | 22 | N | N | 70 | N | 9,460 | 3 | 6 | 59 |
| Ga -------------------- | 55 | 11 | 27 | 15 | 37 | 44 | 16 | 42 | 26 |
| La -------------------- | 54 | 27 | 34 | 150 | 45 | N | 18 | 26 | 43 |
| Mo -------------------- | 1 | 1 | N | 7 | N | N | N | N | 6 |
| Nb -------------------- | 11 | 4 | 11 | 15 | 7 | N | 6 | 13 | 5 |
| Nd -------------------- | 39 | 19 | 19 | 150 | N | N | N | N | N |
| Ni -------------------- | 63 | 45 | 64 | 70 | 45 | 58 | 30 | 38 | 440 |
| Pb -------------------- | 12 | 6 | 38 | 10 | 28 | 12 | 10 | 40 | 12 |
| Pr -------------------- | 8 | 4 | 5 | -- | N | N | N | N | N |
| Rb -------------------- | N | 70 | 100 | -- | N | N | N | N | N |
| Sc -------------------- | 3 | 4 | 16 | 20 | 18 | 3 | 11 | 13 | 5 |
| Sn -------------------- | N | 4 | 9 | N | 9 | N | N | N | 11 |
| Sr -------------------- | 3 | 148 | 198 | 10 | 94 | 3 | 19 | 130 | 62 |
| V --------------------- | 24 | 76 | 121 | 70 | 100 | 24 | 70 | 83 | 73 |
| Y --------------------- | N | 17 | 9 | 50 | 16 | N | 5 | 20 | 8 |
| Yb -------------------- | N | 1 | 1 | 5 | 3 | N | 1 | 6 | 1 |
| Zn -------------------- | 299 | 85 | 99 | N | 130 | 299 | 110 | 110 | 89 |
| Zr -------------------- | 188 | 128 | 136 | 300 | 65 | 188 | 150 | 93 | 81 |

Footnote follows at end of table.

**Table 24.** Chemical and spectrographic analyses and modes for cordierite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| Map Locality No. --- | 121 | 123 | 156 | 192 | 63 | 58 | 31 | 301 | 309 |
|---|---|---|---|---|---|---|---|---|---|
| Sample No. ---------- | W12b-70 | W64-70 | W330a-70 | N146-65 | GH3a-72 | GH190-73 | GH331-75 | ML-6 | ML-15 |
| Lab No. -------------- | W178089 | W178090 | W178091 | W168101 | W194509 | W184717 | W194507 | W197380 | W197386 |
| Modes in volume percent | | | | | | | | | |
| K-feldspar ----------- | 41.8 | 4.2 | 11.7 | 1 | 24 | -- | .1 | 25.7 | 1.5 |
| Plagioclase----------- | 11.8 | 14.6 | 25.7 | 1 | 8 | -- | 2.4 | 14.9 | 22.0 |
| Quartz ---------------- | .9 | 46.8 | 33.3 | 11 | 25 | 1 | 69.2 | 37.2 | 41.6 |
| Cordierite ----------- | 11.3 | 14.0 | 4.4 | 27 | 10 | 80 | 4.4 | 9.1 | 22.0 |
| Biotite ---------------- | 27.5 | 13.4 | 9.7 | 44 | 13 | 13 | 5.5 | 2.4 | 8.9 |
| Sillimanite ----------- | 5.0 | 1.6 | 9.7 | 14 | 16 | 5 | 11.9 | 8.2 | 1.6 |
| Opaque minerals---- | 1.3 | 2.8 | 4.5 | Tr | 4 | 1 | 3.4 | 2.0 | 1.2 |
| Zircon ---------------- | Tr | .4 | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite ----------- | .4 | Tr | -- | 1 | -- | Tr | -- | -- | .3 |
| Rutile ----------------- | -- | -- | -- | Tr | -- | -- | -- | Tr | -- |
| Spinel-Högbomite -- | -- | Tr | Tr | Tr | -- | -- | -- | -- | Tr |
| Chlorite -------------- | -- | .6 | .1 | -- | -- | -- | -- | -- | -- |
| Muscovite-sericite[1] - | -- | 1.6 | .9 | 1 | Tr | -- | 3.1 | .4 | .9 |
| Allanite -------------- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Xenotime-monazite- | -- | -- | -- | -- | -- | -- | Tr | Tr | Tr |

[1]Muscovite-sericite replaces plagioclase.

**Table 25.** Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 345, 349, 367, C.L. Parker. Analysts for rapid-rock analysts for samples from map locality numbers 108, 116, 122, 127, 128, 152, 155, Leonard Shapiro; 35, Hezekiah Smith; 300, 306, 323, Z.A. Hamlin; 230, 263, 343, S.A. Botts, Gillison Chloe, J.L. Glenn, Hezekiah Smith, P.D.L. Elmore, Lowell Artis, James Kelsey. Analysts for spectrographic analyses for samples with map locality numbers 345, 349, 367, J.C. Hamilton; all others by J.L. Harris. N.d., not determined; N, not detected; --, not looked for; <, less than; Tr, trace; x, greater than trace amount found]

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 349 | 345 | 116 | 122 | 127 | 128 | 152 | 155 | 35 |
| Sample No. | EWT-90 | JG-38b | W281a-71 | W18-70 | W97-70 | W121-70 | W321-70 | W328-70 | GH12-74 |
| Lab No. | I4156 | I4157 | W178081 | W178084 | W178085 | W178086 | W178087 | W178088 | W192419 |
| | Chemical analyses in weight percent | | | | | | | | |
| $SiO_2$ | 57.28 | 58.06 | 63.0 | 69.0 | 54.9 | 76.1 | 65.8 | 61.4 | 65.8 |
| $Al_2O_3$ | 21.13 | 20.76 | 19.6 | 15.6 | 21.4 | 11.3 | 16.3 | 20.1 | 18.5 |
| $Fe_2O_3$ | 2.22 | 1.55 | 3.4 | 1.0 | 2.5 | 1.0 | 2.2 | .74 | .80 |
| FeO | 7.90 | 9.72 | 4.3 | 5.7 | 9.2 | 4.3 | 4.4 | 6.1 | 4.8 |
| MgO | 3.04 | 3.23 | 1.2 | 2.1 | 2.6 | 1.6 | 1.9 | 2.2 | 1.9 |
| CaO | .65 | .33 | .12 | .82 | .05 | .08 | .56 | .39 | .66 |
| $Na_2O$ | .97 | .39 | .89 | 1.0 | .48 | .48 | 1.4 | 1.1 | 1.5 |
| $K_2O$ | 3.56 | 3.25 | 3.6 | 2.8 | 4.4 | 3.0 | 4.7 | 5.1 | 3.1 |
| $H_2O+$ | 1.47 | 1.10 | 1.7 | 1.3 | 1.5 | 1.5 | 1.8 | 1.2 | 1.2 |
| $H_2O-$ | .20 | .17 | .28 | .14 | .18 | .21 | .25 | .15 | .23 |
| $TiO_2$ | 1.02 | 1.00 | .90 | .80 | 1.3 | .76 | .91 | .93 | .75 |
| $P_2O_5$ | .07 | .07 | .05 | .03 | .04 | .02 | .09 | .09 | .05 |
| MnO | .14 | .10 | .10 | .10 | .12 | .05 | .07 | .06 | .03 |
| $CO_2$ | .02 | .01 | .01 | .01 | .01 | .01 | .01 | .02 | .02 |
| F | .01 | .01 | .07 | .09 | .10 | .05 | .08 | .03 | .02 |
| Cl | .11 | .12 | .01 | .03 | .03 | .03 | .03 | .02 | .01 |
| S (total) | N.d. | N.d. | .01 | .06 | .00 | .00 | .00 | .00 | .01 |
| Subtotal | 99.79 | 99.87 | 99. | 100. | 99. | 100. | 100. | 100. | 99. |
| Less 0 | .03 | .03 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 99.76 | 99.84 | 99. | 100. | 99. | 100. | 100. | 100. | 99. |
| Bulk density | N.d. | N.d. | 2.80 | 2.78 | 2.83 | 2.73 | 2.70 | 2.78 | N.d. |
| Powder density sink/float | 2.94 | 3.01 | 2.80 | 2.78 | 3.00 | 2.76 | 2.76 | 2.78 | N.d. |
| | Semiquantitative spectrographic analyses in parts per million | | | | | | | | |
| Ba | 1,000 | 1,000 | 570 | 372 | 781 | 393 | 618 | 680 | 600 |
| Be | N | N | 2 | 1 | 3 | N | N | N | 3 |
| Ce | N | N | 122 | 73 | 98 | 54 | 77 | 105 | 91 |
| Co | 30 | 30 | 24 | 17 | 29 | 13 | 20 | 17 | 14 |
| Cr | 200 | 200 | 126 | 61 | 194 | 94 | 139 | 93 | 68 |
| Cu | 30 | 7 | 14 | 20 | 22 | 51 | 2 | 4 | 27 |
| Ga | 50 | 70 | 33 | 20 | 38 | 15 | 27 | 27 | 34 |
| Gd | N | N | 9 | 7 | 10 | 9 | 7 | 7 | N |
| La | 70 | 70 | 67 | 34 | 33 | 31 | 51 | 67 | 40 |
| Mo | 7 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |
| Nb | 15 | 15 | 10 | 10 | 13 | 11 | 11 | 9 | 10 |
| Nd | N | N | 45 | 19 | 18 | 20 | 31 | 38 | 48 |
| Ni | 100 | 100 | 66 | 45 | 69 | 73 | 69 | 53 | 34 |
| Pb | 30 | 15 | 21 | 12 | 22 | 14 | 32 | 21 | 30 |
| P | N | N | 9 | 6 | 6 | 5 | 7 | 10 | N |
| Rb | N | N | 150 | 150 | 300 | 150 | 150 | 150 | N |
| Sc | 50 | 50 | 15 | 9 | 53 | 8 | 18 | 12 | 19 |
| Sn | N | N | 8 | 4 | 11 | 3 | 5 | 4 | N |
| Sr | 300 | 150 | 156 | 178 | 134 | 95 | 219 | 199 | 78 |
| V | 200 | 200 | 161 | 99 | 179 | 99 | 125 | 101 | 120 |
| Y | 50 | 50 | 25 | 27 | 60 | 30 | 34 | 30 | 15 |
| Yb | 7 | 7 | 3 | 2 | 6 | 2 | 3 | 3 | 5 |
| Zn | N | N | 126 | 98 | 168 | 84 | 108 | 109 | 150 |
| Zr | 150 | 150 | 149 | 189 | 174 | 227 | 184 | 210 | 69 |

Footnotes at the end of table.

**Table 25**. Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. ------- | 349 | 345 | 116 | 122 | 127 | 128 | 152 | 155 | 35 |
| Sample No. ------------- | EWT-90 | JG-38b | W281a-71 | W18-70 | W97-70 | W121-70 | W321-70 | W328-70 | GH12-74 |
| Lab No. ---------------- | I4156 | I4157 | W178081 | W178084 | W178085 | W178086 | W178087 | W178088 | W192419 |
| | Modes in volume percent | | | | | | | | |
| K-feldspar -------------- | 3.3 | 1.6 | 11.5 | 7.6 | 7.5 | 16.4 | 20.5 | 34.7 | 9.4 |
| Plagioclase-------------- | 8.0 | 2.0 | 5.3 | 11.2 | 1.4 | 3.1 | 19.1 | 4.6 | 10.6 |
| Quartz ------------------ | 29.6 | 26.1 | 20.7 | 47.7 | 24.0 | 55.8 | 30.6 | 18.8 | 39.9 |
| Cordierite -------------- | 4.3 | 16.4 | 14.0 | 2.4 | 17.1 | [2]8.7 | .3 | 16.2 | 10.5 |
| Biotite ----------------- | 28.9 | 23.6 | 11.0 | 19.1 | 21.2 | 6.1 | 12.8 | 9.7 | 17.9 |
| Garnet ------------------ | 20.1 | 17.3 | 9.9 | 2.9 | 18.5 | 1.5 | 1.6 | 3.7 | 1.7 |
| Sillimanite-------------- | 5.7 | 11.7 | 16.3 | 9.1 | 8.9 | 2.0 | 1.7 | 10.2 | 9.7 |
| Opaque minerals------- | .1 | 1.3 | 4.2 | Tr | 1.4 | 1.2 | .3 | .5 | .3 |
| Zircon ------------------ | Tr | Tr | Tr | -- | Tr | Tr | Tr | Tr | Tr |
| Andalusite -------------- | -- | Tr | Tr | Tr | Tr | Tr | Tr | .3 | -- |
| Chlorite ----------------- | -- | -- | 1.5 | -- | -- | 1.3 | .3 | -- | -- |
| Muscovite-sericite[3] ---- | Tr | -- | [2]5.6 | 3.9 | 12.8 | 1.3 | -- | -- | -- |
| Spinel-högbomite------ | -- | Tr | Tr | -- | Tr | -- | -- | Tr | -- |
| Rutile ------------------- | -- | -- | -- | -- | -- | Tr | -- | -- | -- |
| Xenotime-monazite --- | -- | -- | -- | -- | -- | -- | -- | -- | Tr |
| Apatite ----------------- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | Cordierite-garnet-sillimanite-biotite gneiss | | Cordierite-garnet-biotite gneiss |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. ------- | 323 | 300 | 306 | 263 | 263 | 343 | 108 | 367 | 230 |
| Sample No. ------------- | AP-1 | ML-3 | ML-11 | N338a | N338b | CC-783-1 | W256c-71 | M-497 | N340a-64 |
| Lab No. ---------------- | W197377 | W197379 | W197385 | W173197 | W173198 | W169537 | W178078 | I4195 | W169536 |
| | Chemical analyses in weight percent | | | | | | | | |
| $SiO_2$ -------------------- | 70.0 | 67.7 | 54.3 | 58.6 | 69.2 | 59.6 | 59.6 | 72.38 | 75.8 |
| $Al_2O_3$------------------- | 14.4 | 15.8 | 17.4 | 17.2 | 15.6 | 23.8 | 18.7 | 13.26 | 10.2 |
| $Fe_2O_3$------------------- | 1.1 | 1.6 | 4.4 | 2.4 | .86 | 2.6 | 1.9 | .85 | 1.7 |
| FeO --------------------- | 1.9 | 2.5 | 12.8 | 9.3 | 5.4 | 6.5 | 6.0 | 5.26 | 4.0 |
| MgO --------------------- | .9 | 1.2 | 3.4 | 3.5 | 2.0 | 2.9 | 2.6 | 2.28 | 2.8 |
| CaO---------------------- | 1.2 | 2.1 | 1.2 | .47 | .62 | .17 | 1.1 | .17 | .52 |
| $Na_2O$ -------------------- | 2.7 | 2.3 | .82 | .56 | .75 | .08 | 1.8 | 1.74 | .57 |
| $K_2O$---------------------- | 5.4 | 4.3 | 2.7 | 3.3 | 3.3 | 2.0 | 4.8 | 1.63 | 2.2 |
| $H_2O+$ ------------------ | .74 | 1.3 | 1.2 | 1.4 | 1.2 | .92 | 2.3 | 1.57 | 1.4 |
| $H_2O-$ ------------------- | .13 | .21 | .13 | .40 | .27 | .08 | .18 | .32 | .08 |
| $TiO_2$ -------------------- | .42 | .53 | .79 | 1.8 | .65 | 1.3 | .97 | .20 | .37 |
| $P_2O_5$ -------------------- | .05 | .13 | .18 | .09 | .17 | .06 | .05 | .02 | .05 |
| MnO --------------------- | .35 | .04 | 1.1 | .10 | .05 | .07 | .17 | .10 | .09 |
| $CO_2$ ---------------------- | .02 | .14 | .01 | <.05 | <.05 | <.05 | .01 | .02 | <.05 |
| F------------------------- | .11 | .07 | .10 | .13 | .09 | N.d. | .10 | .09 | N.d. |
| Cl ------------------------ | .02 | .02 | .02 | N.d. | N.d. | N.d. | .03 | .01 | N.d. |
| S (total) ----------------- | .00 | .01 | .04 | N.d. | N.d. | N.d. | .01 | N.d. | N.d. |
| Subtotal---------------- | 99. | 100. | 101. | 99. | 100. | 100. | 100. | 99.00 | 100. |
| Less 0 ------------------ | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .04 | N.d. |
| Total ------------------- | 99. | 100. | 101. | 99. | 100. | 100. | 100. | 99.86 | 100. |
| Bulk density ------------ | N.d. | N.d. | N.d. | 2.81 | 2.77 | N.d. | 2.83 | N.d. | N.d. |
| Powder density sink/float ---- | N.d. | N.d. | N.d. | 3.12 | 3.12 | N.d. | 2.83 | 2.74 | N.d. |

Footnotes follow at end of table.

**Table 25**. Chemical and spectrographic analyses and modes for cordierite-garnet-K-feldspar-sillimanite-biotite gneiss, cordierite-garnet-sillimanite-biotite gneiss, and cordierite-garnet-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | | | | | | Cordierite-garnet-sillimanite-biotite gneiss | | Cordierite-garnet-biotite gneiss |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 323 | 300 | 306 | 263 | 263 | 343 | 108 | 367 | 230 |
| Sample No. | AP-1 | ML-3 | ML-11 | N338a | N338b | CC-783-1 | W256c-71 | M-497 | N340a-64 |
| Lab No. | W197377 | W197379 | W197385 | W173197 | W173198 | W169537 | W178078 | I4195 | W169536 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | |
| Ba | 570 | 700 | 370 | 500 | 500 | -- | 502 | 500 | -- |
| Be | N | N | N | N | N | -- | 1 | N | -- |
| Ce | N | N | 95 | 300 | 300 | -- | 133 | N | -- |
| Co | 8 | 9 | 24 | 30 | 15 | -- | 19 | N | -- |
| Cr | 69 | 64 | 96 | 300 | 200 | -- | 108 | 1 | -- |
| Cu | 3 | 8 | 28 | 20 | 20 | -- | 2 | 300 | -- |
| Ga | 24 | 20 | 27 | 30 | 20 | -- | 32 | 30 | -- |
| Gd | N | N | N | N | N | -- | 8 | -- | -- |
| La | 19 | 19 | 23 | 100 | 100 | -- | 77 | 50 | -- |
| Mo | N | N | 3 | 5 | 3 | -- | N | 5 | -- |
| Nb | 8 | 8 | 7 | 10 | 7 | -- | 12 | N | -- |
| Nd | N | N | N | N | N | -- | 60 | N | -- |
| Ni | 18 | 28 | 54 | 150 | 70 | -- | 47 | N | -- |
| Pb | 42 | 36 | 26 | 7 | 10 | -- | 13 | N | -- |
| Pr | N | N | N | N | N | -- | 10 | -- | -- |
| Rb | N | N | N | N | N | -- | 200 | -- | -- |
| Sc | 6 | 10 | 11 | 50 | 20 | -- | 20 | 7 | -- |
| Sn | N | N | N | N | N | -- | 7 | N | -- |
| Sr | 160 | 280 | 100 | 70 | 150 | -- | 126 | 30 | -- |
| V | 50 | 54 | 81 | 200 | 100 | -- | 113 | N | -- |
| Y | 7 | 9 | 15 | 70 | 50 | -- | 40 | 70 | -- |
| Yb | 1 | 3 | 2 | 7 | 5 | -- | 5 | 10 | -- |
| Zn | 32 | 38 | 81 | N | N | -- | 163 | N | -- |
| Zr | 59 | 39 | 100 | 300 | 500 | -- | 176 | 150 | -- |
| Modes in volume percent | | | | | | | | | |
| K-feldspar | 15.4 | 26.6 | 5.6 | 8.2 | 19.0 | Tr | [1]x | Tr | 6.1 |
| Plagioclase | 28.7 | 23.2 | 11.3 | 5.2 | 4.4 | 6 | x | 9.3 | 4.8 |
| Quartz | 46.4 | 26.8 | 25.8 | 36.6 | 41.8 | 53 | x | 51.6 | 59.3 |
| Cordierite | 1.7 | [2]6.3 | 4.5 | 2.7 | .3 | 2 | x | 1.3 | 1.9 |
| Biotite | 6.7 | 11.8 | 21.6 | 27.9 | 22.4 | 21 | x | 13.8 | 19.5 |
| Garnet | .6 | 1.2 | 30.3 | 11.7 | 7.7 | 7 | x | 2.6 | .1 |
| Sillimanite | .2 | 1.9 | Tr | 5.8 | 3.8 | 10 | x | 11.6 | -- |
| Opaque minerals | .3 | .8 | .5 | 1.3 | .5 | 1 | x | .3 | .3 |
| Zircon | Tr | -- | -- | .1 | Tr | Tr | Tr | Tr | Tr |
| Andalusite | -- | .8 | -- | .3 | -- | -- | -- | Tr | -- |
| Chlorite | Tr | -- | .1 | -- | -- | -- | -- | 9.5 | 2.8 |
| Muscovite-sericite[3] | -- | .6 | .3 | .2 | -- | Tr | x | -- | 5.2 |
| Spinel-högbomite | Tr | -- | -- | Tr | Tr | Tr | -- | Tr | -- |
| Rutile | -- | -- | -- | -- | -- | Tr | -- | -- | Tr |
| Xenotime-monazite | Tr | -- | -- | -- | -- | -- | -- | Tr | -- |
| Apatite | -- | -- | -- | -- | .1 | -- | -- | -- | -- |
| Staurolite | -- | -- | -- | -- | -- | -- | -- | Tr | -- |

[1]Thin section poor.

[2]Includes pinnite.

[3]Muscovite-sericite replaces plagioclase and sillimanite.

**Table 26.** Chemical and spectrographic analyses and modes for cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.

[Analysts for rapid-rock analyses for samples with map locality numbers 153, 154, 158, Leonard Shapiro; 51, Hezekiah Smith; 195, P.D.L. Elmore, Lowell Artis, Hezekiah Smith, Gillison Chloe, S.D. Botts, J.L. Glenn. Analyst for all spectrographic analyses J.L. Harris. N.d., not determined; --, not found; >, greater than; <, less than; Tr, trace]

| | Cordierite-magnetite-sillimanite-biotite gneiss | | Magnetite-sillimanite-biotite gneiss | | |
|---|---|---|---|---|---|
| Map locality No. ----- | 158 | 195 | 153 | 154 | 51 |
| Sample No. ---------- | W346-70 | N196A-64 | W323-70 | W326-70 | GH391-74 |
| Lab No. --------------- | W178094 | W168100 | W178095 | W178096 | W192420 |
| | Chemical analyses in weight percent | | | | |
| $SiO_2$ ------------------ | 44.7 | 53.4 | 70.0 | 60.0 | 69.3 |
| $Al_2O_3$ ---------------- | 28.2 | 26.5 | 14.0 | 19.2 | 16.0 |
| $Fe_2O_3$ ---------------- | 9.7 | 4.1 | 5.0 | 5.2 | 3.6 |
| FeO ------------------- | 6.4 | 6.8 | 2.6 | 3.4 | 3.8 |
| MgO ------------------ | 3.4 | 3.1 | 1.4 | 2.0 | 1.8 |
| CaO ------------------- | .63 | .12 | .29 | .35 | .22 |
| $Na_2O$ ------------------ | 1.4 | .43 | 1.2 | .86 | .47 |
| $K_2O$ ------------------- | 2.3 | 2.6 | 2.7 | 4.1 | 2.1 |
| $H_2O+$ ----------------- | 1.6 | 1.2 | 1.9 | 2.8 | 1.2 |
| $H_2O$ ------------------- | .21 | .20 | .12 | .18 | .19 |
| $TiO_2$ ------------------ | 1.4 | 1.4 | 1.0 | .93 | .99 |
| $P_2O_5$ ------------------ | .05 | .09 | .13 | .10 | .03 |
| MnO ------------------ | .11 | .11 | .04 | .05 | .05 |
| $CO_2$ ------------------- | .01 | < .05 | .02 | .01 | .03 |
| F ----------------------- | .18 | N.d. | .04 | .12 | .02 |
| Cl ---------------------- | < .01 | N.d. | < .01 | < .01 | .02 |
| S (total) --------------- | .01 | N.d. | .00 | .01 | .01 |
| Total ----------------- | 100. | 100. | 100. | 99. | 100. |
| Bulk density --------- | 2.98 | N.d. | 2.80 | 2.80 | N.d. |
| Powder density sink/float ------------ | 3.08 | N.d. | 2.80 | 2.80 | N.d. |
| | Semiquantitative spectrographic analyses in parts per million | | | | |
| Ba --------------------- | 206 | N | 412 | 404 | 290 |
| Be --------------------- | 2 | 3 | N | 1 | 1 |
| Ce --------------------- | 01 | 700 | 82 | 59 | 120 |
| Co --------------------- | 27 | 30 | 13 | 17 | 17 |
| Cr --------------------- | 113 | 150 | 92 | 102 | 91 |
| Cu --------------------- | N | 5 | N | N | 4 |
| Ga --------------------- | 30 | 30 | 10 | 27 | 23 |
| Gd --------------------- | 7 | N | 8 | 5 | N |
| La --------------------- | 48 | 300 | 53 | 29 | 49 |
| Mo -------------------- | 2 | 3 | 2 | 1 | 3 |
| Nb --------------------- | 10 | 20 | 10 | 6 | 19 |
| Nd --------------------- | 22 | 300 | 27 | 19 | N |
| Ni --------------------- | 61 | 100 | 40 | 47 | 41 |
| Pb --------------------- | 7 | 10 | 12 | 4 | 13 |
| Pr --------------------- | 8 | N | N | N | N |
| Rb --------------------- | 150 | N | 70 | 150 | N |
| Sc --------------------- | 8 | 30 | 10 | 11 | 18 |
| Sn --------------------- | 11 | 15 | 8 | 7 | N |
| Sr --------------------- | 68 | 200 | 123 | 87 | 45 |
| V ---------------------- | 103 | 100 | 88 | 99 | 99 |
| Y ---------------------- | 12 | 100 | 28 | 20 | 15 |
| Yb --------------------- | 1 | 10 | 2 | 2 | 1 |
| Zn --------------------- | 222 | N | 94 | 84 | 130 |
| Zr --------------------- | 213 | 500 | 366 | 117 | 140 |

Footnote follows at end of table.

**Table 26.** Chemical and spectrographic analyses and modes for cordierite-magnetite-sillimanite-biotite gneiss and magnetite-sillimanite-biotite gneiss, central Front Range, Colorado.--Continued

| | Cordierite-magnetite-sillimanite-biotite gneiss | | Magnetite-sillimanite-biotite gneiss | | |
|---|---|---|---|---|---|
| Map locality No. ----- | 158 | 195 | 153 | 154 | 51 |
| Sample No. ----------- | W346-70 | N196A-64 | W323-70 | W326-70 | GH391-74 |
| Lab No. --------------- | W178094 | W168100 | W178095 | W178096 | W192420 |
| | Modes in volume percent | | | | |
| K-feldspar ------------ | 1 | 12 | Tr | -- | .6 |
| Plagioclase ----------- | 19 | 2 | 16 | 5 | 1.3 |
| Quartz ---------------- | 7 | 17 | 47 | 37 | 66.3 |
| Cordierite ------------ | 1 | 33 | -- | -- | -- |
| Biotite ---------------- | 26 | 10 | 2 | Tr | 12.7 |
| Sillimanite ----------- | 38 | 15 | 3 | 2 | 14.9 |
| Opaque minerals ----- | 8 | 6 | 5 | 5 | 3.7 |
| Zircon ---------------- | Tr | Tr | Tr | Tr | Tr |
| Chlorite--------------- | -- | Tr | 5 | 5 | Tr |
| Muscovite-sericite[1] -- | Tr | 5 | 22 | 46 | .5 |
| Rutile ----------------- | -- | -- | Tr | Tr | -- |
| Epidote --------------- | Tr | -- | -- | -- | -- |
| Monazite-xenotime -- | -- | -- | -- | -- | Tr |

[1]Muscovite-sericite a replacement of plagioclase and perhaps sillimanite.

**Table 27.** Chemical and spectrographic analyses and modes for thermal cordierite-sillimanite-magnetite-biotite gneiss and thermal biotite-gneiss hornfels, central Front Range, Colorado.

[Analysts for a standard wet chemical analyses for samples from map locality numbers 212 and 223, C.L. Parker. Analysts for rapid-rock chemical analyses for samples from locality numbers 192, 200, 222, P.L.D. Elmore, S.D. Botts, Lowell Artis, Hezekiah Smith, Gillison Chloe, J.L. Glenn; 141 and 147, Leonard Shapiro; 21 and 28, Hezekiah Smith. Analysts for spectrographic analyses for samples from locality numbers 212 and 223, Harriet Neiman; J.L. Harris, all other analyses. N.d., not determined; N, not detected; --, not found; >, greater than; <, less than; Tr, trace]

| | Thermal cordierite-magnetite-sillimanite-biotite gneiss | | | | | | | Thermal biotite-gneiss hornfels | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. -- | 212 | 222 | 223 | 192 | 200 | 141 | 147 | 21 | 28 |
| Sample No. -------- | N69a-64 | N196a-64 | N206-64 | N146-65 | N236-65 | W256-70 | W281-70 | GH175a-75 | GH294-75 |
| Lab No. ------------ | D100744 | W168100 | D100743 | W168101 | W168102 | W178092 | W178093 | W192422 | W192425 |
| **Chemical analyses in weight percent** | | | | | | | | | |
| $SiO_2$ ---------------- | 60.01 | 53.4 | 59.83 | 56.5 | 52.2 | 56.6 | 47.4 | 61.4 | 41.4 |
| $Al_2O_3$ ---------------- | 21.14 | 26.5 | 20.82 | 22.5 | 24.6 | 20.9 | 21.6 | 16.1 | 31.6 |
| $Fe_2O_3$ ---------------- | 4.87 | 4.1 | 2.30 | .72 | 3.9 | 5.8 | 5.9 | 3.3 | 6.2 |
| FeO ----------------- | 4.39 | 6.8 | 5.35 | 8.2 | 5.7 | 4.8 | 8.3 | 4.5 | 7.9 |
| MgO ---------------- | 2.13 | 3.1 | 2.39 | 3.1 | 2.9 | 2.6 | 4.4 | 2.3 | 3.8 |
| CaO ----------------- | .25 | .12 | .38 | .65 | .74 | .63 | 1.2 | 3.5 | .18 |
| $Na_2O$ --------------- | .72 | .43 | .68 | .85 | 2.0 | 1.3 | 1.5 | 2.8 | .33 |
| $K_2O$ ----------------- | 3.79 | 2.6 | 4.98 | 4.4 | 5.0 | 4.2 | 4.6 | 2.6 | 4.9 |
| $H_2O+$ --------------- | 1.00 | 1.2 | 1.73 | 1.4 | 1.4 | 1.2 | 1.4 | 1.3 | 1.7 |
| $H_2O$ ----------------- | .23 | .20 | .18 | .15 | .20 | .17 | .26 | .32 | .26 |
| $TiO_2$ ---------------- | 1.03 | 1.4 | .94 | 1. | 1.2 | 1.2 | 1.8 | 1.4 | 1.4 |
| $P_2O_5$ ---------------- | .06 | .09 | .04 | .08 | .10 | .10 | .08 | .66 | .15 |
| MnO ---------------- | .09 | .11 | .09 | .14 | .08 | .12 | .14 | .08 | .06 |
| $CO_2$ ----------------- | .02 | <.05 | .07 | <.05 | <.05 | .00 | .01 | .02 | .02 |
| F -------------------- | .25 | N.d. | .09 | N.d. | N.d. | .11 | .13 | .27 | .45 |
| Cl ------------------- | .02 | N.d. | .04 | N.d. | N.d. | <.01 | .03 | .04 | .04 |
| S (total) ------------ | N.d. | N.d. | N.d. | N.d. | N.d. | .00 | .03 | .02 | .00 |
| Subtotal ----------- | 100.10 | 100. | 99.91 | 100. | 100. | 100. | 99. | 99. | 101. |
| Less 0 ------------- | .10 | N.d. | .05 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total -------------- | 99.90 | 100. | 99.86 | 100. | 100. | 100. | 99. | 101. | 101. |
| Bulk density ------- | N.d. | N.d. | N.d. | N.d. | N.d. | 2.88 | 2.83 | N.d. | N.d. |
| Powder density sink/float --------- | N.d. | N.d. | N.d. | N.d. | N.d. | 2.88 | 2.83 | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | | |
| Ba ------------------- | 700 | N | 1,500 | N | N | 579 | 626 | 1,400 | 260 |
| Be ------------------- | N | 3 | N | N | N | 2 | 7 | 6 | 7 |
| Ce ------------------- | 200 | 700 | N | 500 | 500 | 121 | 95 | 360 | 210 |
| Co ------------------- | 20 | 30 | 15 | 30 | 30 | 32 | 33 | 18 | 23 |
| Cr ------------------- | 100 | 150 | 100 | 100 | 200 | 161 | 273 | 46 | 240 |
| Cu ------------------- | 5 | 5 | 20 | 70 | 5 | 10 | 22 | 240 | 11 |
| Ga ------------------- | 50 | 30 | 30 | 15 | 30 | 36 | 66 | 44 | 100 |
| Gd ------------------- | -- | -- | -- | -- | -- | 8 | 9 | 15 | -- |
| La ------------------- | 100 | 300 | 50 | 150 | 150 | 71 | 36 | 150 | 63 |
| Mo ------------------- | N | 3 | 7 | 7 | 3 | 2 | 2 | 3 | 4 |
| Nb ------------------- | 20 | 20 | 10 | 15 | 10 | 7 | 17 | 40 | 33 |
| Nd ------------------- | <100 | 300 | N | 150 | 150 | 37 | N | 190 | 50 |
| Ni ------------------- | 70 | 100 | 50 | 70 | 150 | 78 | 85 | 28 | 64 |
| Pb ------------------- | N | 10 | N | 10 | 20 | 25 | 16 | 28 | 21 |
| Pr- ------------------ | -- | -- | -- | -- | -- | 10 | 8 | -- | -- |
| Rb ------------------- | -- | -- | -- | -- | -- | 150 | 100 | -- | -- |
| Sc ------------------- | 30 | 30 | 30 | 20 | 30 | 17 | 13 | 18 | 20 |
| Sn ------------------- | 100 | 15 | -- | N | N | 13 | 12 | N | 27 |
| Sr ------------------- | 150 | 20 | 200 | 10 | 30 | 151 | 239 | 580 | 30 |
| V -------------------- | 150 | 100 | 150 | 70 | 150 | 145 | >215 | 120 | 150 |
| Y -------------------- | 50 | 100 | 50 | 50 | 50 | 26 | 18 | 34 | 29 |
| Yb ------------------- | 5 | 10 | 7 | 5 | 5 | 3 | 2 | 5 | 6 |
| Zn ------------------- | N | N | N | N | N | 176 | 338 | 160 | 250 |
| Zr ------------------- | 300 | 500 | 200 | 300 | 500 | 181 | 252 | 690 | 230 |

Footnote follows at end of table.

**Table 27**. Chemical and spectrographic analyses and modes for thermal cordierite-sillimanite-magnetite-biotite gneiss and thermal biotite-gneiss hornfels, central Front Range, Colorado.--Continued

| | Thermal cordierite-magnetite-sillimanite-biotite gneiss | | | | | | | Thermal biotite-gneiss hornfels | |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. -- | 212 | 222 | 223 | 192 | 200 | 141 | 147 | 21 | 28 |
| Sample No. ------- | N69a-64 | N196a-64 | N206-64 | N146-65 | N236-65 | W256-70 | W281-70 | GH175a-75 | GH294-75 |
| Lab No. ------------ | D100744 | W168100 | D100743 | W168101 | W168102 | W178092 | W178093 | W192422 | W192425 |
| Modes in volume percent | | | | | | | | | |
| K-feldspar --------- | 5 | 12 | 17 | 1 | 40.6 | 12.9 | 7.3 | -- | 13.6 |
| Plagioclase--------- | 10 | 2 | 9 | 1 | 5.3 | 7.0 | 5.4 | 38.4 | 16.6 |
| Quartz -------------- | 45 | 17 | 50 | 11 | 2.4 | 14.4 | .4 | 26.1 | 29.8 |
| Cordierite ---------- | 25 | 33 | 1 | 27 | 26.0 | 26.7 | 58.5 | -- | -- |
| Biotite -------------- | 6 | 10 | 18 | 44 | 9.7 | 9.7 | 7.0 | 29.6 | 25.4 |
| Garnet -------------- | Tr | -- | Tr | -- | -- | -- | -- | -- | -- |
| Sillimanite --------- | 5 | 15 | 3 | 14 | 2.0 | 20.0 | 4.0 | -- | 11.1 |
| Opaque minerals-- | 3 | 6 | 1 | Tr | 7.7 | 7.0 | 14.0 | 3.9 | 2.8 |
| Zircon -------------- | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr | Tr |
| Andalusite --------- | Tr | -- | -- | 1 | 3.0 | -- | .8 | -- | -- |
| Chlorite ------------ | Tr | Tr | Tr | -- | .1 | -- | .9 | -- | -- |
| Muscovite-sericite[1] | Tr | 5 | Tr | 1 | 3.2 | 2.3 | -- | .2 | .7 |
| Spinel-högbomite- | -- | -- | -- | Tr | Tr | -- | 1.2 | -- | -- |
| Rutile --------------- | Tr | -- | Tr | Tr | Tr | -- | -- | -- | -- |
| Corundum --------- | -- | -- | -- | -- | -- | -- | .5 | -- | -- |
| Xenotime-monazite | -- | -- | -- | -- | -- | -- | Tr | -- | Tr |
| Apatite ------------- | -- | -- | -- | -- | -- | -- | -- | 1.0 | -- |
| Allanite ------------ | -- | -- | -- | Tr | -- | -- | -- | .1 | -- |
| Epidote ------------- | -- | -- | -- | -- | -- | -- | -- | .7 | -- |

[1]Muscovite-sericite replaces plagioclase and sillimanite.

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples with map locality numbers 260, 268, 346, E.S. Daniels. Analysts for rapid-rock analyses for samples with map locality numbers 193, 198, 245, P.D.L. Elmore; 103, 108, 116, Leonard Shapiro; 13, 1, 2, 279, Deborah Kobilis. Analysts for spectrographic analyses for samples with map numbers 260 and 346, Joseph Haffty; 103, 108, 116, 198, 245, 268, J.L. Harris; 1, 2, 13, 279, Leung Mei. Normative minerals calculated using the USGS graphic analysis program. N.d., not determined; N, not detected; --, not looked for; <, less than; >, greater than; Tr, trace]

| | Lens or layers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | In or adjacent to the Phoenix layer | | | | | Ward | Mount Audubon | | Central City |
| Map locality No. | 260 | 268 | 198 | 245 | 193 | 116 | 103 | 108 | 346 |
| Sample No. | N-321a | N-400b | N227a-65 | N602a-64 | N169a-65 | W281c-71 | W222b-71 | W256b-71 | D245a |
| Lab No. | D100279 | W175655 | W175650 | W175653 | W175649 | W178083 | W178079 | W178077 | D100277 |
| Chemical Analyses in weight percent | | | | | | | | | |
| $SiO_2$ | 47.44 | 53.6 | 54.1 | 52.5 | 63.4 | 47.6 | 53.0 | 62.4 | 62.77 |
| $Al_2O_3$ | 15.07 | 12.2 | 16.2 | 13.0 | 14.4 | 13.3 | 5.5 | 9.2 | 14.68 |
| $Fe_2O_3$ | 4.60 | 6.0 | 3.6 | 6.1 | 5.0 | 3.2 | 1.7 | 3.1 | 5.30 |
| FeO | 4.32 | 2.9 | 3.1 | 4.4 | 1.7 | 6.3 | 5.1 | 3.6 | .54 |
| MgO | 4.15 | 2.8 | 2.7 | 3.5 | .4 | 9.3 | 13.1 | 7.7 | .42 |
| CaO | 16.70 | 17.0 | 15.2 | 14.8 | 11.5 | 15.8 | 19.2 | 11.7 | 13.38 |
| $Na_2O$ | 1.62 | .33 | 1.7 | .56 | .45 | 1.2 | .41 | .24 | .04 |
| $K_2O$ | 1.13 | .72 | .44 | .41 | .45 | 1.2 | .41 | .32 | .06 |
| $H_2O+$ | 1.53 | 1.1 | 1.0 | 1.6 | .88 | 1.4 | 1.1 | 1.2 | 1.18 |
| $H_2O$ | .09 | .38 | .29 | .13 | .22 | .10 | .38 | .18 | .06 |
| $TiO_2$ | .77 | .85 | .63 | .97 | .65 | .51 | .21 | .34 | .96 |
| $P_2O_5$ | .19 | .23 | .23 | .32 | .59 | .31 | .07 | .10 | .23 |
| MnO | .15 | .21 | .17 | .21 | .10 | .19 | .17 | .20 | .22 |
| $CO_2$ | 2.15 | 1.3 | .72 | .71 | <.05 | .08 | .10 | .04 | .00 |
| F | .07 | .024 | .03 | .07 | .04 | .33 | .21 | .30 | .04 |
| Cl | .03 | .032 | .034 | .03 | .02 | .027 | .013 | .012 | .03 |
| S (total) | N.d. | N.d | N.d. | N.d. | N.d. | 0 | 0 | .00 | N.d. |
| Subtotal | 100.01 | 100. | 100. | 99. | 100. | 100. | 100. | 100. | 99.91 |
| Less O | .04 | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .03 |
| Total | 99.97 | 100. | 100. | 99. | 100. | 100. | 100. | 100. | 99.88 |
| Bulk density | N.d | N.d. | N.d. | N.d. | N.d. | 3.09 | 3.09 | 2.76 | N.d. |
| Powder density sink/float | N.d | N.d | N.d. | N.d. | N.d. | 3.16 | 3.12 | 3.00 | N.d |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | |
| Ba | 300 | 200 | 100 | 150 | 70 | 305 | 87 | 97 | 30 |
| Be | N | 1 | 1 | N | N | 31 | 20 | 4 | N |
| Ce | N | N | N | N | N | 71 | N | 67 | N |
| Co | 70 | 20 | 20 | 15 | 20 | 51 | 43 | 10 | 10 |
| Cr | 105 | 20 | 70 | 150 | 150 | 547 | 549 | 9 | 200 |
| Cu | 15 | 150 | 150 | 20 | 2 | 21 | N | 17 | 70 |
| Ga | 20 | 15 | 15 | 15 | 15 | 7 | N | N | 20 |
| La | N | N | N | N | 50 | 23 | 17 | 21 | 20 |
| Mo | N | N | N | N | N | 3 | 4 | 3 | N |
| Nb | N | N | 3 | N | N | N | 2 | 7 | N |
| Ni | 50 | 50 | 30 | 30 | 15 | 148 | 209 | 11 | 15 |
| Pb | 15 | 30 | 10 | 7 | N | 7 | 4 | 24 | N |
| Rb | -- | -- | -- | -- | -- | 50 | 20 | 20 | -- |
| Sc | 30 | 20 | 15 | 70 | 20 | >68 | 23 | 9 | 20 |
| Sn | N | N | N | N | N | N | N | N | N |
| Sr | 700 | 500 | 700 | 700 | 2,000 | 442 | 105 | 372 | 100 |
| V | 150 | 70 | 70 | 300 | 150 | >215 | 126 | 41 | 100 |
| Y | 15 | 50 | 50 | 50 | 30 | 11 | 7 | 34 | 50 |
| Yb | 2 | 5 | 5 | 5 | 5 | 2 | 2 | 4 | 5 |
| Zn | N | N | N | N | N | 151 | 325 | 258 | N |
| Zr | 30 | 150 | 50 | 70 | 150 | 48 | 29 | 212 | 200 |

Footnotes follow at end of table.

**Table 33**. Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Lens or layers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | In or adjacent to the Phoenix layer | | | | | Ward | Mount Audubon | | Central City |
| Map locality No. ---- | 260 | 268 | 198 | 245 | 193 | 116 | 103 | 108 | 346 |
| Sample No. ---------- | N-321a | N-400b | N227a-65 | N602a-64 | N169a-65 | W281c-71 | W222b-71 | W256b-71 | D245a |
| Lab No. ------------- | D100279 | W175655 | W175650 | W175653 | W175649 | W178083 | W178079 | W178077 | D100277 |
| | [1]Modes in volume percent | | | | | | | | |
| K-feldspar ----------- | 1.0 | -- | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase---------- | 8 | Tr | 58.6 | 14.4 | 24.4 | 9 | -- | -- | -- |
| Quartz --------------- | 5 | 21 | 4.7 | 24.1 | 44.4 | 2 | Tr | 28 | 43 |
| Biotite --------------- | -- | -- | -- | -- | .1 | Tr | -- | -- | -- |
| Hornblende --------- | 1 | 5 | 7.9 | .7 | .6 | 44 | 13 | 9 | -- |
| Pyroxene[2] ----------- | 21 | 25 | 22.7 | -- | -- | 26 | 83 | 27 | -- |
| Opaque minerals---- | Tr | Tr | 1.3 | .1 | 2.6 | Tr | -- | -- | Tr |
| Apatite --------------- | Tr | Tr | Tr | -- | .8 | 1 | Tr | Tr | -- |
| Zircon --------------- | -- | Tr | -- | -- | -- | -- | -- | Tr | -- |
| Calcite--------------- | 26 | 4 | .9 | 1.0 | .1 | -- | Tr | -- | -- |
| Epidote -------------- | 36 | 23 | 2.5 | 41.8 | 11.4 | 8 | 4 | 36 | 45 |
| Muscovite-sericite[3] - | -- | Tr | -- | -- | 1.1 | 10 | -- | -- | -- |
| Sphene -------------- | 2 | 2 | 1.4 | 3.3 | 1.2 | -- | Tr | Tr | 2 |
| Scapolite ------------ | -- | 15 | -- | -- | -- | -- | -- | -- | -- |
| Garnet --------------- | -- | 5 | Tr | -- | 13.3 | -- | -- | -- | Tr |
| Tremolite-actinolite | -- | -- | -- | 11.9 | -- | -- | -- | -- | -- |
| Chlorite ------------- | -- | -- | -- | 2.7 | -- | -- | -- | -- | -- |
| Allanite ------------- | -- | -- | -- | -- | -- | -- | -- | Tr | -- |
| Cummingtonite ----- | -- | -- | -- | -- | -- | -- | -- | -- | 10 |
| | Normative minerals | | | | | | | | |
| Q -------------------- | 5.020 | 22.604 | 15.211 | 20.728 | 39.559 | -- | 3.361 | 29.651 | 39.347 |
| Or -------------------- | 6.691 | 4.302 | 2.612 | 2.447 | 2.677 | 7.056 | 2.427 | 1.886 | .355 |
| Ab-------------------- | 13.514 | 2.599 | 14.228 | 4.562 | 3.684 | 9.882 | 3.401 | 1.952 | .117 |
| An ------------------- | 30.692 | 30.132 | 35.554 | 32.182 | 36.261 | 27.340 | 12.017 | 23.064 | 39.910 |
| Hl -------------------- | .050 | .050 | .050 | .050 | .033 | .049 | .017 | .016 | .050 |
| Wo ------------------- | 15.481 | 18.922 | 14.217 | 14.623 | 7.219 | 19.178 | 33.746 | 13.282 | 10.265 |
| En-------------------- | 10.357 | 7.051 | 6.755 | 8.804 | 1.003 | 14.294 | 32.685 | 19.131 | 1.048 |
| Fs -------------------- | 3.146 | -- | 2.003 | 1.847 | -- | 5.206 | 7.944 | 3.851 | -- |
| Fo -------------------- | -- | -- | -- | -- | -- | 6.133 | -- | -- | -- |
| Fa -------------------- | -- | -- | -- | -- | -- | 2.462 | -- | -- | -- |
| Mt-------------------- | 6.683 | 7.653 | 5.244 | 8.933 | 3.947 | 4.616 | 2.469 | 4.484 | -- |
| Hm------------------- | -- | .789 | -- | -- | 2.311 | -- | -- | -- | 5.312 |
| Il --------------------- | 1.465 | 1.632 | 1.202 | 1.861 | 1.243 | .964 | .400 | .644 | 1.615 |
| Tn-------------------- | -- | -- | -- | -- | -- | -- | -- | -- | .275 |
| Ap-------------------- | .451 | .551 | .547 | .765 | 1.407 | .731 | .166 | .236 | .546 |
| Fr -------------------- | .109 | -- | .020 | .086 | -- | .618 | .419 | .597 | .040 |
| Cc-------------------- | 4.900 | 2.990 | 1.645 | 1.631 | -- | .181 | .228 | .091 | -- |

Footnotes follow at end of table.

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Gold Hill area | | | | | | | Idaho Springs area |
|---|---|---|---|---|---|---|---|---|
| | Calc-silicate coarsely inter-layered with hornblende gneiss | | Calc-silicate interlayered with pyroxene-rich hornblende-bearing gneiss | | Calc-silicate finely interlayered with hornblende gneiss | | | Lens in biotite gneiss |
| Map locality No. | 13 | 13 | 1 | 1 | 2 | 2 | 2 | 279 |
| Sample No. | GH281-3-76 | GH281-4-76 | GH1-5-77 | GH1-6-77 | GH2-1-77 | GH2-2-77 | GH2-6-77 | IS3-80 |
| Lab. No. | W211743 | W211744 | W211745 | W211746 | W211747 | W211748 | W211749 | W211776 |
| **Chemical analyses in weight percent** | | | | | | | | |
| $SiO_2$ | 67.4 | 50.6 | 52.2 | 48.7 | 49.2 | 57.8 | 48.3 | 51.1 |
| $Al_2O_3$ | 9.4 | 12.7 | 3.1 | 14.0 | 13.7 | 16.4 | 13.2 | 17.0 |
| $Fe_2O_3$ | 1.7 | 2.3 | 1.7 | 2.5 | 3.0 | 1.8 | 2.1 | 3.2 |
| FeO | 2.7 | 4.9 | 3.9 | 5.2 | 6.0 | 4.8 | 7.0 | 5.6 |
| MgO | 4.4 | 7.8 | 13.8 | 8.5 | 6.0 | 1.9 | 8.6 | 2.8 |
| CaO | 10.3 | 15.5 | 22.6 | 15.5 | 16.1 | 11.0 | 15.0 | 12.0 |
| $Na_2O$ | 1.8 | 1.4 | .17 | 1.8 | 1.7 | 3.3 | 1.5 | 3.4 |
| $K_2O$ | .53 | .58 | .16 | .62 | .91 | .85 | .72 | .63 |
| $H_2O+$ | .65 | .79 | .37 | .68 | 1.1 | .74 | .99 | .78 |
| $H_2O-$ | .33 | .35 | .10 | .20 | .18 | .26 | .10 | .14 |
| $TiO_2$ | .39 | .73 | .05 | 1.3 | 1.9 | .98 | 1.8 | 2.5 |
| $P_2O_5$ | .15 | .10 | .04 | .14 | .25 | .22 | .21 | .38 |
| MnO | .16 | .22 | .21 | .14 | .20 | .13 | .16 | .11 |
| $CO_2$ | .04 | .55 | .36 | .10 | .19 | .22 | .06 | .53 |
| F | .06 | .14 | .06 | .4 | .09 | .07 | .3 | .05 |
| Cl | .008 | .01 | .008 | .032 | .009 | .010 | .010 | .013 |
| S (total) | .01 | .01 | .01 | .05 | .07 | .01 | .01 | .01 |
| Subtotal | 100. | 99. | 99. | 99. | 100. | 100. | 100. | 100. |
| Less O | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total | 100. | 99. | 99. | 99. | 100. | 100. | 100. | 100. |
| Bulk density | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| **Semiquantitative spectrographic analyses in parts per million** | | | | | | | | |
| Ba | 110 | 360 | 62 | 230 | 240 | 260 | 290 | 130 |
| Be | 4 | 2 | 6 | N | 22 | 2 | 4 | 1 |
| Ce | N | N | N | N | N | N | N | N |
| Co | 17 | 39 | 5 | 48 | 54 | 22 | 49 | 33 |
| Cr | 35 | 470 | 2 | 670 | 410 | 14 | 430 | 110 |
| Cu | 17 | 6 | 5 | 26 | 1,300 | 30 | 35 | 41 |
| Ga | 10 | 10 | 5 | 8 | 13 | 20 | 14 | 19 |
| La | 42 | N | N | N | N | 34 | N | 25 |
| Mo | N | 2 | 3 | 1 | 2 | 2 | 2 | N |
| Nb | 7 | 5 | 6 | 6 | 8 | 8 | 6 | 15 |
| Ni | 28 | 130 | 6 | 200 | 150 | 16 | 130 | 49 |
| Pb | 17 | 15 | 11 | 28 | 61 | 22 | 17 | 12 |
| Rb | -- | -- | -- | -- | -- | -- | -- | -- |
| Sc | 11 | 41 | 2 | 38 | 44 | 25 | 37 | 30 |
| Sn | 3 | N | 4 | N | 5 | 3 | 3 | -- |
| Sr | 290 | 280 | 230 | 300 | 420 | 870 | 360 | 400 |
| V | 77 | 160 | 19 | 140 | 170 | 110 | 170 | 140 |
| Y | 47 | 11 | 7 | 14 | 11 | 21 | 9 | 26 |
| Yb | 5 | 1 | 1 | 1 | 1 | 2 | 1 | 2 |
| Zn | 130 | 190 | 190 | 80 | 200 | 130 | 130 | 130 |
| Zr | 150 | 35 | 90 | 41 | 47 | 100 | 31 | 260 |

Footnotes follow at end of table.

**Table 33.** Chemical and spectrographic analyses, modes, and normative minerals for calc-silicate gneiss, central Front Range, Colorado.--Continued

| | Gold Hill area | | | | | | | Idaho Springs area |
|---|---|---|---|---|---|---|---|---|
| | Calc-silicate coarsely inter-layered with hornblende gneiss | | Calc-silicate interlayered with pyroxene-rich hornblende-bearing gneiss | | Calc-silicate finely interlayered with hornblende gneiss | | | Lens in biotite gneiss |
| Map locality No. ---- | 13 | 13 | 1 | 1 | 2 | 2 | 2 | 279 |
| Sample No. ---------- | GH281-3-76 | GH281-4-76 | GH1-5-77 | GH1-6-77 | GH2-1-77 | GH2-2-77 | GH2-6-77 | IS3-80 |
| Lab. No. ------------- | W211743 | W211744 | W211745 | W211746 | W211747 | W211748 | W211749 | W211776 |
| | | | [1]Modes in volume percent | | | | | |
| K-feldspar ----------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Plagioclase----------- | 35. | 34. | -- | 26.3 | 34.4 | 59.7 | 27.4 | 51.1 |
| Quartz --------------- | 30. | -- | -- | 1.4 | -- | 7.4 | .1 | 5.8 |
| Biotite --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hornblende ---------- | 3. | 12. | -- | 28.0 | 12.4 | 7.8 | 41.0 | 11.4 |
| Pyroxene[2] ------------ | 25. | 42. | 83. | 31.6 | 42.8 | 17.8 | 29.6 | 16.0 |
| Opaque minerals---- | Tr | Tr | -- | Tr | .2 | Tr | -- | .9 |
| Apatite -------------- | Tr | Tr | -- | -- | .5 | .3 | .4 | .5 |
| Zircon --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Calcite--------------- | -- | 1. | 5. | -- | -- | -- | -- | 1.2 |
| Epidote -------------- | 7. | 10. | Tr | 1.1 | 7.5 | 5.6 | .6 | 10.9 |
| Muscovite-sericite[3] - | -- | -- | 2. | -- | -- | -- | -- | -- |
| Sphene -------------- | Tr | 1. | -- | 1.5 | 2.2 | 1.4 | .9 | 2.2 |
| Scapolite ------------ | -- | -- | -- | 10.5 | -- | -- | -- | -- |
| Garnet --------------- | -- | -- | -- | -- | -- | -- | -- | -- |
| Tremolite-actinolite | -- | -- | -- | -- | -- | -- | -- | -- |
| Chlorite ------------- | Tr | -- | 10. | -- | -- | -- | -- | -- |
| Allanite ------------- | Tr | -- | -- | -- | -- | -- | -- | -- |
| Cummingtonite ----- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | Normative minerals | | | | | |
| Q --------------------- | 33.000 | 4.625 | 2.213 | -- | 1.985 | 12.851 | -- | 5.210 |
| Or -------------------- | 3.153 | 3.500 | .959 | 3.690 | 5.367 | 5.026 | 4.266 | 3.725 |
| Ab-------------------- | 15.257 | 12.023 | 1.384 | 15.117 | 14.282 | 27.867 | 12.653 | 28.714 |
| An ------------------- | 16.149 | 27.262 | 7.364 | 28.612 | 27.048 | 27.482 | 27.270 | 29.321 |
| Hl -------------------- | .017 | .017 | .017 | .050 | .016 | .016 | .017 | .016 |
| Wo ------------------- | 14.072 | 19.236 | 43.149 | 18.548 | 20.602 | 9.989 | 18.173 | 10.144 |
| En-------------------- | 11.031 | 19.839 | 34.853 | 18.632 | 14.913 | 4.735 | 19.138 | 6.978 |
| Fs -------------------- | 3.208 | 6.414 | 6.130 | 4.836 | 5.619 | 5.934 | 7.527 | 3.698 |
| Fo -------------------- | -- | -- | -- | 1.885 | -- | -- | 1.638 | -- |
| Fa -------------------- | -- | -- | -- | .539 | -- | -- | .710 | -- |
| Mt-------------------- | 2.481 | 3.406 | 2.500 | 3.651 | 4.341 | 2.611 | 3.053 | 4.643 |
| Il --------------------- | .746 | 1.416 | .096 | 2.487 | 3.601 | 1.862 | 3.428 | 4.751 |
| Ap-------------------- | .358 | .242 | .096 | .334 | .591 | .521 | .499 | .901 |
| Fr -------------------- | .096 | .275 | .118 | .802 | .139 | .104 | .579 | .033 |
| Pr -------------------- | .019 | .019 | .019 | .094 | .131 | .019 | .019 | .019 |
| Cc -------------------- | .092 | 1.277 | .830 | .229 | .431 | .501 | .137 | 1.206 |

[1]Modes estimated for samples D245a, GH281-3-76, GH-281-4-76, and GH1-5-77.
[2]Pyroxene undifferentiated, but mostly diposide.
[3]Muscovite-sericite is replacement of plagioclase.

**Table 34.** Chemical and spectrographic analyses and modes for garnet-magnetite-hornblende-quartz gneiss, Central City quadrangle, central Front Range, Colorado.

[Analysts for all rapid-rock analyses, H.F. Phillip, P.D.L. Elmore, P.W. Scott, K.E. White. Analyst for all spectrographic analyses, R.G. Havens. N.d., not determined; N, not detected; N.A., not available; --, not found; <, less than; Tr, trace]

| Map locality No. --- | 327 | 328 | 332 | 342 | 330 | 331 |
|---|---|---|---|---|---|---|
| Sample No. --------- | A125-55 | A126-55 | GO-51A-55 | GO-51B-55 | Mary 1 | Mary 2 |
| Lab No. ------------- | 140572 | 140573 | 140577 | 140578 | 140579 | 140580 |
| | | | Chemical analyses in weight percent | | | |
| $SiO_2$ ----------------- | 52.8 | 49.7 | 52.4 | 51.4 | 49.7 | 43.1 |
| $Al_2O$----------------- | 11.1 | 10.5 | 8.2 | 9.4 | 7.8 | 9.7 |
| $Fe_2O_3$--------------- | 3.4 | 4.9 | 11.7 | 10.9 | 11.0 | 7.6 |
| FeO ------------------ | 16.5 | 16.8 | 13.9 | 15.0 | 13.9 | 17.9 |
| MgO ----------------- | 2.0 | 2.0 | 2.8 | 3.8 | 1.9 | 2.4 |
| CaO------------------ | 2.4 | 2.3 | 5.4 | 3.0 | 2.4 | 2.4 |
| $Na_2O$ --------------- | .05 | .09 | .10 | .09 | .06 | .06 |
| $K_2O$------------------ | .21 | .31 | .49 | 1.8 | 1.2 | .91 |
| $H_2O$+ --------------- | 1.2 | 1.4 | .74 | .87 | 1.3 | 1.3 |
| $H_2O$- ---------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| $TiO_2$ ----------------- | .42 | .38 | .32 | .52 | .30 | .42 |
| $P_2O_5$ ----------------- | .89 | .52 | .70 | .59 | .94 | .76 |
| MnO----------------- | 3.5 | 3.5 | 3.5 | 3.2 | 3.0 | 3.7 |
| $CO_2$------------------ | 5.6 | 8.0 | .25 | .13 | 6.4 | 9.6 |
| F---------------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Cl -------------------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| S (total) ------------ | 1.3 | 1.2 | 1.2 | .94 | 1.2 | .86 |
| Total -------------- | 100. | 100. | 101. | 100. | 100. | 100. |
| | | | Semiquantitative spectrographic analyses in parts per million | | | |
| Ba -------------------- | 30 | 150 | 150 | 700 | 150 | 150 |
| Be -------------------- | N | N | 1 | N | 1 | N |
| Co-------------------- | 30 | 30 | 15 | 30 | 30 | 30 |
| Cr -------------------- | 70 | 70 | 30 | 70 | 70 | 70 |
| Cu-------------------- | 300 | 300 | 150 | 300 | 300 | 150 |
| Ga-------------------- | N | N | <30 | <30 | <30 | <30 |
| La -------------------- | 30 | 30 | 30 | 30 | 30 | 30 |
| Mo ------------------- | 30 | 70 | 15 | 15 | 30 | 30 |
| Ni -------------------- | 70 | 70 | 30 | 70 | 70 | 70 |
| Pb -------------------- | 15 | 15 | N | N | 15 | 15 |
| Sc -------------------- | 15 | 15 | 7 | 15 | 7 | 15 |
| Sr -------------------- | 7 | 15 | 15 | 30 | 15 | 15 |
| V --------------------- | 150 | 150 | 70 | 150 | 150 | 150 |
| Y --------------------- | 70 | 30 | 30 | 70 | 70 | 70 |
| Yb-------------------- | <10 | <10 | <10 | <10 | <10 | <10 |
| Zn-------------------- | 300 | 300 | 300 | 300 | 300 | 300 |
| Zr -------------------- | 150 | 150 | 70 | 150 | 70 | 70 |
| | | | Modes in volume percent | | | |
| K-feldspar ---------- | N.A. | N.A. | -- | -- | N.A. | N.A. |
| Plagioclase---------- | N.A. | N.A. | -- | -- | N.A. | N.A. |
| Quartz --------------- | N.A. | N.A. | 37 | 20 | N.A. | N.A. |
| Biotite --------------- | N.A. | N.A. | 11 | 7.5 | N.A. | N.A. |
| Hornblende --------- | N.A. | N.A. | 11 | 28.5 | N.A. | N.A. |
| Garnet --------------- | N.A. | N.A. | 32 | 30 | N.A. | N.A. |
| Opaque minerals--- | N.A. | N.A. | [1]8.5 | 12 | N.A. | N.A. |
| Apatite -------------- | N.A. | N.A. | .5 | 2 | N.A. | N.A. |
| Sphene -------------- | N.A. | N.A. | -- | Tr | N.A. | N.A. |

[1]Pyrite 0.5 percent.

**Table 35.** Average chemical composition for calc-silicate gneiss by area, central Front Range, Colorado.

| Oxide | Nederland | Central City | Ward Mt. Audubon | Ward excluding Mt. Audubon | Idaho Springs | Gold Hill: Interlayered with hornblende gneiss | Gold Hill: Interlayered with pyroxene-rich gneiss |
|---|---|---|---|---|---|---|---|
| $SiO_2$----- | 54.2 | 62.8 | 57.7 | 47.6 | 51.1 | 54.7 | 50.4 |
| $Al_2O_3$---- | 14.2 | 14.7 | 7.4 | 13.3 | 17.0 | 13.1 | 8.6 |
| $Fe_2O_3$---- | 5.1 | 5.3 | 2.4 | 3.2 | 3.2 | 2.2 | 2.1 |
| FeO ------ | 3.3 | .54 | 4.4 | 6.3 | 5.6 | 5.1 | 4.6 |
| MgO----- | 2.7 | .42 | 10.4 | 9.3 | 2.8 | 5.8 | 11.2 |
| CaO------ | 15.0 | 13.4 | 15.5 | 15.8 | 12.0 | 13.6 | 19.1 |
| $Na_2O$ ---- | .9 | .04 | .33 | 1.2 | 3.4 | 1.9 | 1.0 |
| $K_2O$------ | .6 | .06 | .37 | 1.2 | .63 | .8 | 0.39 |
| $TiO_2$ ----- | .58 | .96 | .28 | .51 | 2.50 | 1.06 | .90 |
| $P_2O_5$ ----- | .31 | .23 | .09 | .31 | .38 | .18 | .90 |
| MnO----- | .17 | .22 | .19 | .19 | .11 | .17 | .18 |

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.

[Analysts for wet chemical analyses for samples from map locality numbers 206, 228, 390, G.O. Riddle; 261, 366, 367, 369, E.S. Daniels; 339, 341, 347, D.F. Powers and P.R. Barnett; 348, L.N. Tarrant; 350, Jean Theobold. Analysts for rapid rock chemical analyses for samples from map locality numbers 98, 114, 116, 145, Leonard Shapiro; 193, 198, 245, 268, P.D.L. Elmore; 302, 303, Z.A. Hamlin; 33, Kay Coates and Hezekiah Smith; 270, Deborah Kobilis; 199, 310, 311, 312, 313, 361, 362, 363, 364, P.D.L. Elmore, S.D. Botts, Gillison Chloe, Lowell Artis, Hezekiah Smith, James Kelsey, J.L. Glenn, Joseph Budinsky. Analysts for spectrographic analyses for samples from locality numbers 206, 228, 390, Barbara Tobin; 366, 367, J.L. Sutton, Jr.; 33, Norma Rait; 261, J.G. Haffty; 369, H.G. Neiman; 270, Leung Mei; 339, 341, 347, P.R. Barnett; 310, 311, 312, 313, 361, W.B. Crandell; 98, 114, 116, 193, 198, 199, 245, 268, 302, 303, 304, 362, 363, J.L. Harris. Normative minerals calculated using the USGS graphic analysis program. N.d., not determined; N, not detected; --, not looked for; Tr, trace; <, less than; x, present but quantity unknown]

| | Phoenix layer | | | | | | [1]Inclusion in Caribou stock | [1]Baltimore layer | [1]Lens northeast of Cardinal |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 268 | 198 | 245 | 261 | 228 | 199 | 193 | 390 | 306 |
| Sample No. | N-400a | N227-65 | N602-64 | N322a | N278-64 | N233-65 | N169-65 | N-126 | N354a-65 |
| Lab. No. | W175654 | W175651 | W175652 | D100280 | D101256 | W171837 | W175648 | D101254 | D101255 |
| Chemical analyses in weight percent | | | | | | | | | |
| $SiO_2$ | 50.4 | 48.2 | 52.8 | 44.75 | 49.15 | 46.3 | 52.5 | 49.35 | 46.49 |
| $Al_2O_3$ | 13.8 | 13.4 | 15.4 | 14.34 | 16.07 | 16.3 | 15.2 | 14.58 | 13.16 |
| $Fe_2O_3$ | 4.6 | 4.2 | 3.4 | 3.70 | 3.28 | 4.7 | 4.1 | 4.66 | 3.63 |
| FeO | 4.7 | 7.6 | 6.7 | 8.30 | 7.16 | 5.7 | 6.0 | 8.01 | 9.27 |
| MgO | 3.0 | 7.6 | 5.5 | 8.50 | 6.54 | 6.1 | 6.8 | 6.96 | 7.34 |
| CaO | 17.4 | 11.0 | 8.2 | 13.63 | 11.16 | 18.1 | 6.8 | 10.37 | 14.16 |
| $Na_2O$ | .74 | 1.7 | 3.2 | 1.74 | 2.83 | .94 | 2.5 | 2.69 | 1.86 |
| $K_2O$ | .55 | 2.1 | .82 | 1.24 | .87 | .05 | 2.1 | .64 | .59 |
| $H_2O+$ | 1.2 | 1.5 | 1.0 | 1.78 | 1.11 | .72 | 1.6 | 1.28 | 1.02 |
| $H_2O-$ | .19 | .25 | .11 | .07 | .04 | .13 | .20 | .06 | .05 |
| $TiO_2$ | 1.9 | 1.1 | 1.2 | .95 | .84 | .63 | .97 | .95 | 1.16 |
| $P_2O_5$ | .27 | .30 | .29 | .20 | .13 | .21 | .13 | .11 | .16 |
| MnO | .24 | .28 | .26 | .22 | .19 | .20 | .23 | .22 | .27 |
| $CO_2$ | 1.3 | .21 | .22 | .40 | .42 | <.05 | <.05 | .00 | .74 |
| F | .027 | .23 | .14 | .12 | .23 | <.01 | .21 | .15 | .13 |
| Cl | .021 | .16 | .01 | .02 | .02 | .01 | .05 | .03 | .03 |
| S (total) | N.d. | N.d. | N.d. | N.d. | N.d. | .00 | N.d. | N.d. | N.d. |
| Subtotal | 100 | 99. | 99. | 99.96 | 100.04 | 100 | 99. | 100.06 | 100.06 |
| Less O | N.d. | N.d. | N.d. | .05 | .10 | N.d. | N.d. | .07 | .06 |
| Total | 100 | 99. | 99. | 99.91 | 99.94 | 100. | 99. | 99.99 | 100.00 |
| Bulk density | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float | N.d. | N.d. | N.d. | N.d. | 3.00 | 3.32 | N.d. | 3.02 | 3.13 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | |
| Ba | 200 | 1,000 | 100 | 500 | 200 | 20 | 200 | 200 | 150 |
| Be | 1 | 1 | N | 0 | 0 | 3 | N | 0 | 0 |
| Ce | N | N | N | 0 | 0 | N | 500 | 0 | 0 |
| Co | 20 | 50 | 50 | 50 | 30 | 20 | 15 | 70 | 50 |
| Cr | 50 | 300 | 100 | 150 | 300 | 500 | 300 | 700 | 200 |
| Cu | 2 | 50 | 15 | 70 | 70 | 7 | 10 | 100 | 15 |
| Ga | 15 | 15 | 10 | 15 | 20 | 15 | 15 | 30 | 20 |
| Gd | N | -- | -- | -- | -- | -- | -- | -- | -- |
| La | N | N | N | 0 | 0 | N | 150 | 0 | 0 |
| Mo | N | N | N | 0 | 0 | 5 | 3 | 0 | 0 |
| Nb | N | N | N | 0 | 0 | N | N | 0 | 0 |
| Nd | N | N | N | N | N | N | N | N | 0 |
| Ni | 30 | 150 | 50 | 150 | 70 | 70 | 100 | 70 | 100 |
| Pb | 15 | 10 | N | 15 | 0 | N | N | 0 | 0 |
| Pr | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Rb | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Sc | 30 | 30 | 50 | 30 | 50 | 50 | 20 | 70 | 70 |
| Sn | N | N | N | N | N | N | N | N | -- |
| Sr | 300 | 700 | 200 | 1,500 | 200 | 2,000 | 1,000 | 300 | 200 |
| V | 100 | 150 | 150 | 200 | 300 | 300 | 100 | 500 | 700 |
| Y | 30 | 30 | 50 | 20 | 2 | 50 | 50 | 30 | 20 |
| Yb | 3 | 3 | 5 | 2 | N | 5 | 5 | N | -- |
| Zn | -- | N | N | N | 0 | N | N | 0 | 0 |
| Zr | 100 | 70 | 70 | 30 | 30 | 30 | 200 | 30 | 50 |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Phoenix layer | | | | | | [1]Inclusion in Caribou stock | [1]Baltimore layer | [1]Lens northeast of Cardinal |
|---|---|---|---|---|---|---|---|---|---|
| Map locality No. | 268 | 198 | 245 | 261 | 228 | 199 | 193 | 390 | 206 |
| Sample No. ------ | N-400a | N227-65 | N602-64 | N322a | N278-64 | N233-65 | N169-65 | N-126 | N354a-65 |
| Lab. No.---------- | W175654 | W175651 | W175652 | D100280 | D101256 | W171837 | W175648 | D101254 | D101255 |
| | | | | Modes of volume percent | | | | | |
| K-feldspar ------- | 5 -- | .9 | -- | -- | -- | -- | Tr | -- | -- |
| Plagioclase------- | 7 | 34.6 | 47.3 | 4.4 | [6]46.6 | 35.2 | 33.0 | 38.5 | 25.6 |
| Quartz ----------- | 21 | .8 | 8.0 | .2 | 1.9 | .2 | 11.3 | 1.0 | 13.0 |
| Biotite ----------- | -- | Tr | 5.6 | -- | -- | -- | 29.2 | -- | -- |
| Sericite ---------- | -- | -- | -- | 15.5 | -- | -- | -- | -- | -- |
| Hornblende ------ | 26 | 48.2 | 34.3 | 65.1 | 39.6 | -- | 19.8 | 56.6 | 44.9 |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Clinopyroxene[7] - | 5 | 9.3 | Tr | 14.4 | 10.1 | 45.5 | .3 | 1.2 | 5.2 |
| Orthophyroxene- | Tr | -- | -- | -- | Tr | -- | -- | Tr | -- |
| Apatite ----------- | Tr | .6 | .5 | .4 | .4 | .4 | 2.1 | Tr | .4 |
| Opaque minerals | 2 | 2.3 | 2.8 | Tr | -- | 4.0 | 3.9 | 2.7 | 4.9 |
| Allanite ---------- | -- | -- | -- | Tr | -- | -- | -- | -- | -- |
| Sphene ----------- | 2 | .6 | .1 | -- | .1 | -- | -- | Tr | -- |
| Zircon ------------ | Tr | -- | .1 | -- | -- | -- | -- | Tr | -- |
| Calcite------------ | 2 | .5 | 1. | Tr | -- | Tr | -- | -- | .2 |
| Chlorite ---------- | -- | .5 | .3 | -- | .2 | -- | -- | -- | .3 |
| Epidote----------- | 35 | 1.7 | -- | -- | 1.1 | 14.7 | .4 | -- | 5.5 |
| | | | | Normative minerals | | | | | |
| Q ----------------- | 46.578 | -- | 5.968 | -- | -- | 1.104 | 39.559 | -- | -- |
| C ----------------- | 14.232 | -- | -- | -- | -- | -- | -- | -- | -- |
| Or ---------------- | 3.849 | 12.510 | 4.896 | 7.478 | 5.206 | .298 | 2.677 | 3.838 | 3.527 |
| Ab---------------- | 7.241 | 13.308 | 27.285 | 9.212 | 24.250 | 8.015 | 3.684 | 23.097 | 15.923 |
| An --------------- | -- | 23.547 | 25.537 | 28.225 | 29.214 | 40.418 | 36.261 | 26.198 | 26.119 |
| Hl ---------------- | .039 | .266 | .017 | -- | -- | -- | .033 | -- | -- |
| Ne---------------- | -- | -- | -- | 3.150 | -- | -- | -- | -- | -- |
| Wo --------------- | -- | 11.128 | 4.761 | 15.395 | 9.730 | 20.327 | 7.219 | 10.554 | 16.352 |
| En---------------- | 7.503 | 18.531 | 13.841 | 9.529 | 11.552 | 15.308 | 1.003 | 17.426 | 12.329 |
| Fs ---------------- | 2.534 | 8.998 | 8.080 | 4.963 | 6.670 | 5.961 | -- | 9.751 | 8.505 |
| Fo ---------------- | -- | .386 | -- | 8.462 | 3.464 | -- | -- | .114 | 4.321 |
| Fa ---------------- | -- | .206 | -- | 4.857 | 2.204 | -- | -- | .071 | 3.285 |
| Mt---------------- | 7.899 | 6.139 | 4.981 | 5.475 | 4.816 | 6.867 | 3.947 | 6.856 | 5.325 |
| Hm --------------- | -- | -- | -- | -- | -- | -- | 2.311 | -- | -- |
| Il ----------------- | 4.274 | 2.106 | 2.303 | 1.841 | 1.616 | 1.831 | 1.243 | 1.831 | 2.229 |
| Ap---------------- | .757 | .716 | .694 | .483 | .312 | .264 | 1.407 | .264 | .383 |
| Fr ---------------- | .598 | .421 | .237 | -- | -- | -- | -- | -- | -- |
| Cc ---------------- | 2.159 | .481 | .506 | .928 | .967 | -- | -- | -- | 1.703 |
| Mg --------------- | 1.131 | -- | -- | -- | -- | -- | -- | -- | -- |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Golden Gate layer | | | | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Map locality No- | [8]310 | [8]311 | 312 | [8]313 | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. ------ | GG-1 | GG-2 | GG-3 | GG-4 | SP-1-80 | SP-1a-80 | M-250a | M-276a | M-279a | M-300 | M-488a |
| Lab. No.---------- | W170057 | W170058 | W170059 | W170060 | W211750 | W211751 | W170053 | W170054 | W170055 | W170056 | D101105 |
| Chemical analyses in weight percent | | | | | | | | | | | |
| $SiO_2$ ------------- | 52.3 | 53.1 | 61.4 | 51.2 | 47.6 | 45.5 | 51.1 | 48.9 | 49.6 | 48.5 | 50.74 |
| $Al_2O$------------- | 13.4 | 14.5 | 11.3 | 13.7 | 13.4 | 15.6 | 15.0 | 13.8 | 15.9 | 15.7 | 13.93 |
| $Fe_2O_3$------------ | 3.7 | 2.7 | 2.5 | 2.7 | 1.9 | 3.8 | 2.7 | 2.7 | 2.1 | 2.1 | 3.02 |
| FeO -------------- | 11.5 | 10.6 | 6.6 | 8.1 | 9.1 | 7.2 | 9.2 | 9.7 | 9.5 | 9.9 | 9.23 |
| MgO ------------- | 4.4 | 3.7 | 3.9 | 7.7 | 5.1 | 4.4 | 4.8 | 7.1 | 5.6 | 6.8 | 7.33 |
| CaO -------------- | 8.7 | 8.5 | 9.0 | 9.6 | 12.3 | 15.2 | 9.4 | 11.0 | 10.9 | 11.0 | 8.78 |
| $Na_2O$ ------------ | 2.6 | 3.1 | 2.2 | 3.0 | 2.5 | 1.8 | 3.7 | 2.2 | 2.4 | 2.3 | 1.51 |
| $K_2O$--------------- | .28 | .45 | .59 | .91 | 1.3 | .63 | .58 | 1.4 | .49 | .68 | 1.19 |
| $H_2O+$ ----------- | .87 | .81 | .69 | .77 | 1.5 | 1.3 | .90 | 1.0 | 1.0 | .77 | 2.45 |
| $H_2O-$ ------------ | .13 | .09 | .09 | .07 | .20 | .07 | .07 | .08 | .09 | .06 | .18 |
| $TiO_2$ ------------- | 1.4 | 1.6 | .82 | 1.0 | 4.5 | 4.2 | .96 | .92 | .95 | .98 | .95 |
| $P_2O_5$ ------------- | .17 | .24 | .52 | .18 | .48 | .43 | .17 | .12 | .15 | .17 | .09 |
| MnO ------------- | .27 | .26 | .18 | .22 | .18 | .21 | .32 | .26 | .23 | .21 | .23 |
| $CO_2$ -------------- | <.05 | <.05 | .30 | .06 | .68 | 1.1 | .31 | .08 | .40 | <.05 | .35 |
| F----------------- | N.d. | N.d. | N.d. | N.d. | .1 | .05 | N.d. | N.d. | N.d. | N.d. | .07 |
| Cl ---------------- | N.d. | N.d. | N.d. | N.d. | .024 | .014 | N.d. | N.d. | N.d. | N.d. | .04 |
| S (total) --------- | N.d. | N.d. | N.d. | N.d. | .01 | .19 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Subtotal -------- | 100. | 100. | 100. | 99. | 101. | 101. | 99. | 99. | 99. | 99. | 100.09 |
| Less O ----------- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | .05 |
| Total ----------- | 100. | 100. | 100. | 99. | 101. | 101. | 99. | 99. | 99. | 99. | 100.04 |
| Bulk density ----- | 3.02 | 2.96 | 2.86 | 2.97 | N.d. | N.d. | 2.90 | N.d. | N.d. | 2.98 | N.d. |
| Powder density sink/float ------ | 3.08 | 3.08 | 2.98 | 3.05 | N.d. | N.d. | 3.03 | 3.10 | 3.05 | 3.10 | 3.03 |
| Semiquantitative spectrographic analyses in parts per million | | | | | | | | | | | |
| Ba --------------- | 500 | 200 | 700 | 300 | 150 | 120 | 70 | 200 | 150 | 200 | 100 |
| Be --------------- | N | N | 2 | 1 | N | 1 | 1 | N | N | N | N |
| Ce --------------- | N | N | N | N | N | N | N | N | N | N | N |
| Co --------------- | 30 | 30 | 30 | 50 | 38 | 47 | 50 | 30 | 50 | 50 | 50 |
| Cr --------------- | N | 10 | 150 | 300 | 180 | 230 | 70 | 70 | 50 | 150 | 100 |
| Cu --------------- | 50 | 2 | 15 | 20 | 32 | 80 | 500 | 20 | 30 | 7 | 20 |
| Ga --------------- | 20 | 20 | 10 | 15 | 21 | 19 | 20 | 15 | 15 | 15 | <30 |
| Gd --------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| La --------------- | N | N | 100 | N | N | N | N | N | N | N | N |
| Mo --------------- | 5 | 3 | 3 | 3 | N | 1 | 3 | 3 | 3 | 3 | N |
| Nb --------------- | N | N | 3 | N | 6 | 13 | N | N | N | N | -- |
| Nd --------------- | N | N | N | 100 | N | N | -- | N | N | N | -- |
| Ni --------------- | 10 | 15 | 50 | 70 | 57 | 70 | 70 | 50 | 30 | 7 | 70 |
| Pb --------------- | N | N | N | N | 13 | 11 | N | N | N | N | 20 |
| Pr --------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| Rb --------------- | -- | -- | -- | -- | N | N | -- | -- | -- | -- | -- |
| Sc --------------- | 20 | 30 | 20 | 50 | 22 | 31 | 50 | 50 | 50 | 30 | 50 |
| Sn --------------- | N | N | N | N | N | N | N | N | N | N | N |
| Sr --------------- | 150 | 200 | 500 | 300 | 290 | 530 | 700 | 300 | 300 | 300 | 70 |
| V ---------------- | 150 | 200 | 150 | 200 | 140 | 150 | 200 | 150 | 300 | 150 | 500 |
| Y ---------------- | 30 | 50 | 30 | 30 | 12 | 17 | 30 | 20 | 30 | 30 | 20 |
| Yb --------------- | 3 | 5 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 3 | <3 |
| Zn --------------- | N | N | N | N | 150 | 170 | N | N | N | N | N |
| Zr --------------- | 50 | 70 | 150 | 70 | 57 | 150 | 70 | 30 | 50 | 7 | 50 |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Golden Gate layer | | | | Clear Creek layer | | Morrison layers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Map locality No- | [8] 310 | [8]311 | 312 | [8]313 | 270 | 270 | 361 | 362 | 363 | 364 | 366 |
| Sample No. ------ | GG-1 | GG-2 | GG-3 | GG-4 | SP-1-80 | SP-1a-80 | M-250a | M-276a | M-279a | M-300 | M-488a |
| Lab. No.---------- | W170057 | W170058 | W170059 | W170060 | W211750 | W211751 | W170053 | W170054 | W170055 | W170056 | D101105 |
| | | | | | Modes in volume percent | | | | | | |
| K-feldspar ------- | -- | -- | -- | -- | Tr | 5 | -- | -- | -- | -- | -- |
| Plagioclase------- | 26.8 | 35.4 | 12.6 | 34.9 | 36.0 | 25. | 51.9 | 35.6 | 40.7 | 34.9 | .7 |
| Quartz------------ | 10.9 | 9.9 | 44.0 | 3.1 | 1.5 | .5 | .8 | Tr | .9 | 1.0 | 12.1 |
| Biotite ------------ | .5 | .1 | .4 | 2.5 | 1.0 | -- | -- | -- | -- | -- | -- |
| Sericite ----------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 34.3 |
| Hornblende ------ | 60.6 | 52.3 | 30.8 | 56.9 | 49.4 | 25. | 44.2 | 56.6 | 56.5 | 62.3 | 25.8 |
| Cummingtonite - | -- | -- | -- | -- | 1.8 | Tr | -- | -- | -- | -- | 20.4 |
| Clinopyroxene[7] - | -- | -- | 2.0 | -- | 5.3 | 36. | .1 | 7.4 | -- | 1.1 | -- |
| Orthopyroxene -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite ----------- | .4 | .4 | .7 | .1 | -- | 1. | .2 | .2 | Tr | Tr | .1 |
| Opaque minerals | .8 | 1.2 | Tr | .3 | .2 | .5 | .5 | Tr | .1 | -- | 5.8 |
| Allanite ---------- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | .3 |
| Sphene ----------- | -- | .7 | 1.9 | 1.1 | 3.4 | 8. | .4 | .1 | .7 | .7 | -- |
| Zircon ------------ | -- | -- | -- | -- | -- | -- | .2 | -- | -- | -- | -- |
| Calcite------------ | Tr | 4.1 | 1.1 | .1 | 1.4 | 4. | -- | .8 | Tr | -- | -- |
| Chlorite ---------- | -- | -- | -- | -- | -- | -- | .2 | -- | -- | -- | Tr |
| Epidote----------- | -- | -- | .7 | -- | -- | -- | 1.5 | -- | .3 | -- | .5 |
| | | | | | Normative minerals | | | | | | |
| Q ----------------- | 7.968 | 7.032 | 23.927 | -- | 0.825 | 3.413 | 0.194 | -- | 1.152 | -- | 5.779 |
| Or----------------- | 1.676 | 2.692 | 3.510 | 5.466 | 7.649 | 3.666 | 3.475 | 8.426 | 2.948 | 4.086 | 7.223 |
| Ab----------------- | 22.283 | 26.559 | 18.740 | 25.803 | 20.843 | 14.926 | 31.746 | 18.959 | 20.674 | 19.788 | 13.124 |
| An ---------------- | 24.374 | 24.624 | 19.343 | 21.577 | 21.527 | 32.167 | 22.923 | 24.081 | 31.726 | 31.018 | 28.469 |
| Hl ----------------- | -- | -- | -- | -- | .049 | .016 | -- | -- | -- | -- | -- |
| Wo ---------------- | 7.606 | 6.883 | 8.465 | 10.543 | 13.116 | 13.526 | 7.882 | 12.603 | 8.247 | 9.745 | 5.593 |
| En----------------- | 11.100 | 9.330 | 9.778 | 17.303 | 12.647 | 10.791 | 12.121 | 11.572 | 14.198 | 11.810 | 18.751 |
| Fs ----------------- | 16.460 | 15.264 | 9.095 | 10.287 | 7.990 | 3.099 | 13.864 | 9.519 | 14.831 | 10.612 | 13.674 |
| Fo ----------------- | -- | -- | -- | 1.534 | -- | -- | -- | 4.511 | -- | 3.791 | -- |
| Fa ----------------- | -- | -- | -- | 1.005 | -- | -- | -- | 4.089 | -- | 3.753 | -- |
| Mt----------------- | 5.434 | 3.964 | 3.649 | 3.979 | 2.743 | 5.426 | 3.969 | 3.990 | 3.100 | 3.096 | 4.498 |
| Il ------------------ | 2.693 | 3.077 | 1.568 | 1.930 | 8.510 | 7.855 | 1.849 | 1.780 | 1.837 | 1.892 | 1.853 |
| Ap----------------- | .408 | .576 | 1.240 | .433 | 1.132 | 1.003 | .408 | .290 | .362 | .409 | .219 |
| Fr ----------------- | -- | -- | -- | -- | .117 | .024 | -- | -- | -- | -- | -- |
| Pr ----------------- | -- | -- | -- | -- | .019 | .350 | -- | -- | -- | -- | -- |
| Cc----------------- | -- | -- | .687 | .139 | 1.540 | 2.464 | 1.568 | .185 | .926 | -- | .818 |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Lens in cordierite gneiss-- Morrison | | Lens and layers near Ward | | [2]Lens upper Green Lakes | [2]Layers, Lake Isabelle area | |
|---|---|---|---|---|---|---|---|
| Map locality No- | [8]369 | 367 | 114 | [8]116 | 145 | [8]98 | 98 |
| Sample No------- | M532-C2 | M-497c | W266a-1-71 | W281b-71 | W275b-70 | W151-71 | W151a-71 |
| Lab. No.---------- | D100505 | D101106 | W178074 | W178082 | W178080 | W178075 | W178076 |
| | | | Chemical analyses in weight percent | | | | |
| $SiO_2$ -------------- | 49.34 | 51.10 | 54.6 | 44.5 | 54.6 | 45.5 | 61.5 |
| $Al_2O_3$------------ | 14.52 | 13.14 | 17.8 | 14.4 | 14.1 | 12.7 | 14.4 |
| $Fe_2O_3$------------ | 3.89 | 5.53 | 5.9 | 3.7 | 6.2 | 3.3 | 2.0 |
| FeO --------------- | 9.0 | 10.46 | 3.7 | 6.1 | 7.3 | 7.9 | 4.1 |
| MgO -------------- | 7.43 | 5.68 | 3.3 | 9.8 | 5.2 | 9.7 | 5.5 |
| CaO--------------- | 9.68 | 8.35 | 8.3 | 16.4 | 7.7 | 13.6 | 5.9 |
| $Na_2O$ ------------- | 2.04 | 1.07 | 2.2 | 1.0 | .65 | .69 | 2.5 |
| $K_2O$--------------- | .65 | .70 | 1.4 | 1.4 | 1.8 | 2.2 | 1.8 |
| $H_2O+$ ----------- | 1.70 | 1.72 | 1.9 | 2.0 | 1.0 | 1.7 | 1.2 |
| $H_2O-$ ------------ | .06 | .22 | .20 | .15 | .06 | .26 | .11 |
| $TiO_2$ -------------- | 1.17 | 1.53 | .54 | .57 | 1.6 | .54 | .37 |
| $P_2O_5$ ------------- | .12 | .21 | .24 | .35 | .29 | .12 | .07 |
| MnO -------------- | .25 | .24 | .22 | .19 | .16 | .29 | .18 |
| $CO_2$--------------- | .04 | .06 | .08 | .02 | .00 | .01 | .01 |
| F------------------- | .06 | .12 | .18 | .83 | .18 | .33 | .34 |
| Cl ----------------- | .04 | .01 | .02 | .02 | .01 | .03 | .03 |
| S (total)---------- | N.d. | N.d. | .01 | .00 | .05 | .19 | .00 |
| Subtotal--------- | 99.99 | 100.14 | 100. | 100. | 100. | 99. | 99. |
| Less O------------ | .04 | .05 | N.d. | N.d. | N.d. | N.d. | N.d. |
| Total ------------ | 99.95 | 100.09 | 100. | 100. | 100. | 99. | 99. |
| Bulk density ----- | N.d. | N.d. | 2.91 | 3.02 | 3.04 | 3.00 | 2.75 |
| Powder density sink/float ------- | 3.03 | 3.08 | 2.92 | 3.16 | 3.04 | 3.08 | 2.80 |
| | | | Semiquantitative spectrographic analyses in parts per million | | | | |
| Ba ----------------- | 70 | 70 | 392 | 570 | 397 | 173 | 302 |
| Be ----------------- | 0 | 2 | N | 2 | 1 | 1 | 5 |
| Ce ----------------- | -- | -- | N | 122 | 88 | N | 66 |
| Co----------------- | 30 | 50 | 20 | 24 | 35 | 48 | 3 |
| Cr ----------------- | 150 | 50 | 4 | 126 | 13 | 481 | 8 |
| Cu----------------- | 70 | 30 | 21 | 14 | 27 | 47 | 23 |
| Ga----------------- | 20 | <50 | 9 | 33 | 15 | 2 | 21 |
| Gd----------------- | -- | -- | N | N | 12 | N | 14 |
| La ----------------- | 0 | 0 | N | 67 | 16 | N | 34 |
| Mo ---------------- | 0 | 0 | 3 | 2 | 3 | 3 | 2 |
| Nb----------------- | 0 | 0 | N | 10 | 3 | -- | 13 |
| Nd----------------- | -- | 0 | N | 45 | 76 | -- | 69 |
| Ni ----------------- | 50 | 50 | 4 | 66 | 44 | 251 | 5 |
| Pb ----------------- | 10 | 0 | 13 | 21 | 11 | 4 | 42 |
| Pr ----------------- | -- | -- | 4 | 9 | 5 | -5 | 7 |
| Rb----------------- | -- | -- | 70 | 150 | 100 | 100 | 70 |
| Sc ----------------- | 100 | 50 | 31 | 15 | >68 | 43 | 26 |
| Sn ----------------- | -- | -- | 2 | 8 | <3 | .7 | 4 |
| Sr ----------------- | 300 | 100 | 486 | 156 | 457 | 200 | 534 |
| V ------------------ | 200 | 500 | 215 | 161 | >215 | >215 | 21 |
| Y ------------------ | 30 | 30 | 13 | 25 | 27 | 9 | 122 |
| Yb----------------- | 5 | <5 | 2 | 3 | 3 | 2 | 9 |
| Zn----------------- | 0 | 0 | 109 | 126 | 126 | 196 | 282 |
| Zr ----------------- | 50 | 50 | 39 | 149 | 56 | 22 | 499 |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | Lens in cordierite gneiss-- Morrison | | Lens and layers near Ward | | [2]Lens upper Green Lakes | [2]Layers, Lake Isabelle area | |
|---|---|---|---|---|---|---|---|
| Map locality No. | [8]369 | 367 | 114 | [8]116 | 145 | [8]98 | 98 |
| Sample No. ------ | M532-C2 | M-497c | W266a-1-71 | W281b-71 | W275b-70 | W151-71 | W151a-71 |
| Lab. No.---------- | D100505 | D101106 | W178074 | W178082 | W178080 | W178075 | W178076 |
| **Modes in volume percent** | | | | | | | |
| K-feldspar ------- | -- | -- | 5 | -- | -- | -- | .1 |
| Plagioclase------- | 21.5 | 1.7 | 60 | -- | 33 | 31.0 | 33. |
| Quartz ------------ | 2.7 | 23.4 | 10 | -- | 23 | -- | 37. |
| Biotite ------------ | 6.3 | -- | -- | -- | 19 | 25.5 | 10. |
| Sericite ----------- | -- | 22.1 | -- | 3 | -- | Tr | -- |
| Hornblende ------ | 68.2 | 49.0 | 25 | 77 | 16 | 3.2 | 19. |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- |
| Clinopyroxene[7] - | -- | -- | -- | 3 | -- | 37.1 | -- |
| Orthopyroxene -- | -- | -- | -- | -- | -- | -- | -- |
| Apatite ----------- | .1 | .5 | x | 1 | 1 | -- | Tr |
| Opaque minerals | 1.2 | 3.3 | x | 1 | 8 | 3.2 | Tr |
| Allanite ---------- | -- | -- | -- | -- | Tr | -- | -- |
| Sphene ----------- | -- | -- | -- | -- | -- | -- | -- |
| Zircon ------------ | Tr | -- | -- | -- | Tr | -- | Tr |
| Calcite------------ | Tr | Tr | -- | -- | -- | -- | -- |
| Chlorite- --------- | -- | -- | x | -- | -- | -- | -- |
| Epidote ----------- | -- | -- | x | 15 | -- | -- | -- |
| **Normative minerals** | | | | | | | |
| Q ----------------- | 2.247 | 13.441 | 15.292 | -- | 19.301 | -- | 18.921 |
| Or ---------------- | 3.914 | 4.217 | 8.264 | 8.209 | 10.563 | 13.213 | 10.675 |
| Ab----------------- | 17.589 | 9.231 | 18.448 | 2.625 | 5.388 | 5.561 | 21.008 |
| An ---------------- | 29.084 | 29.550 | 34.599 | 30.510 | 30.068 | 25.587 | 22.954 |
| Ne----------------- | -- | -- | -- | 3.047 | -- | .080 | -- |
| Hl ----------------- | -- | -- | .033 | .033 | .016 | .050 | .050 |
| Wo ---------------- | 7.847 | 4.551 | 1.378 | 17.547 | 2.031 | 16.596 | 1.439 |
| En----------------- | 18.855 | 14.423 | 8.210 | 12.274 | 12.860 | 10.643 | 13.747 |
| Fs ----------------- | 12.071 | 12.804 | 1.415 | 3.800 | 5.795 | 4.862 | 5.621 |
| Fo ----------------- | -- | -- | -- | 8.371 | -- | 9.747 | -- |
| Fa ----------------- | -- | -- | -- | 2.856 | -- | 4.908 | -- |
| Mt----------------- | 5.747 | 8.175 | 8.545 | 5.323 | 8.927 | 4.863 | 2.910 |
| Il ------------------ | 2.264 | 2.963 | 1.024 | 1.074 | 3.018 | 1.042 | .705 |
| Ap----------------- | .290 | .507 | .568 | .823 | .682 | .289 | .166 |
| Fr ----------------- | -- | -- | .326 | 1.629 | .314 | .667 | .688 |
| Pr ----------------- | -- | -- | .019 | -- | .093 | .361 | -- |
| Cc----------------- | .093 | .139 | .182 | .045 | -- | .023 | .023 |

Footnotes follow at end of table

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | [3]Layer James of 4th Creek area | [4]Southeast July mine | | Lens and layers Central City area | | | | |
|---|---|---|---|---|---|---|---|---|
| Map locality No- | 33 | 302 | 303 | 339 | 341 | 347 | 348 | 350 |
| Sample No. ------ | GH350-75 | ML-7a | ML-8a | CC-309b | CC-730 | S472c-53 | EWT10-54 | EWT281-54 |
| Lab. No.---------- | W194508 | W197381 | W197382 | G-3102 | G-3103 | G-3104 | A-4 | A1-72 |
| | | | | Chemical analyses in weight percent | | | | |
| $SiO_2$ -------------- | 57.9 | 50.8 | 47.7 | 50.01 | 49.43 | 48.54 | 48.19 | 55.27 |
| $Al_2O_3$------------ | 16.1 | 14.7 | 12.0 | 13.86 | 15.02 | 17.18 | 15.66 | 16.17 |
| $Fe_2O_3$------------ | 2.4 | 2.6 | 3.6 | 2.95 | 3.11 | 3.61 | 3.86 | 2.27 |
| FeO --------------- | 4.8 | 6.7 | 9.2 | 10.35 | 8.73 | 10.61 | 9.08 | 6.30 |
| MgO -------------- | 3.8 | 7.5 | 5.6 | 5.99 | 5.88 | 5.42 | 7.17 | 3.42 |
| CaO --------------- | 7.8 | 13.5 | 18.4 | 10.33 | 10.18 | 7.87 | 8.68 | 7.49 |
| $Na_2O$ ------------ | 2.0 | 1.4 | .46 | 2.57 | 3.38 | 3.14 | .92 | 4.65 |
| $K_2O$-------------- | 1.4 | .76 | .37 | .57 | 1.06 | .34 | 1.07 | 1.31 |
| $H_2O+$ ----------- | 1.0 | .71 | 1.2 | 1.18 | .95 | 1.46 | 3.17 | .99 |
| $H_2O-$ ------------ | .38 | .12 | .11 | .08 | .06 | .10 | .67 | .03 |
| $TiO_2$ ------------- | .84 | .56 | .91 | 1.19 | 1.33 | 1.05 | .75 | .98 |
| $P_2O_5$------------- | .14 | .18 | .12 | .12 | .20 | .13 | .12 | .24 |
| MnO -------------- | .10 | .16 | .30 | .22 | .21 | .29 | .26 | .19 |
| $CO_2$--------------- | .01 | .26 | .33 | .33 | .27 | .27 | .01 | .48 |
| F------------------ | .06 | .12 | .05 | .07 | .09 | .09 | N.d. | .17 |
| Cl ---------------- | .01 | .02 | .02 | .02 | .05 | .01 | N.d. | N.d. |
| S (total)--------- | N.d. | .00 | .20 | .10 | .01 | .04 | N.d. | .01 |
| Subtotal --------- | 99. | 100. | 101. | 99.94 | 99.96 | 100.15 | 99.61 | 99.98 |
| Less O ----------- | N.d. | N.d. | N.d. | .08 | .06 | .06 | N.d. | N.d. |
| Total ----------- | 99. | 100. | 101. | 99.86 | 99.90 | 100.09 | 99.61 | 99.98 |
| Bulk density ----- | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. | N.d. |
| Powder density sink/float ------- | N.d. | N.d. | N.d. | 3.06 | 3.04 | 3.01 | N.d. | N.d. |
| | | | | Semiquantitative spectrographic analyses in parts per million | | | | |
| B ----------------- | 7 | 9 | 19 | N | N | N | N | N |
| Ba ---------------- | 220 | 120 | 41 | 70 | 211 | 70 | -- | 200 |
| Be ---------------- | 2 | 2 | 8 | 0 | 0 | 0 | -- | -- |
| Ce ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Co ---------------- | 26 | 34 | 29 | 50 | 50 | 34 | -- | -- |
| Cr ---------------- | 68 | 600 | 37 | 60 | 200 | 16 | -- | -- |
| Cu ---------------- | 24 | 4 | 84 | 73 | 5 | 16 | -- | -- |
| Ga ---------------- | 21 | 12 | 17 | 23 | 20 | 23 | -- | -- |
| Gd ---------------- | 13 | N | N | -- | -- | -- | -- | -- |
| La ---------------- | 19 | 14 | N | <100 | <50 | <100 | -- | -- |
| Mo --------------- | N | N | N | 0 | 2 | 0 | -- | -- |
| Nb ---------------- | 10 | 6 | 7 | 0 | 0 | 0 | -- | -- |
| Nd ---------------- | N | N | N | 0 | 0 | 0 | -- | -- |
| Ni ---------------- | 33 | 140 | 32 | 44 | 70 | 12 | -- | -- |
| Pb ---------------- | 17 | 16 | N | <30 | 10 | <30 | -- | -- |
| Pr ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Rb ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Sc ---------------- | 33 | 33 | >9 | 77 | 30 | 67 | -- | -- |
| Sn ---------------- | N | N | N | -- | -- | -- | -- | -- |
| Sr ---------------- | 210 | 130 | 130 | 150 | 311 | 180 | -- | -- |
| V ----------------- | 180 | 150 | 190 | 410 | 500 | 410 | -- | -- |
| Y ----------------- | 30 | 12 | 15 | 50 | 30 | 40 | -- | -- |
| Yb ---------------- | 4 | 1 | 3 | 5 | 4 | 4 | -- | -- |
| Zn ---------------- | 140 | 98 | 190 | 0 | 0 | 0 | -- | -- |
| Zr ---------------- | 67 | 24 | 62 | 90 | 200 | 100 | -- | -- |

Footnotes follow at end of table.

**Table 37.** Chemical and spectrographic analyses, modes, and normative minerals for hornblende gneiss and amphibolite, central Front Range, Colorado.--Continued

| | [3]Layer James of 4th Creek area | [4]Southeast July mine | Lens and layers Central City area | | | | | |
|---|---|---|---|---|---|---|---|---|
| Map locality No.-- | 33 | 302 | 303 | 339 | 341 | 347 | 348 | 350 |
| Sample No.-------- | GH350-75 | ML-7a | ML-8a | CC-309b | CC-730 | S472c-53 | EWT10-54 | EWT281-54 |
| Lab. No.---------- | W194508 | W197381 | W197382 | G-3102 | G-3103 | G-3104 | A-4 | A1-72 |
| Modes in volume percent | | | | | | | | |
| K-feldspar ------- | -- | -- | -- | -- | .6 | -- | -- | N.d. |
| Plagioclase------- | 52.0 | 29.2 | 23.5 | 30.5 | 36.1 | 40.4 | 38.3 | N.d. |
| Quartz ----------- | 18.2 | 5.9 | 2.1 | 6.5 | 7.1 | 9.0 | 12.9 | N.d/ |
| Biotite ----------- | 4.9 | .4 | -- | .3 | 1.0 | -- | -- | N.d. |
| Sericite ---------- | -- | .3 | .3 | -- | -- | -- | -- | N.d. |
| Hornblende ------ | 23.7 | 50.9 | 23.2 | 58.9 | 51.7 | 40.3 | 48.8 | N.d. |
| Cummingtonite - | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Clino-pyroxene[7] | -- | 9.6 | 41.9 | 1.9 | 2.2 | -- | -- | N.d. |
| Ortho-pyroxene - | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Apatite ---------- | -- | .5 | .4 | .3 | .5 | .3 | -- | N.d. |
| Opaque minerals | .2 | Tr | -- | .4 | Tr | 3.0 | -- | N.d. |
| Allanite --------- | -- | -- | -- | -- | -- | -- | -- | N.d. |
| Sphene ---------- | .5 | .4 | 3.4 | -- | .6 | -- | -- | N.d. |
| Zircon- ---------- | -- | -- | -- | -- | .1 | -- | -- | N.d. |
| Calcite----------- | -- | 1.4 | -- | -- | .1 | 2.6 | -- | N.d. |
| Chlorite --------- | .5 | -- | -- | .9 | -- | 4.4 | -- | N.d. |
| Epidote- --------- | -- | 1.4 | 5.2 | -- | Tr | -- | -- | N.d. |
| Normative minerals | | | | | | | | |
| Q ---------------- | 18.058 | 3.811 | 4.188 | 1.630 | -- | -- | 55.85 | 3.307 |
| Or ---------------- | 8.420 | 4.500 | 2.179 | 3.377 | 6.277 | 2.011 | 6.434 | 7.754 |
| Ab---------------- | 17.149 | 11.723 | 3.732 | 21.654 | 28.290 | 26.520 | 7.922 | 39.411 |
| An --------------- | 31.406 | 31.725 | 29.562 | 24.740 | 22.925 | 31.846 | 36.064 | 19.411 |
| Hl ---------------- | .017 | .033 | .033 | .033 | .083 | .016 | -- | -- |
| Wo --------------- | 2.768 | 13.277 | 24.326 | 9.739 | 10.077 | 1.712 | 2.878 | 5.055 |
| En---------------- | 9.632 | 18.717 | 13.899 | 14.956 | 8.041 | 12.405 | 18.171 | 8.531 |
| Fs ---------------- | 6.298 | 9.548 | 12.520 | 14.845 | 6.389 | 13.991 | 12.954 | 8.421 |
| Fo ---------------- | -- | -- | -- | -- | 4.649 | .755 | -- | -- |
| Fa ---------------- | -- | -- | -- | -- | 4.071 | .963 | -- | -- |
| Mt---------------- | 3.542 | 3.777 | 5.202 | 4.288 | 4.519 | 5.239 | 5.695 | 3.297 |
| Il ----------------- | 1.624 | 1.066 | 1.722 | 2.266 | 2.531 | 1.996 | 1.449 | 1.864 |
| Ap---------------- | .338 | .427 | .283 | .285 | .475 | .308 | .289 | .569 |
| Fr- --------------- | .099 | .214 | .080 | .122 | .149 | .161 | -- | .309 |
| Pr ---------------- | -- | -- | .373 | .188 | .019 | .075 | -- | .019 |
| Cc---------------- | .023 | .593 | .748 | .752 | .615 | .615 | .023 | 1.093 |

[1]Nederland quadrangle.
[2]Ward quadrangle.
[3]Gold Hill quadrangle.
[4]Monarch Lake quadrangle.
[5]Estimated mode.
[6]Includes some sericite.
[7]Mostly diopside.
[8]Amphibolite

# APPENDIX III

## TABLES 28-32, 36, AND 38-40

## GENERAL INFORMATION

**Table 28.**--Averaged modes and chemical analyses for biotite gneiss north and south of the Idaho Springs-Ralston shear zone, central Front Range, Colorado.

[Tr, trace]

| Mineral | Biotite gneiss | Garnet-biotite gneiss | Sillimanite-biotite gneiss | Garnet-sillimanite-biotite gneiss |
|---|---|---|---|---|
| | Modes south of shear zone (volume percent) | | | |
| K-feldspar ---------- | 6.5 | 10.4 | 4.7 | 2.3 |
| Plagioclase---------- | 22.4 | 25.8 | 13.3 | 12.1 |
| Quartz --------------- | 45.6 | 36.5 | 44.2 | 45.8 |
| Biotite --------------- | 15.9 | 16.5 | 20.0 | 17.9 |
| Garnet --------------- | 0 | .8 | 0 | 1.1 |
| Sillimanite ---------- | 0 | 0 | 8.4 | 3.9 |
| Opaque minerals---- | .7 | 1.0 | .8 | 1.3 |
| Muscovite-sericite -- | 7.5 | 6.7 | 8.1 | 9.6 |
| Chlorite ------------- | .1 | 0 | Tr | .1 |
| | Modes north of shear zone (volume percent) | | | |
| K-feldspar ---------- | 9.6 | 9.6 | 6.6 | 8.8 |
| Plagioclase---------- | 30.8 | 31.0 | 14.2 | 10.5 |
| Quartz --------------- | 37.5 | 40.7 | 38.0 | 39.7 |
| Biotite --------------- | 16.2 | 13.2 | 21.1 | 21.7 |
| Garnet --------------- | 0 | 3.3 | 0 | 3.8 |
| Sillimanite ---------- | 0 | 0 | 8.8 | 8.6 |
| Opaque minerals---- | 1.7 | .6 | 1.4 | .8 |
| Muscovite-sericite -- | 3.5 | .4 | 8.1 | 5.4 |
| Chlorite ------------- | .2 | Tr | Tr | .2 |

| Mineral | Major Oxides (weight percent): South of shear zone (34 analyses) | North of shear zone (62 analyses) |
|---|---|---|
| $SiO_2$ | 68.4 | 60.6 |
| $Al_2O_3$ | 15.7 | 19.2 |
| $Fe_2O_3$ | 2.7 | 3.0 |
| FeO | 4.1 | 5.9 |
| MgO | 1.8 | 2.5 |
| CaO | .9 | 1.2 |
| $Na_2O$ | 1.4 | 1.1 |
| $K_2O$ | 3.5 | 3.3 |

Note: Cordierite not shown in garnet-sillimanite-biotite gneiss for either of the areas. It is common in the northern area and sparse in the southern area.

**Table 29.** Summary of oxides in central Front Range biotite-gneiss assemblages.

[N.d., not determined]

| Number of analyses | 12 | 5 | 2 | 29 | 14 | 3 | 5 |
|---|---|---|---|---|---|---|---|
| Oxide | Biotite gneiss | Garnet-biotite gneiss | Garnet-hornblende-biotite gneiss | Sillimanite-biotite gneiss | Garnet-sillimanite-biotite gneiss | Magnetite-sillimanite-biotite gneiss | Cordierite-magnetite-sillimanite-biotite gneiss |
| $SiO_2$ ---- | 70.6 | 61.9 | 66.5 | 65.9 | 61.5 | 66.4 | 50.9 |
| $Al_2O_3$--- | 13.2 | 15.1 | 12.6 | 17.5 | 17.2 | 16.4 | 24.4 |
| $Fe_2O_3$--- | 2.4 | 1.8 | 3.6 | 2.7 | 2.3 | 4.6 | 5.9 |
| FeO ----- | 3.0 | 6.3 | 4.3 | 4.1 | 5.4 | 3.3 | 6.4 |
| MgO---- | 1.7 | 2.2 | 1.9 | 1.9 | 2.3 | 1.7 | 3.3 |
| CaO----- | 1.9 | 2.0 | 3.0 | .7 | 1.3 | .29 | .7 |
| $Na_2O$ --- | 2.1 | 2.2 | 1.3 | 1.2 | 1.8 | .84 | 1.3 |
| $K_2O$----- | 2.8 | 3.1 | 3.8 | 3.6 | 3.6 | 3.0 | 3.7 |
| $TiO_2$ ---- | .95 | .73 | 1.2 | 1.2 | .95 | .97 | 1.4 |
| $P_2O_5$---- | .21 | .13 | .37 | .11 | .10 | .09 | .08 |
| MnO---- | .07 | .12 | .13 | .08 | .10 | .05 | .11 |
| $CO_2$----- | .02 | .28 | .41 | .03 | .03 | .02 | .01 |
| F--------- | .13 | .08 | .03 | .10 | .11 | .06 | N.d. |
| S (total) | .06 | .02 | .10 | .01 | .01 | .01 | .2 |
| $K_2O/Na_2O$ (weight percent) | | | | | | | |
| | 1.3 | 1.4 | 2.9 | 3.0 | 2.0 | 3.6 | 3.3 |
| CaO/MgO (weight percent) | | | | | | | |
| | 1.12 | .91 | 1.58 | .37 | .56 | .17 | .20 |

| Number of analyses | 1 | 15 | 1 | 9 | 7 | 5 |
|---|---|---|---|---|---|---|
| | | | | | Thermal | |
| Oxide | Cordierite-garnet-biotite gneiss | Cordierite-garnet-K-feldspar-sillimanite-biotite gneiss | Cordierite-garnet-sillimanite-biotite gneiss | Cordierite-sillimanite-biotite gneiss | Cordierite-magnetite-biotite gneiss | Biotite gneiss |
| $SiO_2$ ---- | 75.8 | 63.1 | 72.4 | 60.7 | 55.1 | 51.4 |
| $Al_2O_3$--- | 10.2 | 18.0 | 13.3 | 20.0 | 22.6 | 23.9 |
| $Fe_2O_3$--- | 1.7 | 1.7 | .9 | 3.4 | 3.9 | 4.8 |
| FeO ----- | 4.0 | 6.3 | 5.3 | 5.1 | 6.2 | 6.2 |
| MgO---- | 2.8 | 2.3 | 2.3 | 2.7 | 2.9 | 3.1 |
| CaO----- | .52 | .7 | .17 | .59 | .40 | 1.8 |
| $Na_2O$ --- | .57 | 1.1 | 1.7 | 1.2 | 1.1 | 1.6 |
| $K_2O$----- | 2.2 | 3.7 | 1.6 | 3.2 | 4.2 | 3.8 |
| $TiO_2$ ---- | .37 | .93 | .20 | .90 | 1.1 | 1.4 |
| $P_2O_5$---- | .05 | .07 | .02 | .07 | .08 | .41 |
| MnO---- | .09 | .17 | .10 | .08 | .11 | .07 |
| $CO_2$----- | N.d. | .02 | .02 | .01 | .02 | .02 |
| F--------- | N.d. | .07 | .09 | .07 | .15 | .36 |
| S (total) | N.d. | .10 | N.d. | .04 | N.d. | .02 |
| $K_2O/Na_2O$ (weight percent) | | | | | | |
| | 3.8 | 3.4 | .9 | 2.7 | 3.8 | 2.4 |
| CaO/MgO (weight percent) | | | | | | |
| | .19 | .30 | .07 | .22 | .14 | .58 |

**Table 30.** Comparison of the average chemical composition of Archean and Early Proterozoic clastic sedimentary rocks with average Front Range biotite gneiss.

[--, nothing reported]

| | Oxides in weight percent | | |
|---|---|---|---|
| Oxides | [1]Archean | [1]Early Proterozoic | Front Range biotite gneiss |
| $SiO_2$ -------- | 65.9 | 70.9 | 65.1 |
| $Al_2O_3$------- | 14.9 | 14.0 | 16.2 |
| [2]$FeO_t$ ------- | 6.4 | 6.1 | 7.4 |
| MgO ------- | 3.6 | 2.4 | 2.3 |
| CaO -------- | 3.3 | 1.3 | 1.3 |
| $Na_2O$ ------- | 2.9 | 1.3 | 1.4 |
| $K_2O$ -------- | 2.3 | 3.0 | 3.4 |
| $TiO_2$ -------- | .6 | .6 | .9 |
| MnO ------- | -- | -- | .12 |
| $P_2O_5$ -------- | -- | -- | .7 |

[1]McLennan, 1982.

[2]$FeO_t$, represents total iron.

**Table 31.** Spectrographic analyses for selected trace elements in central Front Range biotite gneiss by area

[X-ray spectrographic analyses for Nb, Rb, Sr, Y, Zr, analysts: R.G. Johnson, and K.O. Dennen. Quantitative optical spectrographic analyses for Ba, Ce, Cr, Sc, V; analyst: P.H. Briggs, <, less than]

| Area and map locality No. | Trace elements in parts per million | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
| **Central City** | | | | | | | | | | |
| 340 | 1,200 | 74 | 199 | 17 | 233 | 23 | 148 | 137 | 18 | 216 |
| 345 | 605 | 112 | 130 | 15 | 118 | 41 | 77 | 112 | 67 | 228 |
| 349 | 485 | 286 | 162 | 14 | 135 | 23 | 98 | 111 | 46 | 212 |
| **Idaho Springs** | | | | | | | | | | |
| 277 | 1,950 | 249 | 29 | 14 | 145 | 9 | 686 | 68 | 33 | 276 |
| 280 | 492 | 99 | 103 | 15 | 144 | 13 | 94 | 66 | 26 | 288 |
| 281 | 329 | 111 | 27 | 13 | 121 | 10 | 196 | 27 | 43 | 377 |
| 282 | 1,010 | 87 | 3 | 13 | 83 | 10 | 54 | 4 | 44 | 268 |
| 284 | 369 | 88 | 156 | 10 | 86 | 10 | 185 | 64 | 34 | 225 |
| 285 | 1,010 | 121 | 35 | 11 | 134 | 11 | 162 | 22 | 61 | 555 |
| **Ralston Buttes** | | | | | | | | | | |
| 351 | 477 | 96 | 217 | 15 | 167 | 16 | 86 | 93 | 31 | 232 |
| 352 | 392 | 109 | 217 | 71 | 126 | 11 | 90 | 72 | 36 | 248 |
| 353 | 713 | 124 | 267 | 11 | 134 | 8 | 31 | 84 | 38 | 317 |
| 354 | 509 | 71 | 177 | 26 | 164 | 12 | 122 | 79 | 27 | 204 |
| 355 | 349 | 76 | 176 | 14 | 182 | 13 | 19 | 74 | 36 | 246 |
| 356 | 349 | 113 | 134 | 13 | 185 | 9 | 51 | 68 | 40 | 230 |
| 357 | 517 | 236 | 283 | 30 | 307 | 32 | 59 | 157 | 80 | 368 |
| 358 | 516 | 80 | 173 | 22 | 113 | 10 | 139 | 67 | 31 | 222 |
| **Morrison** | | | | | | | | | | |
| 367 | 441 | 90 | 3 | 11 | 20 | 4 | 33 | <2 | 50 | 250 |
| 368A[1] | 495 | 91 | 2 | 13 | 69 | 11 | 11 | <2 | 69 | 278 |
| 368B[1] | 549 | 54 | 3 | 17 | 97 | 8 | 13 | <2 | 51 | 253 |
| **Indian Hills** | | | | | | | | | | |
| 315 | 1,140 | 79 | 79 | 13 | 197 | 18 | 195 | 92 | 23 | 179 |
| 317 | 565 | 77 | 56 | 17 | 180 | 12 | 168 | 45 | 34 | 201 |
| 319 | 592 | 73 | 82 | 11 | 78 | 8 | 125 | 48 | 23 | 223 |
| 320 | 311 | 108 | 94 | 9 | 69 | 6 | 225 | 32 | 39 | 398 |
| **Evergreen** | | | | | | | | | | |
| 322 | 1,100 | 126 | 85 | 15 | 161 | 11 | 436 | 56 | 39 | 222 |
| **Squaw Pass** | | | | | | | | | | |
| 271 | 471 | 91 | 76 | 8 | 79 | 6 | 89 | 37 | 29 | 396 |
| 272 | 649 | 82 | 83 | 15 | 219 | 15 | 118 | 68 | 46 | 216 |
| 274 | 817 | 109 | 111 | 12 | 167 | 19 | 66 | 101 | 41 | 185 |
| 275 | 374 | 55 | 163 | 7 | 107 | 10 | 144 | 74 | 24 | 200 |
| 276 | 576 | 123 | 90 | 18 | 138 | 12 | 138 | 64 | 38 | 226 |
| **Tungsten** | | | | | | | | | | |
| 161 | 765 | 89 | 167 | 8 | 110 | 10 | 214 | 74 | 27 | 245 |
| 174 | 882 | 162 | 161 | 20 | 136 | 19 | 130 | 116 | 41 | 298 |
| 177 | 744 | 117 | 165 | 20 | 157 | 33 | 19 | 146 | 55 | 278 |
| **Nederland** | | | | | | | | | | |
| 200 | 1,320 | 142 | 243 | 21 | 166 | 28 | 206 | 169 | 44 | 279 |
| 230 | 312 | 99 | 37 | 23 | 132 | 9 | 46 | 33 | 49 | 249 |
| 255 | 977 | 121 | 181 | 10 | 92 | 23 | 321 | 134 | 66 | 341 |
| 257 | 892 | 100 | 172 | 15 | 246 | 26 | 130 | 136 | 39 | 212 |
| 263 | 586 | 106 | 227 | 16 | 149 | 26 | 52 | 127 | 43 | 212 |
| **East Portal** | | | | | | | | | | |
| 325 | 851 | 142 | 132 | 15 | 226 | 15 | 91 | 83 | 24 | 228 |
| **Monarch Lake** | | | | | | | | | | |
| 300 | 785 | 88 | 98 | 13 | 165 | 12 | 332 | 54 | 28 | 196 |
| 301 | 700 | 124 | 109 | 20 | 198 | 12 | 206 | 83 | 37 | 188 |
| 303 | 546 | 86 | 94 | 15 | 132 | 18 | 145 | 86 | 36 | 179 |
| 305 | 443 | 84 | 96 | 11 | 125 | 18 | 139 | 82 | 33 | 175 |
| 309 | 347 | 218 | 212 | 15 | 112 | 8 | 141 | 99 | 23 | 317 |
| **Allens Park** | | | | | | | | | | |
| 323 | 368 | 84 | 80 | 19 | 150 | 12 | 160 | 44 | 30 | 241 |

Footnote follows at end of table.

**Table 31.** Spectrographic analyses for selected trace elements in central Front Range biotite gneiss by area.--Continued

| Area and map locality No. | Trace elements in parts per million | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
| **Ward** | | | | | | | | | | |
| 88 -------------------- | 397 | 167 | 27 | 18 | 219 | 8 | 47 | 28 | 52 | 342 |
| 90 -------------------- | 730 | 107 | 127 | 15 | 217 | 17 | 62 | 100 | 33 | 231 |
| 109-------------------- | 218 | 78 | 115 | 10 | 93 | 9 | 149 | 71 | 26 | 245 |
| 122-------------------- | 778 | 83 | 108 | 17 | 185 | 19 | 160 | 99 | 34 | 331 |
| 137-------------------- | 414 | 61 | 50 | 9 | 142 | 14 | 487 | 93 | 17 | 162 |
| 141-------------------- | 946 | 156 | 179 | 17 | 200 | 24 | 158 | 131 | 43 | 263 |
| 154-------------------- | 823 | 113 | 133 | 14 | 202 | 18 | 103 | 101 | 25 | 209 |
| 155-------------------- | 1,230 | 154 | 85 | 17 | 153 | 15 | 200 | 63 | 31 | 273 |
| 156-------------------- | 698 | 91 | 123 | 16 | 100 | 14 | 201 | 86 | 26 | 223 |
| 158-------------------- | 607 | 177 | 228 | 17 | 180 | 33 | 127 | 177 | 27 | 312 |
| **Gold Hill** | | | | | | | | | | |
| 18 -------------------- | 1,010 | 113 | 103 | 19 | 182 | 19 | 270 | 97 | 17 | 251 |
| 19 -------------------- | 180 | 112 | 141 | 53 | 268 | 16 | 11 | 99 | 17 | 253 |
| 26 -------------------- | 334 | 127 | 171 | 16 | 176 | 19 | 13 | 121 | 19 | 294 |
| 31 -------------------- | 260 | 98 | 144 | 13 | 46 | 14 | 36 | 98 | 20 | 380 |
| 35 -------------------- | 981 | 84 | 70 | 13 | 118 | 16 | 309 | 65 | 27 | 206 |
| 51 -------------------- | 885 | 98 | 113 | 11 | 91 | 10 | 138 | 74 | 34 | 258 |
| 58 -------------------- | 47 | 30 | 596 | 10 | 35 | 2 | <05 | 29 | 08 | 163 |
| 73 -------------------- | 903 | 142 | 174 | 18 | 278 | 30 | 95 | 116 | 29 | 205 |

[1]Two distinct layers of biotite gneiss same location.

**Table 32.** Comparison of averaged amounts of trace elements in biotite geneiss of the central Front Range, Colorado, with those in an average shale.

| Trace element (in parts per million) | Ba | Ce | Co | Cr | Cu | Ga | La | Mo | Nb | Ni | Pb | Rb | Sc | Sr | V | Y | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Front Range biotite gneiss | 666 | 114 | 19 | 134 | 35 | 28 | 50 | 4 | 17 | 56 | 28 | 149 | 16 | 145 | 80 | 37 | 85 | 261 |
| [1]Average shale | [2]580 | 50 | 20 | 100 | 57 | [2]19 | 40 | 2 | 20 | 95 | 20 | [2]140 | 10 | 450 | 130 | 30 | 80 | 200 |

[1]Includes Holocene shales (Krauskopf, 1967).

[2]Turekian and Wedpohl, 1964, p. 186.

**Table 36.** Comparison of trace elements in average calc-silicate gneiss, central Front Range, with average carbonate rock, average deep-sea carbonate rock, and average basalt given in parts per million, as reported by Turekian and Wedepohl (1964).

[--, no data; <, less than; * from Krauskopf, 1967]

| Trace element | Calc-silicate gneiss | Carbonate rock | Deep-sea carbonate rock | Basalt |
|---|---|---|---|---|
| Ba ---------- | 239 | 10 | 190 | *330 |
| Ce ---------- | 20 | < 1 | < 1 | * 1 |
| Cr ---------- | 412 | 11 | 11 | *170 |
| Nb ---------- | 8 | -- | -- | 20 |
| Rb ---------- | 35 | -- | -- | 30 |
| Sc----------- | 39 | 1 | 2 | * 30 |
| Sr----------- | 423 | | | 465 |
| V ----------- | 236 | 20 | 20 | *250 |
| Y ----------- | 18 | | | 25 |
| Zr----------- | 70 | | | 150 |

**Table 38.** Average chemical composition of central Front Range hornblende gneiss and amphibolite, and that of several types of basalt.

| | Front Range hornblende gneiss and amphibolite | | | | | | | Typical basalts | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oxide | Phoenix layer | Morrison layer | Central City lenses | Golden Gate layer | Clear Creek layer | Other lenses and layers | [1]Average for Front Range | [2]Tholeiitic basalt | [3]Icelandic basalt | [4]Hawaii basalt | [2]Normal alkali basalt |
| $SiO_2$ ----- | 48.6 | 49.8 | 50.3 | 54.5 | 46.6 | 51.2 | 50.2 | 50.83 | 47.96 | 49.8 | 45.78 |
| $Al_2O_3$---- | 14.9 | 14.9 | 15.6 | 13.2 | 14.5 | 14.4 | 14.6 | 14.07 | 15.53 | 14.0 | 14.64 |
| $Fe_2O_3$---- | 4.0 | 2.5 | 3.2 | 2.9 | 2.9 | 4.0 | 3.3 | 2.88 | 2.06 | 2.5 | 3.16 |
| FeO ------ | 6.7 | 9.5 | 9.0 | 9.2 | 8.2 | 6.5 | 8.2 | 9.0 | 8.34 | 8.5 | 8.73 |
| MgO ----- | 6.2 | 6.3 | 5.6 | 4.9 | 4.8 | 6.5 | 5.7 | 6.34 | 9.70 | 7.2 | 9.39 |
| CaO ------ | 13.2 | 10.2 | 8.9 | 9.0 | 13.8 | 10.8 | 11.0 | 10.42 | 13.32 | 11.3 | 10.74 |
| $Na_2O_3$ --- | 1.9 | 2.4 | 2.9 | 2.7 | 2.2 | 1.6 | 2.3 | 2.23 | 1.82 | 2.2 | .95 |
| $K_2O$------ | .94 | .87 | .87 | .56 | 1.0 | 1.2 | .91 | .82 | .30 | .62 | .95 |
| $TiO_2$ ----- | 1.10 | .95 | 1.10 | 1.20 | 4.3 | .90 | 1.59 | 2.03 | .96 | 2.60 | 2.63 |
| $P_2O_5$ ----- | .23 | .14 | .16 | .28 | .45 | .17 | .24 | .23 | .21 | .32 | .39 |
| MnO ----- | .23 | .25 | .23 | .23 | .19 | .25 | .23 | .18 | .18 | .18 | .20 |

[1]Average of table 37.
[2]Nockolds (1954).
[3]Flanagan (1984).
[4]Brenner and Harel (1976).

**Table 39**. Spectrographic analyses for selected trace elements in parts per million in hornblende gneiss, amphibolite, and calc-silicate gneiss by area, central Front Range, Colorado.

[Quantitative optical spectrographic analyses for the elements Ba, Ce, Cr, Sc, V; analyst, P.H. Briggs. X-ray spectrographic analyses for the elements Nb, Rb, Sr, Zr, Y; analysts R.R. Larson, R.G. Johnson, and K.O. Dennen; <, less than]

| Area and map locality No. | Ba | Ce | Cr | Nb | Rb | Sc | Sr | V | Y | Zr |
|---|---|---|---|---|---|---|---|---|---|---|
| Idaho Springs | | | | | | | | | | |
| [1]279 ----------- | 96 | 33 | 114 | 11 | 10 | 25 | 502 | 131 | 23 | 200 |
| Morrison | | | | | | | | | | |
| 364 ------------ | 220 | 11 | 254 | 7 | 13 | 39 | 254 | 262 | 24 | 70 |
| 367 ------------ | 51 | 18 | 97 | 9 | 7 | 53 | 233 | 355 | 32 | 87 |
| Squaw Pass | | | | | | | | | | |
| 270 ------------ | 77 | 26 | 257 | 12 | 16 | 31 | 159 | 218 | 31 | 134 |
| Nederland | | | | | | | | | | |
| 198------------ | 676 | 35 | 421 | 8 | 64 | 34 | 1,710 | 208 | 27 | 74 |
| 199------------ | 25 | 15 | 407 | 5 | 34 | 44 | 258 | 286 | 17 | 37 |
| 228------------ | 290 | 17 | 130 | 8 | 12 | 39 | 301 | 285 | 25 | 44 |
| [1]260 ----------- | 470 | 14 | 4 | 5 | 45 | <2 | 213 | 74 | 11 | 43 |
| 261------------ | 461 | 24 | 301 | 8 | 45 | 31 | 635 | 259 | 33 | 58 |
| 390------------ | 118 | 10 | 237 | 9 | 15 | 53 | 635 | 302 | 33 | 58 |
| Monarch Lake | | | | | | | | | | |
| 302 ------------ | 180 | 19 | 836 | 10 | 12 | 35 | 149 | 179 | 20 | 43 |
| 303 ------------ | 204 | 18 | 118 | 8 | 21 | 53 | 139 | 368 | 34 | 75 |
| Ward | | | | | | | | | | |
| 98------------- | 268 | 13 | 1,150 | 8 | 112 | 37 | 575 | 206 | 18 | 29 |
| 114 ------------ | 466 | 26 | 14 | 6 | 92 | 26 | 402 | 170 | 17 | 41 |
| 116 ------------ | 290 | 33 | 698 | 6 | 51 | 50 | 254 | 264 | 18 | 45 |
| Gold Hill | | | | | | | | | | |
| [1]01 ------------ | 435 | 30 | 683 | 6 | 59 | 42 | 435 | 206 | 19 | 46 |
| [1]01 ------------ | 58 | 12 | 2 | 6 | 4 | <2 | 228 | 14 | 12 | 52 |
| 01------------- | 170 | 9 | 1,150 | 10 | 14 | 37 | 146 | 193 | 18 | 44 |

[1]Calc-silicate gneiss.

**Table 40.** Frequency distribution for trace elements that occur above their mean in biotite gneiss, central Front Range, Colorado.

7½' Quadrangles

| | |
|---|---|
| CC, Central City | M, Morrison |
| EV-SP, Evergreen and Squaw Pass | N, Nederland |
| GH, Gold Hill | T, Tungsten |
| IH, Indian Hills | RB, Ralston Buttes |
| IS, Idaho Springs | W, Ward |
| ML, Monarch Lake | |

| | Quadrangles | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | M | IH | EV-SP | CC | IS | N | T | RB | W | GH | ML |
| Ba ------------- | | | x | x | x | x | x | | | | |
| Be ------------- | | | | | | | | | x | x | x |
| Ce ------------- | | x | x | x | x | x | | x | x | x | x |
| Cu------------- | x | x | | x | | | | | | | |
| Cr ------------- | | | | x | | x | x | x | x | x | |
| Ga ------------- | x | | | x | | x | x | | x | x | |
| La ------------- | | x | x | x | x | x | x | x | x | x | x |
| Mo ------------ | x | | | x | | x | x | x | x | x | |
| Nb------------- | | | | | | | | x | | | |
| Ni ------------- | | | x | x | | x | x | x | x | x | x |
| Pb ------------- | | x | x | x | x | | | | | | |
| Rb ------------- | | | x | x | | | | x | x | | |
| Sc-------------- | x | | | x | | x | x | x | x | x | x |
| Sn ------------- | | | | | | x | x | | x | x | |
| V -------------- | | | | x | | x | x | | | | |
| Y -------------- | x | x | x | x | x | x | x | x | x | | x |
| Zr-------------- | x | x | x | x | x | x | x | x | x | x | x |