AN ABSTRACT OF THE THESIS OF

MARK H. BAILEY for the degree of Master of Science in Geology presented on June 7, 1979

Title: BEDROCK GEOLOGY OF WESTERN TAYLOR PARK, GUNNISON COUNTY, COLORADO

Abstract approved: Signature redacted for privacy.

Dr. Robert D. Lawrence

The western Taylor Park area covers about 65 square miles on the western flank of the Sawatch Range. It is underlain chiefly by Precambrian rocks, partially covered on the east by glacial debris and overlapped on the west and south by Paleozoic sedimentary rocks.

The Precambrian rocks include a group of metasedimentary rocks of an undetermined age greater than 1700 m.y. The metasedimentary rocks include five mineralogically distinct units, quartzite, quartz-muscovite schist, quartz-epidote schist, quartz-plagioclase-biotite schist, and quartz-biotite-microcline-sillimanite schist. The higher grade sillimanite-bearing biotite schists are restricted to the western half of the map area and closely associated with the Forest Hill granitic rocks.

The metasedimentary rocks were intruded twice during Precambrian time. The oldest intrusive event resulted in syntectonic emplacement of granodiorite and biotite tonalite rocks. These rocks correlate with the 1700 m.y. old Denny Creek granodiorite gneiss and Kroenke granodiorite which are mapped and informally named in the adjoining Mount Harvard quadrangle.

The second, post-tectonic, igneous event produced granitic rocks that are dated at 1030 m.y. by Rb-Sr methods. These rocks include two comagmatic granitic phases,

the Forest Hill porphyritic granite and the Forest Hill cataclastic granite. A third phase, the Forest Hill hornblende granodiorite, intrudes the porphyritic granite and, therefore, is younger than the granitic phases.

The 1030 m.y. age is very significant because the only other 1000 m.y. old intrusive rocks in Colorado (the Pikes Peak batholith) are restricted to the Front Range.

Paleozoic sedimentary rocks are exposed along the western and southern margins of the map area. They range in age from Cambrian through Permian.

Tertiary igneous rocks, occurring as plugs, dikes and flows, crop out locally. Two major episodes of Tertiary activity occurred in the region, one during the Laramide orogenic event and the other during Oligocene time. The Tertiary rocks in the map area were formed during the later igneous event.

The principle structural features of the area include: (1) northeast-trending Precambrian shear zones and faults, (2) northwest-trending folding and faulting, (3) east-west-trending tear faults in the Paleozoic rocks along the western margin of the map area. Although the northeast and northwest-trending structural trends originated during the Precambrian, reactivation along these zones of weakness probably occurred into mid-Tertiary time.

Bedrock Geology of Western Taylor Park, Gunnison County, Colorado

by

Mark Hopkins Bailey

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed June 7, 1979

Commencement June 1980

ACKNOWLEDGMENTS

The writer wishes to express a sincere thanks to Exxon Company U.S.A. for the material and financial support received during this investigation. I would like to give special thanks to Art Pansze, Bob Woodfill and H. Gassaway Brown who were instrumental in initiating and supporting this study.

I thank my advisor Dr. Robert D. Lawrence and faculty members Dr. Cyrus W. Field, Dr. Harold E. Enlows, and Dr. Edward M. Taylor for their constructive criticism during the final preparation of this report.

I would also like to thank my family and friends for their moral support throughout this endeavor.

TABLE OF CONTENTS

Table of Contents (Cont'd.)

Table of Contents (Cont'd.)

ILLUSTRATIONS

Illustrations (Cont'd.)

Illustrations (Cont'd.)

Tables

Plates

Bedrock Geology of Western Taylor Park, Gunnison County, Colorado

INTRODUCTION

Taylor Park is a wide, open, and comparatively level valley situated on the western flank of the Sawatch Range. The Sawatch Range, a north northwest-trending anticlinorium 90 miles long and 40 miles wide, is the westernmost range of the four main north-south trending mountain ranges that compose the Rocky Mountains of Colorado. The irregular boundaries of the Sawatch Range are determined by the contact of Paleozoic sedimentary rocks against the Precambrian core along the west side, by the Arkansas Valley (northern extension of the Rio Grande Rift) on the east side and topographic termination of the northern and southern limits of the range. The continental divide follows the axis of the range for most of its length. The northeast-trending Colorado Mineral belt (Tweto and Sims, 1963) transects and includes nearly all the range except for its northernmost extremities.

The area of this report is located near the center of the Sawatch Range and is bounded on the south and west by Paleozoic sedimentary rocks. Most of the detailed work done in this study was on the portion of the Sawatch Range between the flanking Paleozoic rocks on the west and Taylor Park on the east. Mapping was carried across Taylor Park to correlate rock units between the Mount Harvard quadrangle and the west Taylor Park area.

Location and Access

The thesis area is in the northeast corner of Gunnison County, Colorado, with its center approximately 35 miles northeast of the town of Gunnison (see figure 1). The area described by this report covers about 65 square miles on the western flank of the Sawatch Range including T13S, T14S, R82W and R83W. The irregular shape of the map area is approximately bounded at the northwest corner by latitude 38° 56' N., longitude 106° 44' W., the northeast corner at latitude 38° 54' N., 106° 30' W., the southeast corner at latitude 38° 52' N., longitude 106° 30' W., and the southwest corner at latitude 38° 51' N., longitude 106° 42' W. The thesis area lies entirely within the Gunnison National Forest, at elevations ranging from 9300' in Taylor Park to 12,444' on Forest Hill. Figures 2 and 3 show the general extent of the map area.

The area is easily accessible by a paved road from Almont, Colorado, up Taylor River Canyon to the Taylor Park Reservoir. Secondary dirt roads branch from this main road up Spring Creek Canyon along the west side of the area, Trail Creek in the center, and Taylor Park along the east side. In addition, logging roads, ranch roads, forest service roads, and old mining roads provide access to many parts of the area. Other major means of access into Taylor Park include the Cottonwood Pass road which crosses the Sawatch Range from Buena Vista, and the Cumberland Pass road which comes from Pitkin and Tincup, south of Taylor Park.

Purpose and Methods of Study

Previous geologic studies of the Taylor Park area have been generalized and superficial. The primary objective of this report is to provide a detailed map and petrographic description of the Precambrian rocks. Secondary objectives include describing the structural geology, determining metamorphic grade, and correlation (lithological and age) with Precambrian rocks described elsewhere in the Rocky Mountains of Colorado.

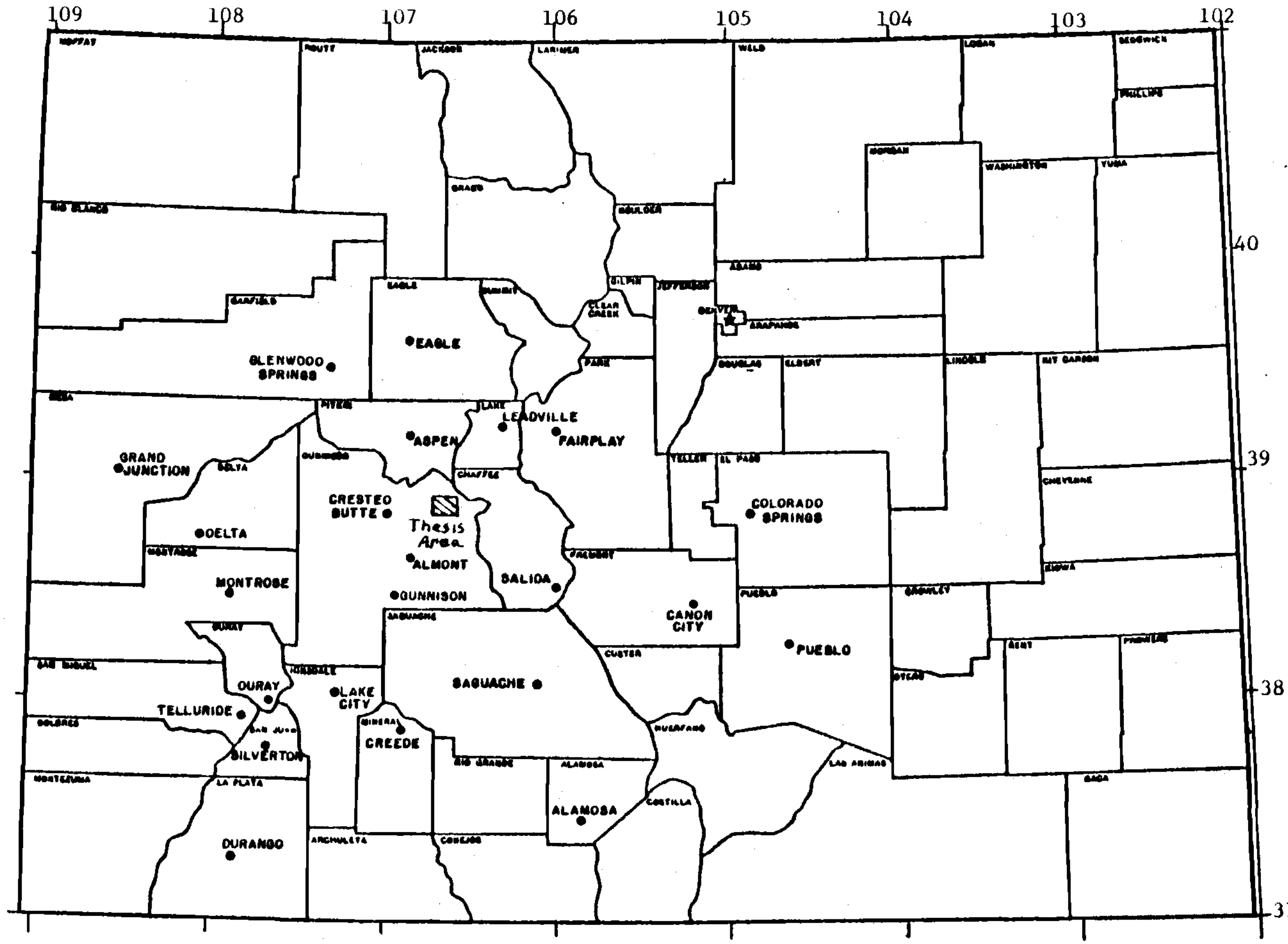

Figure 1. Index Map of Colorado

0 25 50 Miles

Figure 2. Panorama of the eastern half of the map area. Looking east from the center of the area. The continental divide follows the axis of the Sawatch Range in the distance. Taylor Park can be seen at the base of the mountains. All the hills in the foreground and the center of Taylor Park are included in the map area.

Figure 3. Western half of the thesis area looking north from the southwest corner of the area. Spring Creek is visible along the left side of the photo. Rocky Brook road can be seen along the bottom of the photograph. Forest Hill, the highest mountain in the area, can be seen in the right center portion of the photo. Tree line is about 11,600 feet. Paleozoic rocks are visible in the cliff above Spring Creek Reservoir.

Field interpretations were supported by appropriate chemical, mineralogical, and petrographic studies of samples collected during field mapping.

A preliminary survey of the literature on the geology of the Sawatch Range was conducted during the spring of 1977. Field mapping was carried out from June through September 1977. Geologic data were plotted in the field on the U. S. Geological Survey 1:24,000 Pieplant, Italian Mountain, Matchless Mountain and Taylor Park Reservoir quadrangles. Local and regional correlations were made on the basis of lithological similarities and age dates.

One hundred and fifty thin sections were examined. Forty selected igneous and meta-igneous samples were point counted at a minimum of 500 counts each on a 1 mm by 1 mm grid, to determine modal compositions. Anorthite content was determined using the Michel-Levy method, combined carlsbad-albite twinning and A-normal methods depending on the orientation of plagioclase crystals. Plutonic rocks are classified according to the International Union of Geological Science (Streckeisen 1973) scheme. Metamorphic facies are identified by mineral assemblages and classified according to Turner (1968).

Six select samples were dated by radiogenic isotope techniques (see appendix I) to determine a Rb/Sr isochron for two cogenetic intrusive phases. Whole rock chemical analyses were run on 19 samples (see appendix II for laboratory techniques).

Previous Work

The first geologic information on the Sawatch Range was recorded by members of the Hayden survey (1872-1874). The data from this survey resulted in only a superficial treatment of the Precambrian rocks in the region. Early papers on the geology in the Sawatch Range include Howell (1919) who examined the geology of the Twin Lakes District northeast of Taylor Park. South of the Taylor Park area, Crawford (1913, 1916) studied the geology of the Monarch-Tomichi and Gold Brick Mining Districts. Goddard (1935) studied the geology of the Tincup Mining District, which is ten miles southwest of the field area. Koksoy (1961) re-studied a portion of the Tincup Mining District. Stark (1934) identified reverse faulting in the Sawatch Range and later Zoerner (1973) recognized gravity emplaced thrust sheets associated with uplift of the Sawatch Range in the Pearly Pass and Italian Creek quadrangles to the north. Barnes (1935) in a doctoral dissertation presented the most detailed study of the Precambrian rocks of the Sawatch Range. Precambrian igneous rocks mapped in nearby Garfield quadrangle as Silver Plume and Pikes Peak granite (Dings and Robinson, 1957) have been redefined by Barker and Brock (1965) and Tweto (1977). Brock and Barker (1972) mapped the Precambrian intrusive rocks of the Mount Harvard quadrangle and identified three separate granodiorite bodies. Barker and others (1974, 1976) related a 1700 m.y. old trondhjemite (Kroenke Granodiorite of the Mount Harvard quadrangle east of Taylor Park) to other trondhjemites in the southwest (New Mexico). Stark (1935) studied migmatites and pegmatites associated with Precambrian intrusive rocks to the south of Taylor Park near Gunnison, Colorado.

Broad regional studies of Precambrian rocks in Gunnison County have included studies of the basement rocks and structures as well as younger features. Urbani and Blackburn (1974) and Navarro (1974) carried out regional studies of the basement rocks of the Almont area. Edwards (1966) related broad petrologic and structural features of the Precambrian basement rocks of Colorado. Tweto and Sims (1963) linked the Colorado mineral belt with Precambrian structures in the basement rocks that transect the Sawatch Range.

Age determinations of the Precambrian rocks in the Sawatch Range have been conducted utilizing different techniques such as K-Ar methods by Giffin and Kulp (1960), Rb-Sr techniques by Wetherill and Bickford (1965) and fission-track studies by Church and Bickford (1971). In an excellent synthesis, Tweto (1977) describes six main age groups of Precambrian rock ages in Colorado.

Although no detailed published reports or geologic maps of the thesis area exist, unpublished theses covering the Paleozoic rocks bordering the area along the west and south sides have been done by: O'Conner (1961), Prather (1961), Conyers (1957), and Meissner (1954). The Italian Mountain stock bordering on the northwest edge of the thesis area has been studied in detail by Cunningham (1973). Previous to this report, the most detailed geologic map encompassing the west Taylor Park area was the Montrose $1^{\circ} \times 2^{\circ}$ quadrangle by Tweto and Sims (1976).

Geologic Setting

The location of the thesis area in respect to the more prominent geomorphic features in Colorado is illustrated on figure 4.

The Taylor Park area is composed of sedimentary, metamorphic and igneous rocks (both intrusive and extrusive), which range in age from Precambrian to Tertiary, leaving some intervening periods unrepresented. Quaternary deposits of glacial and fluvial origin are locally abundant.

The oldest rocks (1700 m.y.) exposed in the Sawatch Range are highly metamorphosed sediments comprising a series of schists and gneisses composed essentially of quartz, feldspar, and micas. Much of the exposure occurs as xenoliths, pods, and lenses in Precambrian intrusive rocks. Associated with and grading into the schistose rocks are occasional beds of quartzite and conglomeratic gneiss.

The process of migmatization (arteritic migmatite) is widespread in the Sawatch Range. Migmatization locally occurs in the thesis area, but due to poor exposure and the

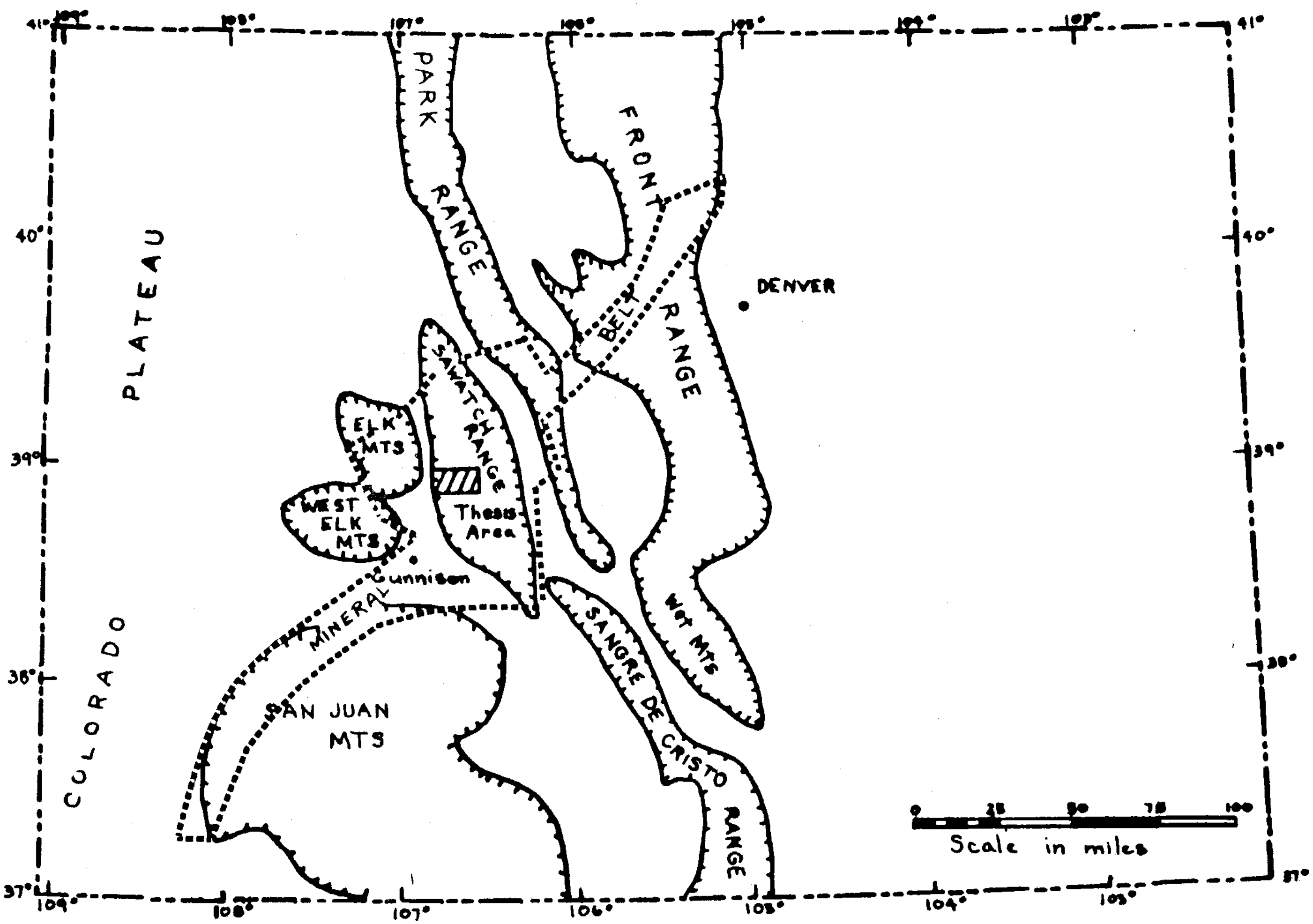

Figure 4. Prominent geomorphic features of Colorado.

scale of mapping, separate migmatite bodies were not mapped. All migmatites occurring in the thesis area are restricted to the outcrops of Denny Creek gneiss.

Precambrian igneous rocks cropping out in the map area are of two distinct intrusive ages, 1700 m.y. and 1030 m.y. The reasons for assigning these ages will be discussed in detail in a later section. Briefly, these include lithologic similarities, proximity to type area, identical relations to associated rocks, and radiogenic age dates. Rocks of the older intrusive event commonly show gneissic structure, migmatization, and metamorphism. On the other hand, one of the younger, 1030 m.y. old intrusive phases is a homogeneous porphyritic granite, while a second phase exhibits a cataclastic texture as a result of shearing.

Pegmatitic bodies cut all of the Precambrian rocks in the thesis area. A preponderance of them occur in close association with the 1030 m.y. old granites.

The contact of Precambrian rocks with the flanking Paleozoic sediments was generally taken as the limit of the area to be mapped. A cursory inspection of the Paleozoic rocks was conducted to determine their structural relations to the underlying crystalline rocks. At a few select locations the Paleozoic sedimentary rocks were traversed to determine their identity and relationships to the Precambrian bedrock and each other. Cambrian Sawatch quartzite overlain by Ordovician, Devonian, and Mississippian limestones, sandstones and shales and Permo-Carboniferous shales and redbeds were identified along the western and southern margins of the thesis area. Identification was based on lithological comparison to previously mapped Paleozoic rocks in the region.

Tertiary igneous rocks, occurring as plugs, dikes, and flows crop out locally in the map area. Tertiary batholiths crop out along the axis of the Sawatch Range and to the west in the Elk Mountains, but not in the area of this report.

Quaternary deposits including glacial, fluvio-glacial, alluvial and colluvial material cover much of the area obscuring the bedrock geology.

PRECAMBRIAN ROCKS AND THEIR NOMENCLATURE

Naming the Precambrian rocks of Colorado has been a controversial issue for many decades. Recently, Tweto (1977) published a reappraisal of the nomenclature for the Precambrian rocks of Colorado, pointing out a need for establishing a comprehensive terminology for these rocks. Tweto lists six major age classes, of these the two post 1700 m.y. old metasedimentary units that are areally restricted to the Uinta and Needle Mountains, do not appear to pertain to the thesis area, and are not further discussed. The remaining four classes of interest herein include a metasedimentary complex older than 1700 m.y. and three intrusive episodes which occurred at about 1700 m.y., 1400 m.y., and 1000 m.y. ago (see table 1). Three of these four age groups are represented in the thesis area.

Precambrian rocks of metasedimentary origin include a group of schists, gneisses and quartzites older than 1700 m.y., which are commonly classified as Idaho Springs age equivalent rocks even though they are not spatially close to the type area. I prefer to call these metasedimentary rocks by their lithological description and group them under the general title of metasedimentary rocks older than 1700 m.y., rather than applying a formal name. Most of the metasedimentary rocks occur as small xenoliths and pods in the igneous bodies and, therefore, are undifferentiated on my map (plate I). Where the size is sufficient individual bodies are separately mapped.

These metasedimentary rocks were twice intruded in the thesis area. The first intrusives are syntectonic and equivalent in age to Denny Creek rocks (1700 m.y.). I have informally applied the names Denny Creek granodiorite gneiss and Kroenke granodiorite to these rocks because rocks with similar lithologies are so named in the adjoining Mount

Harvard quadrangle (Barker and Brock, 1965). A biotite tonalite, mapped in the thesis area, is also considered to be of Denny Creek equivalent age. Because of the lithological continuity with the formally named units of the Mount Harvard quadrangle, the use of these names is considered consistent, even though corresponding age dates are lacking.

Both metasedimentary and older intrusive units are post-tectonically intruded by younger granitic rocks. These rocks are tentatively dated at 1030 m.y. and crop out over a large part of the map area. They are informally named the Forest Hill porphyritic granite, Forest Hill cataclastic granite and Forest Hill hornblende granodiorite. With subsequent work and confirmation of the 1030 m.y. age these rocks could be formally named for their type locality. Although the age is equivalent to rocks of the Pikes Peak batholith, because of the distance between the two, a separate informal name will be used here.

Table 1. Classification of Precambrian rock units in Colorado.

U.S. Geological Survey Precambrian Subdivisions (James, 1972)	Four of the six major subdivisions of Precambrian rocks in Colorado (Tweto, 1977)	Formally named Precambrian rocks of Colorado (Tweto, 1977)	Informally named Precambrian rocks of this report and their ages
Precambrian Z 600-800 m.y.			
Precambrian Y 800-1600 m.y.	Granitic rocks of 1000 m.y. age group.	Pikes Peak Granite 1040 ± 60 m.y. Hedge (1970)	Forest Hill Granitic rocks 1030 ± 40 m.y.
	Granitic rocks of 1400 m.y. age group	Silver Plume Granite 1400-1450 m.y. Peterman and Hedge (1968) Sherman Granite 1410 m.y. Peterman and Hedge (1968) St. Kevin Granite 1390 ± 60 m.y. Pearson and others (1966)	
Precambrian X 1600-2500 m.y.	Granitic rocks of 1700 m.y. age group	Boulder Creek Granite 1700 m.y. Peterman & Hedge (1968) Denny Creek Granodiorite 1715 m.y. Kroenke Granodiorite 1700 m.y. Barker and others (1974)	Denny Creek and Kroenke granodiorites 1700 m.y.
	Rocks of Pre-1700 m.y. age group	Idaho Springs Fm 1700 m.y. Hedge and others 1967	Metasedimentary rocks 1700 m.y.
Precambrian W 2500 m.y.			

METASEDIMENTARY ROCKS OLDER THAN 1700 M.Y.

General Statement

The oldest rocks in the thesis area are a group of schists, gneisses and quartzites of a sedimentary origin. These rock units are lithologically similar to the Idaho Springs Formation of the Central Front Range, and the widespread metasedimentary rocks of the Sawatch Range. These rocks are also intruded by igneous rocks dated at 1700 m.y. as are other metasedimentary rocks of Colorado. Although the various types of metasedimentary rocks shown on the geologic map are distinct mappable units, there are hundreds of blocks and xenoliths contained in the intrusive phases that are too small to be mapped at the scale of this report.

The five metamorphic rock units described in this report are quartzite, quartz-muscovite schist, quartz-epidote schist, quartz-plagioclase-biotite schist, and quartz-biotite-microcline-sillimanite schist. The mineralogic compositions of all metasedimentary rocks were established by visual estimate and averaging a minimum of three thin sections for each rock type. Results are listed in table 2 on page 38.

Quartzite

Field Description

Lenses or beds of quartzite crop out in the area between Trail Creek and Taylor Park. The two largest exposures occur along the crest of a ridge in section 25, T13S, R83W, and down the slope of a knoll in section 30, T13S, R82W. A small outcrop, exposed in a bulldozer cut, occurs across a ravine from the quartzite that is exposed in section 30. At both of these locations quartz-muscovite schist, in contact with quartzite, grades into quartz-biotite schist away from the contact.

Megascopically, these quartzites range in color from light gray to light brownish-gray, are fine- to medium-grained with minor amounts of interstitial muscovite and specular hematite visible in hand sample. Interbedded with the fine-grained quartzite beds in section 25 is a thin quartz pebble conglomerate, with flattened quartz pebbles aligned subparallel to foliation. Zones of hematite, muscovite and feldspar occur interstitial to the quartz pebbles. Pebbles range in size from 5 cm to less than 1 cm long and 2 cm to less than .5 cm wide. Evidence of a sedimentary origin for these quartzites include relict bedding, equigranular texture, and interlayering with the quartz pebble conglomerate and quartz-mica schists.

Petrography

Further confirmation of the sedimentary origin is found microscopically in the granular texture and abundance of quartz, up to 95% in some samples. Megascopically, recrystallization in many samples has completely obscured the original clastic texture, but in thin section rounded grains of quartz, outlined by impurities with secondary quartz overgrowths are visible. Mineralogy of the quartzites is shown on table 2 and modal estimates are given in appendix III.

The variation in composition of the quartzite and quartz pebble conglomerate beds may be due either to the composition of the original sediments and/or metasomatic additions from the younger Precambrian intrusive phases, which invade the region.

Quartz-Muscovite Schist

Field Description

Outcrops of quartz-muscovite schist are restricted to the area east of Trail Creek. Foliation is moderately to well developed and in a few places the schist grades into gneiss. The foliation is planar in some samples but in others is highly contorted, crumpled, or microfolded. Hand specimens are light olive-gray (5Y 5/2) to dark greenish-gray (5G 4/1) in color. Foliation strikes west to northwest and dips moderately to the north.

Petrography

Under the microscope, these rocks show a well-formed schistose texture (gneissic in some samples) defined by bands of muscovite flakes. Deformation in many of the samples has created crenulations and microfolds from the planar foliations (figures 5 and 6).

Mineralogy is listed in table 2 and modal analyses are shown in appendix III. Quartz is usually the most abundant mineral constituent although in a few slides muscovite is approximately equal in abundance. Quartz occurs as fine irregular shaped grains and as large lensoidal or augen-shaped masses that commonly exhibit undulatory extinction. Most grains are fairly clear with only minor, fine opaque material as inclusions.

Muscovite occurs as fine tabular plates oriented parallel to the foliation. Figure 5 is a good example of this parallel alignment of muscovite plates defining a lepidoblastic texture. Figure 6 shows the distorted nature of the muscovite schist and the mineral segregation into muscovite bands and quartz bands.

Plagioclase grains range in size from less than .1 mm to 1 mm in length. The majority of plagioclase is oligoclase (An_{20-30}) but in two slides it approaches albite in

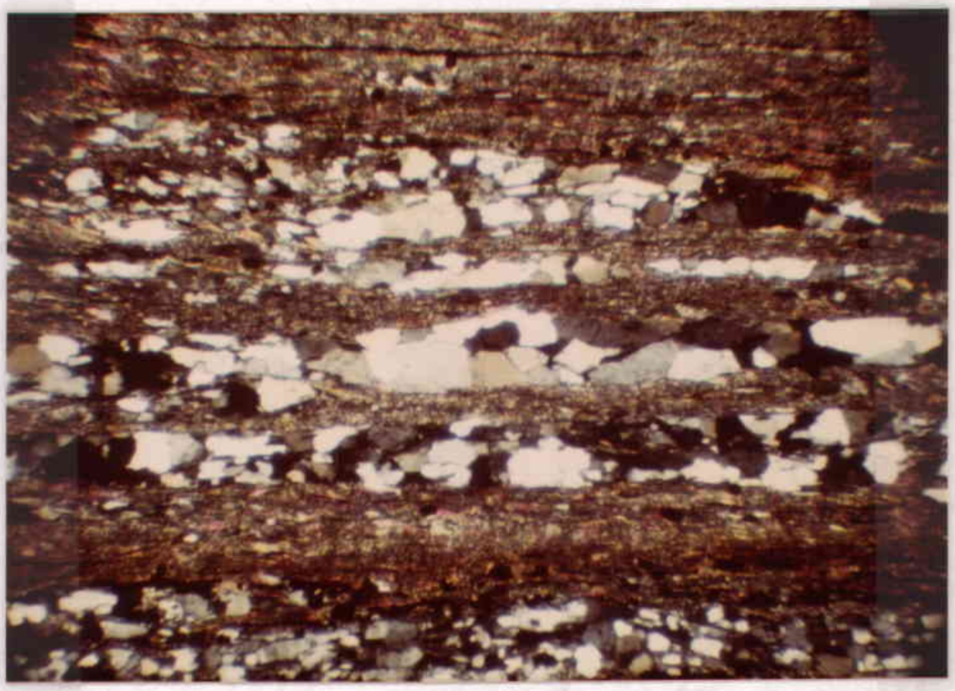

Figure 5. Photomicrograph of quartz-muscovite schist. Planar foliation is exhibited by alternating quartz-plagioclase layers and muscovite-opaque-rich layers.

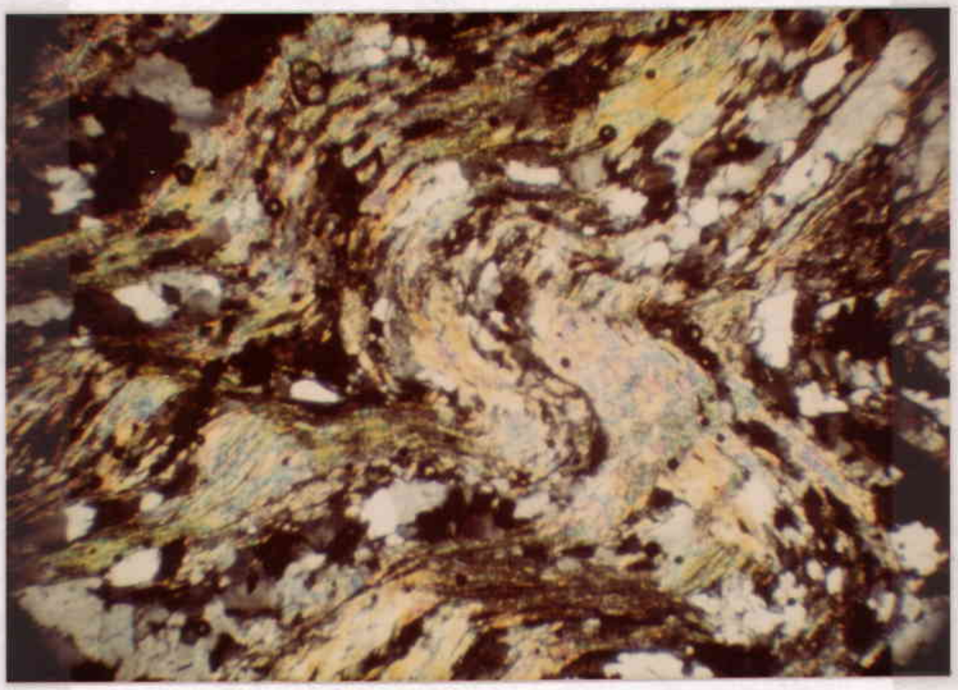

Figure 6. Contorted quartz-muscovite schist. Photomicrograph is taken from same thin section as figure 5. Planar foliation of figure 5 becomes highly deformed less than 1 cm away.

composition (An_{8-12}). Much of the plagioclase is poorly twinned, and exhibits varying degrees of alteration to white mica.

Biotite is present in most of the specimens ranging from a trace to 15 percent in modal abundance. Subhedral tan to greenish-brown (in plane light) biotite plates are commonly interwoven with muscovite subparallel to the foliation. Chloritic alteration of biotite, due to weathering, is common in all the thin sections studied.

Opaque minerals are fairly abundant (3-10 percent) in the samples studied. Magnetite is by far the most abundant with lesser amounts of leucoxene and hematite occurring locally. In both figures 5 and 6, magnetite occurs subparallel to foliation and closely associated with the micaceous layers.

Alteration products (retrograde or weathering) include chlorite, epidote, and fine-grained white mica (sericite). Chlorite is the common alteration product of biotite, ranging in abundance from a trace up to 9 percent in rocks with increasing biotite content. Chlorite replaces biotite along cleavage planes and along grain borders, sometimes in association with leucoxene and/or epidote. Epidote is present in some specimens as an alteration product of biotite as well as plagioclase. Epidote may also be present as an original metamorphic mineral but due to its limited abundance and mode of occurrence in most samples, it is believed to be an alteration product. Sericite is a common alteration product of the plagioclase grains. Identified in all thin sections studied, sericite is more prevalent in specimens containing plagioclase with an anorthite content greater than An_{12}.

The variation in abundance of minor minerals (biotite, chlorite, epidote, cordierite, and tourmaline) may represent local chemical differences in the pre-metamorphic sediments. The paucity of chlorite and biotite in some quartz-muscovite schists may indicate a cleaner sandstone or siltstone parent (arkosic or feldspathic) versus quartz-muscovite schist containing an abundance of chlorite and biotite (wackes or mudstones). Quartz-muscovite schist may be produced directly from either regional metamorphism of pelitic sediments, argillaceous sandstones and graywackes, or from metamorphism and alteration (sericitization) of arkosic or feldspathic sandstones. In general, the range in plagioclase composition An_8 to An_{30} may indicate higher grades of metamorphism for the more calcic plagioclases, however other circumstances, such as availability of calcium may affect the composition. Local equilibrium or lack of calcium homogenization may also explain this variation in composition. Incidental minerals include cordierite, tourmaline, apatite, zircon, rutile and microcline. Cordierite was identified in three thin sections associated with biotite. Cordierite is more typical of thermally metamorphosed pelitic rocks, but it can occur in regionally metamorphosed rocks (high grade gneisses) or in regionally metamorphosed rocks followed by a period of thermal metamorphism (Moorhouse, 1959 and Deer, Howie and Zussman, 1966). Tourmaline occurs as aggregates of subhedral crystals, some containing inclusions of quartz, muscovite and opaques. Apatite and zircon are commonly associated with biotite flakes. Needles of rutile can be seen in some grains of quartz. Microcline is present but not abundant, except for one sample where it is 5 percent of the rock. Gridiron twinning and lack of extreme alteration are characteristic.

Quartz-Epidote Schist

Field Description

Quartz-epidote schist crops out at two locations between Taylor Park and Trail Creek in sections 30, 32, 33, T13S, R82W. At the first location in section 30, quartz-epidote schist grades into quartz-muscovite schist below and is overlain by quartzite, possibly recording original bedding. The second occurrence of this schist is in sections 32 and 33. In outcrop and hand sample this schist is pale greenish-yellow (10Y 8/2) to a dark greenish-gray (5G 4/1). Weathered surfaces are pale yellowish-brown (10YR 6/2).

Petrography

Viewed microscopically, the quartz-epidote schist is fine-grained, allotriomorphic with a gneissic texture (figure 7). In some slides quartz and plagioclase form lenticular or elongated grains, conforming with the general platy habit of the rocks.

Anhedral quartz is the main constituent of these rocks averaging about 50 percent of the composition in the slides studied. Grains commonly exhibit faint undulatory extinction, straight or poorly sutured borders, and locally occur as lenticular polycrystalline masses. Inclusions are scarce, usually consisting of fine dust-size opaque material and occasionally mica flakes. In two samples cataclasis has resulted in highly strained quartz with reduced grain size.

Epidote varies in abundance from fine disseminated grains, composing 10 percent of the rock, to lenticular masses composing 25 percent of the rock. Epidote alternates with quartz defining a planar foliation. One specimen (CB7-159) consists predominantly of quartz and epidote with only minor accessory minerals present. Most epidote is anhedral, although an orientation of prismatic grains subparallel to the foliation is present in some samples.

Muscovite varies from a minor accessory mineral to a major constituent of the rock. Fine tabular muscovite plates are oriented parallel to the planar foliation except where microfolds have dissrupted the planar features.

Chlorite occurs as fine flakes intergrown subparallel with muscovite and epidote. Chlorite typically exhibits pale tan to green pleochroism and a tabular shape.

Microcline occurs as fine anhedral masses commonly displaying poorly formed gridiron twinning. Grains are rela-

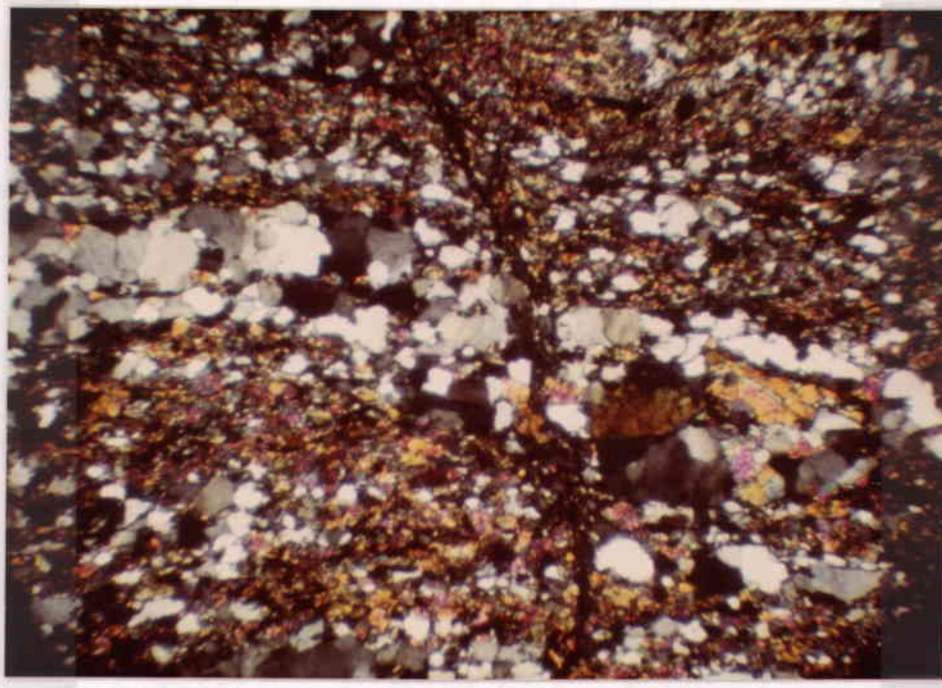

Figure 7. Quartz-epidote schist. Foliated rock exhibits microfracturing. Quartz, epidote and opaque minerals are abundant with some chlorite also visible.

tively unaltered compared to plagioclase which usually is saussuritized. In one slide, microcline crystals are concentrated into poorly defined layers.

Magnetite usually occurs as disseminated subhedral and euhedral grains. In some samples, magnetite occurs as elongate anhedral grains, subparallel to foliation and intergrown with muscovite. Hematite is a common oxidation product of the magnetite grains.

Plagioclase is a minor constituent of these rocks, usually occurring as anhedral to subhedral grains with poorly developed polysynthetic twinning. In some samples, alteration obscures any twinning that might be present. Anorthite content (An_{14-26}) was determined using as many grains as possible, per slide, that retained albite twinning in the correct orientation.

Biotite occurs as a subordinate component of these rocks (trace to 5%). Biotite occurring as fine subhedral plates is commonly intergrown with muscovite and epidote subparallel to foliation. In many of the samples chlorite has almost completely replaced the biotite.

The opaque minerals include magnetite, leucoxene and hematite which occur as elongate masses parallel to the foliation and in distinct layers. Hematite occurs as an oxidation product of the magnetite grains and leucoxene as a hydrothermal alteration product of biotite.

Biotite Schist

Two varieties of biotite schist are recognized in the thesis area: quartz-plagioclase-biotite schist and quartz-biotite-sillimanite-microcline schist. Interlayers of these two types are common with individual layers ranging from about 1 cm up to larger bodies greater than 10 ms thick. It appears that this interlayering represents original bedding with sillimanite-rich schist representing the more pelitic parent rocks, and the slightly coarser grained biotite schist being from more quartzo-feldspathic parent material.

Quartz-Plagioclase-Biotite Schist

Field Description

The typical appearance of this variety of biotite schist is fine to medium-grained, medium-gray (N5) to dark-gray (N3). Texturally, the biotite-quartz-plagioclase schists range from a fine-grained, equigranular, lepidoblastic, and locally gneissic variety to a medium-grained, biotite-rich inequigranular, highly foliated variety with lineation and foliation defined by the alignment and concentration of biotite crystals into layers. In places, this rock has been cataclastically deformed, producing microbreccia and mylonitic zones which further reduce the grain size. In the fine-grained type, quartz and plagioclase form a mosaic groundmass through which biotite plates are disseminated.

Petrography

The proportion of major mineral constituents, quartz, plagioclase and biotite are quite variable as is evident from figure 2 and appendix III.

Quartz is anhedral, with crystal size variable but generally averaging .5 to 7 mm in diameter. Quartz exhibits straight extinction and occurs in a mosaic pattern with plagioclase. Quartz with sutured borders and undulatory extinction is common in the intensely deformed biotite schists. Secondary quartz is present in most slides as unstrained, inclusion-free, subrounded blebs in plagioclase and biotite grains. Segregation of polycrystalline quartz into lensoidal layers and augen is common in the more gneissic and biotite-rich varieties.

Anhedral to subhedral plagioclase ranges from calcic oligoclase to calcic andesine in composition (An_{28-42}). Crystals are mostly unzoned and exhibit poorly developed albite, carlsbad, and rarely percline twins. Sericitic alteration of plagioclase is minor but pervasive.

Biotite crystals occur as fine-grained (less than 2 mm in length) shards, interstitial to quartz and plagioclase in the fine-grained schist. The lepidoblastic texture is defined by the subparallel alignment of these plates (figure 8). In contrast, the biotite in the medium-grained schistose rocks are concentrated into bands that define a foliation as well as occurring as interstitial plates. This variety of schist has a higher percent of biotite with crystals ranging from fine shards to prismatic plates 12 mm in length. Pleochroism is tan or straw yellow to greenish-brown. A crystal ratio of 1:10 is common for width versus length in the larger plates.

Muscovite, where present, occurs as intergrowths with biotite and locally transects biotite plates. Muscovite plates are subhedral with a width to length ratio of about 1:2 for most of the crystals.

Garnet is locally present as fine subrounded to angular crystals, usually associated with biotite in poorly defined gneissic layers.

Sillimanite is observed in one thin section (CB7-110A), occurring as fine radiating needles transitional into biotite. This sample contains a fine layer, about 3 mm thick, of biotite-sillimanite-cordierite-muscovite-quartz schist believed to be a relict bedding feature.

Magnetite is an important accessory mineral reaching concentrations greater than 1 percent in some samples. Crystals are subhedral to euhedral ranging from .2 to greater than 1 mm in length. The usual occurrence is as disseminated grains in the fine-grained schist. In the biotite gneiss, the magnetite is elongate parallel to foliation and concentrated in biotite-rich bands, suggesting a secondary origin after biotite. Hematite is an oxidation product of

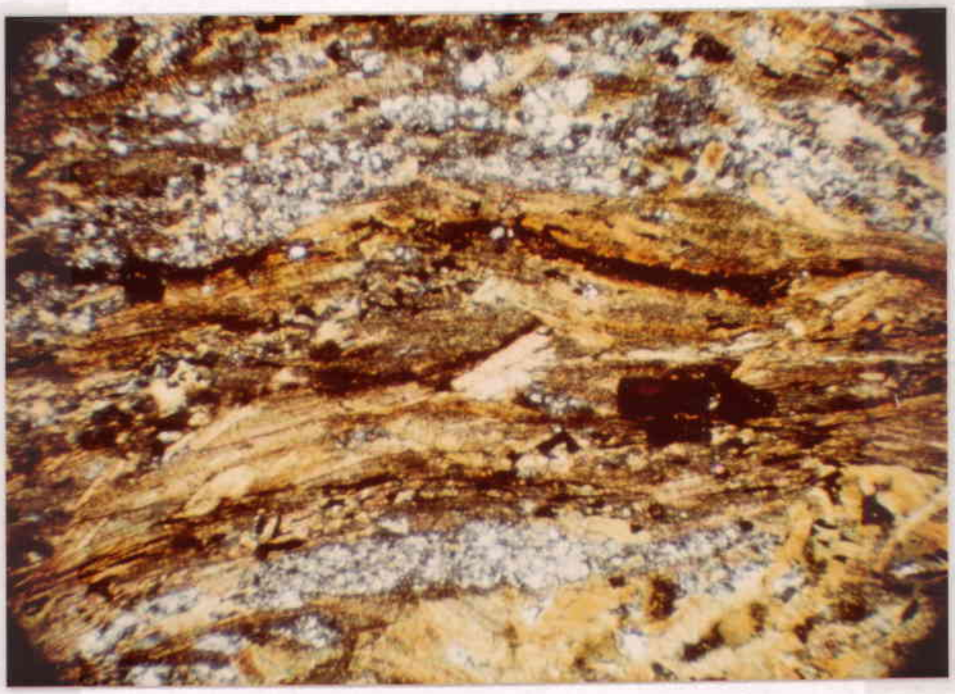

Figure 8. Quartz-plagioclase-biotite schist. Lepidoblastic texture exhibited by the parallel alignment of biotite flakes.

magnetite in most samples.

Rounded crystals of zircon, allanite and apatite occur in many of the samples indicating a sedimentary origin.

Alteration products include chlorite, epidote and sericite. Chlorite occurs along cleavage planes in some biotite crystals and completely replaces others as a result of hydrothermal alteration. Pale-yellow pleochroic epidote occurs as intergrowths in biotite and is associated with white mica in some plagioclase feldspar crystals. Allanite crystals are commonly rimmed by epidote. White mica is ubiquitous as rims around many of the feldspar grains in the mosaic groundmass. Cores of some larger plagioclase crystals exhibit alteration to white mica indicating some compositional variation in plagioclase (zoning).

Quartz-Biotite-Microcline-Sillimanite Schist

Field Description

Outcrops of biotite-sillimanite schist, except for one sample are restricted to the area west of Trail Creek. The occurrence of this variety of biotite schist is usually as small xenoliths and larger lenses in Forest Hill porphyritic granite (figure 9). On top of Forest Hill and along the ridge to the northwest outcrops of biotite schist represent small roof pendants and large blocks of country rock contained in Forest Hill granite.

In hand specimen sillimanite-biotite schist is brownish-gray (5YR 4/1) to dark-gray (N3) and medium-gray (N5) on freshly cut surfaces. Weathered surfaces are commonly irregular with resistant sillimanite and garnet crystals protruding from the rock. A slightly differentiated layering is visible in some samples, produced by the concentration of biotite flakes. Biotite, sillimanite, quartz and locally microcline and garnets are visible megascopically. In some samples (CB7-250 and 253B) sillimanite crystals 3

Figure 9. Xenoliths of biotite-sillimanite schist in Forest Hill porphyritic granite. Outcrop on top of Forest Hill.

cm long and 1.5 cm wide were measured, while some garnets reached 1 cm in diameter.

Petrography

The major constituents identified microscopically include quartz, biotite, sillimanite, and microcline. Most of the quartz is anhedral exhibiting weak undulatory extinction. Grain borders are usually straight except for a few samples which have quartz that exhibits sutured borders. Large quartz grains, between 1 and 3 mm in diameter, contain inclusions of fine dust-size opaque material, zircon and locally sillimanite. Layers of mosaic quartz with aligned interstitial biotite flakes occur in some slides, while layers of polycrystalline quartz are locally segregated from heterogeneous layers in other slides. Intergrowths of quartz with sillimanite are common as are unstrained, rounded quartz blebs in biotite and microcline, resulting from recrystallization. In the more gneissic samples, quartz appears elongate parallel to foliation.

Biotite is strongly pleochroic from tan to dark-brown and in some slides tan to intense reddish-brown. Crystal shapes range from finely disseminated flakes less than .5 mm in length to aggregates of large plates averaging 1 mm and defining foliation. Zircon inclusions with pleochroic halos are common in biotite flakes. Quartz inclusions are less common. In slides cut at right angles to each other, sillimanite has a preferred orientation parallel to foliation. In slides perpendicular to foliation, cross sections of sillimanite range from less than 1 mm to 3 mm in diameter.

Sillimanite forms subhedral to euhedral porphyroblasts ranging from less than 1 mm to 6 mm in length. Grains are commonly ragged, broken and partially replaced by quartz (figure 10). Large aggregates of sillimanite plates are interwoven with quartz and biotite (figure 11), and reach

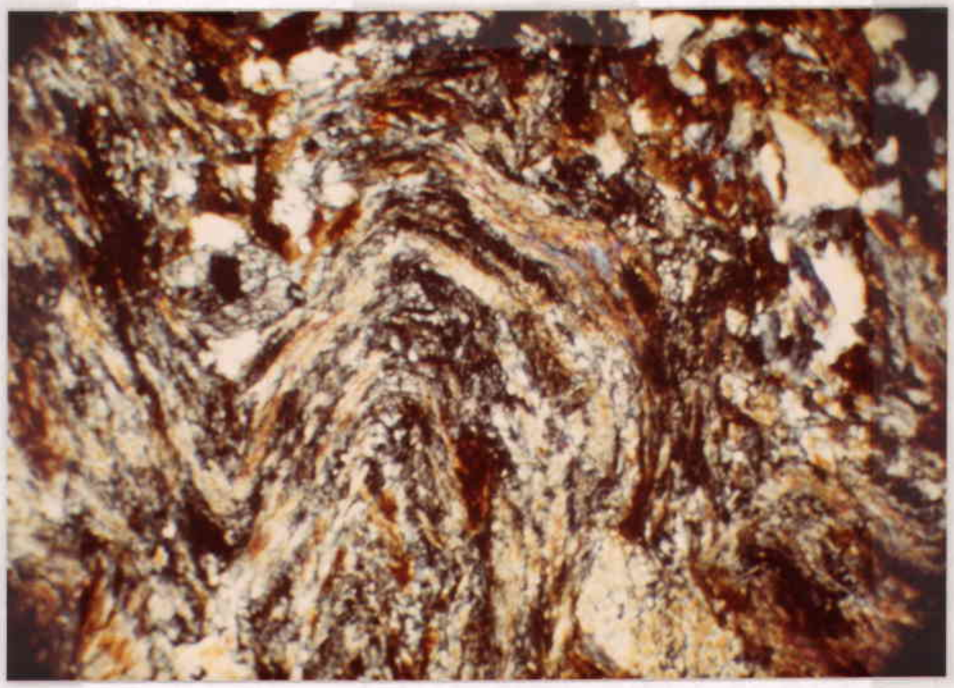

Figure 10. Quartz-biotite-sillimanite-microcline schist. Highly deformed plates of biotite and needles of sillimanite interwoven with quartz, microcline, and some cordierite.

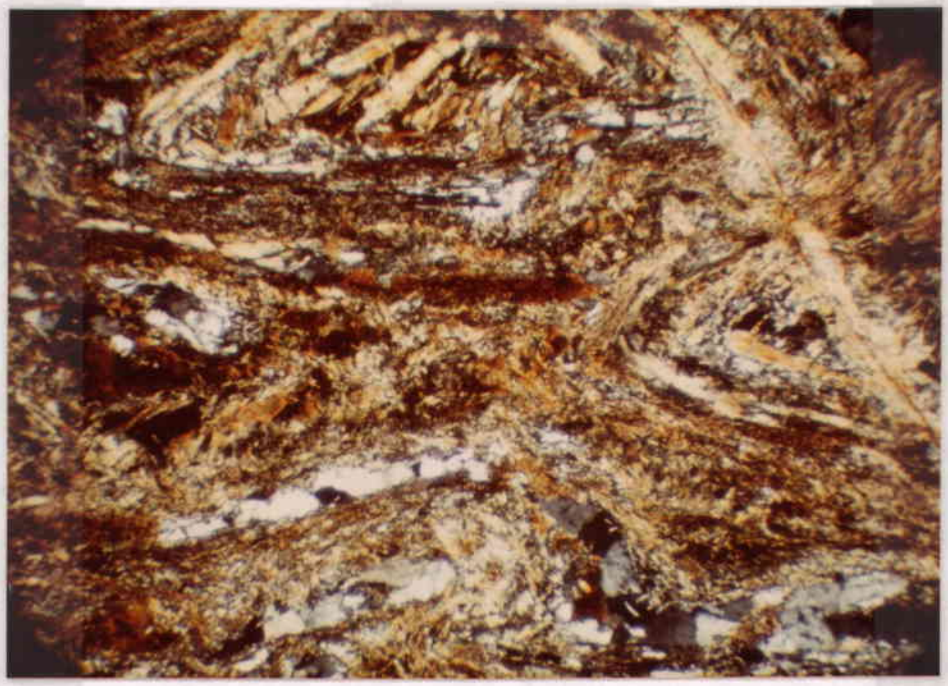

Figure 11. Quartz-biotite-sillimanite-microcline schist. Highly deformed, matted sillimanite and biotite plates as a result of polymetamorphic deformation.

dimensions greater than 7 mm in length. Sillimanite occurs in gradations from porphyroblastic crystals to fine fibrous needles. Typically woven together, the crystals form a matted network usually subparallel to foliation and transitional into biotite flakes. In many samples, fine fibers of sillimanite penetrate all the other major minerals as well as biotite.

The concentration of microcline is variable, being as high as 30 percent in sample (CB7-219), but only a minor constituent in most samples. Many microcline crystals are poikilioblastic with inclusions of quartz and biotite common. Gridiron twinning is well-developed with some grains showing perthitic stringers and flame structures. Locally, zones rich in microcline are interlayered with biotite-rich layers resulting in a gneissic foliation.

Garnet is present in some of the slides as anhedral crystals ranging from less than 1 mm to 3 mm in diameter. Many of the larger grains are poikilioblastic with inclusions of biotite and quartz. Garnet is commonly intergrown with reddish-biotite along gneissic layers, but may also be seen in quartz-feldspar zones.

Plagioclase is a minor constituent of these rocks. Faint wavey extinction and poorly formed twin lamellae make determining the anorthite composition problematic in many grains. A range of anorthite compositions (An_{26-40}) were measured using the Michel-Levy method. Plagioclase grains are usually anhedral to subhedral with embayments by quartz and microcline common in some specimens. Myrmekite is observed in several slides consisting of wormy blebs of quartz in plagioclase grains near microcline. Minor alteration to white mica is common, usually along twin planes.

Muscovite, where present, is intergrown with biotite and commonly contains sillimanite needles apparently forming from the muscovite. The amount of muscovite decreases in rocks where sillimanite and microcline are abundant, possibly resulting from a reaction of muscovite with quartz to form potassium-feldspar and sillimanite.

Accessory minerals include magnetite which occurs along cleavage planes in biotite indicating a secondary origin. Zircon crystals with pleochroic halos occur as inclusions in biotite. Zircon crystals also occur in the feldspars and occasionally in quartz.

Alteration products include chlorite, which occurs along rims and cleavage planes in biotite and sericite forming in altered plagioclase crystals.

The percentage of quartz is varied, being least abundant in rocks with high microcline and/or sillimanite content. This, along with the inverse relationship of muscovite and sillimanite and the lack of evidence for the occurrence of andalusite or kyanite, indicates that sillimanite probably formed during regional metamorphism from the direct reactions of quartz, biotite and muscovite as follows:

$$KAl_2(AlSi_3O_{10})(OH)_2 + SiO_2 = KAlSi_3O_8 + Al_2SiO_5 + H_2O$$

$$\text{Muscovite} + \text{Quartz} = \begin{matrix}\text{Potassium}\\ \text{feldspar}\end{matrix} + \text{Sillimanite} + \text{Water}$$

The occurrence of high grade metamorphic rocks (sillimanite-almandine-microcline subfacies of the Amphibolite facies) in the western portion of the field area and their close association with the Forest Hill granite may be the result of: (1) The thermal effects from intrusion of Forest Hill granite, or (2) these rocks being from a more pelitic parent assemblage than those to the east, therefore, supplying more aluminum, resulting in the formation of aluminum-rich metamorphic minerals.

Relict bedding may be seen in figure 12. The contact between quartz-biotite schist and quartz-biotite-sillimanite-cordierite schist may be an expression of compositional variation between a pelitic rock and a quartzo-feldspathic rock.

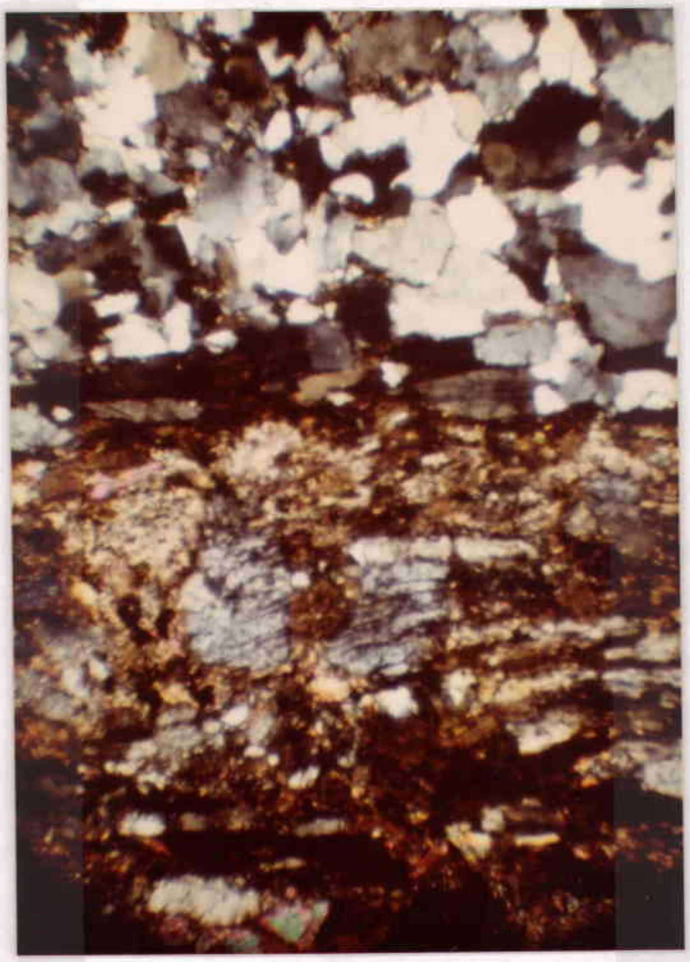

Figure 12. Sharp contact between quartz-biotite schist and quartz-biotite-sillimanite-cordierite schist. Possibly relict bedding contact between pelitic and quartzose-feldspathic rocks.

Table 2. Table of Mineralogy for the Metasedimentary Rocks

Minerals	Quartzite	Quartz-Muscovite Schist	Quartz-Epidote Schist
Quartz	M	M	M
Plagioclase	M	M	M
K-spar	---	---	i
Biotite	m	m	m
Muscovite	m	M	M
Chlorite	i	M	M
Epidote	i	i	M
Sillimanite	---	---	---
Zircon	i	i	i
Apatite	---	i	i
Opaques	i	M	i
Cordierite	---	i	---
Tourmaline	---	i	i
Rutile	---	i	---
Sphene	---	---	i
Allanite	---	i	---
Garnet	---	---	---
Plagioclase composition	An_{30-34}	An_{20-30} * 8-12	An_{14-26}

M - Major constituent, always present and abundant >5%

m - Minor constituent, usually present not abundant 1-5%

i - Incidental, sometimes present <1%

* - On two slides An content was 8-12

Table 2. (Cont'd.)

Minerals	Quartz-Biotite Schist	Quartz-Biotite-Sillimanite Schist
Quartz	M	M
Plagioclase	M	i
K-spar	---	M
Biotite	M	M
Muscovite	i	i
Chlorite	i	i
Epidote	i	---
Sillimanite	i	M
Zircon	i	i
Apatite	i	---
Opaques	i	i
Cordierite	i	i
Tourmaline	---	---
Rutile	---	---
Sphene	---	---
Allanite	i	---
Garnet	i	i
Plagioclase composition	An_{26-40}?	An_{26-40}?

MIGMATITES

Locally, many of the metasedimentary rocks have been converted to migmatite. The process of migmatization was an intimate part of the intrusion of syntectonic plutons and is well exhibited in the intercalated paragneisses (quartz-biotite schists) and orthogneisses (Denny Creek granodiorite gneiss) that are exposed along the west side of Taylor Park (figure 13). Migmatites, which are characteristic of the older Denny Creek age intrusive rocks are lacking in the younger Forest Hill granitic rocks.

Migmatites in the thesis area are believed to have formed by mineral segregation and partial melting of the metasedimentary rocks during regional metamorphism and syntectonic intrusion of igneous rocks. Leucosomes consisting of feldspar and quartz occur as veinlets and pods in the migmatite segregates leaving residual refractory minerals such as biotite in the melansomes. The partial melting and subsequent coarse crystallization of the leucocratic minerals may be a result of high grade regional metamorphism of sedimentary rocks in the presence of water. The water could have come from interstitial pore fluids in the original sediments and/or dehydration of hydrous minerals such as biotite and hornblende.

Evidence indicating the migmatites formed prior to and during the emplacement of Denny Creek age intrusive bodies includes the following: (1) Contorted yet conformable nature of leucosome implies that the migmatites formed during deformation. (2) Inclusions of metamorphic wall rocks containing typical migmatites are common in Denny Creek granodiorite gneiss. (3) Localized occurrences of migmatite are restricted to outcrops of Denny Creek age rocks. Lack of migmatites in the Forest Hill granitic rocks indicates a low temperature, post-tectonic mesozonal or epizonal intrusion.

Figure 13. Outcrop from west side of Taylor Park consisting of polymetamorphic Denny Creek granodiorite gneiss, migmatite and quartz-biotite schist.

INTRUSIVE ROCKS

Intrusive rocks equivalent in age to two of the main Precambrian orogenic events of Colorado have been tentatively identified in the field area. Rocks from the older of the two age groups have been mapped by outcrops and float from the southwest 1/4 of the Pieplant 7.5' quadrangle and northwest 1/4 of the Taylor Park Reservoir 7.5' quadrangle eastward towards the adjoining Mount Harvard 15' quadrangle. These rocks are tentatively correlated with the 1700 m.y. old age group of Denny Creek granodiorite gneiss and Kroenke granodiorite, mapped in the Mount Harvard quadrangle by Barker and Brock (1965). Lithological varieties include gneissic metaigneous rocks ranging from granite to tonalite in composition, weakly foliated to massive leucogranodiorite, believed to be equivalent to Kroenke granodiorite, and a massive biotite tonalite of problematic Denny Creek age.

The younger intrusive rocks underlie the remainder of the thesis area between Denny Creek equivalent rocks on the east and Paleozoic strata on the west. These rocks have tentatively been dated at 1030 m.y. $\pm$ 40 m.y. by Rb/Sr analyses of six samples taken from two cogenetic granite phases. The discovery of rocks in the thesis area with a 1030 m.y. age is very significant, if confirmed, because prior to this study the only 1000 m.y. old igneous rocks in Colorado were restricted to the Pikes Peak batholith in the Front Range. These rocks equivalent in age to Pikes Peak rocks include a massive porphyritic granite, a medium-grained cataclastic granite and a hornblende granodiorite.

Denny Creek Granodiorite Gneiss

Field Description

A narrow band of rocks tentatively correlated with the Denny Creek granodiorite gneiss of the Mount Harvard quadrangle crop out along the west side of Taylor Park from Illinois Creek north to Trail Creek. It is bordered on the west by younger Precambrian granite. The granodiorite gneiss extends under glacial cover across Taylor Park into the Mount Harvard quadrangle to the east.

In outcrop typical Denny Creek granodiorite gneiss is medium-grained, mottled grayish-black (N2) to light-gray (N7). These rocks commonly display a greenish hue due to the chloritization of biotite. Augen and lenticular single grains and aggregates of feldspar and quartz are set in a schistose matrix of biotite.

Concordant interfingering of orthogneiss (Denny Creek granodiorite) with paragneiss is observed at nearly every outcrop and makes differentiation of metaigneous and metasedimentary bodies nearly impossible at the scale this area was mapped. Xenoliths of biotite and muscovite-epidote paragneiss are common in exposures of Denny Creek granodiorite gneiss. Migmatite is common throughout the area mapped as equivalent in age to Denny Creek rocks.

Petrography

The average modal composition based on 13 samples of Denny Creek granodiorite gneiss is about 33 percent quartz, 31 percent plagioclase, 8 percent potassium feldspar, 18 percent biotite, 5 percent muscovite, and 6 percent accessory and alteration minerals (table 3). A plot of recalculated quartz, plagioclase and potassium feldspar on a ternary Q-A-P diagram shows that this unit ranges in composition from granite to biotite tonalite (figure 14).

Table 3. Modal analyses (volume percent) of Denny Creek granodiorite gneiss (minimum of 500 points counted for each sample).

Major minerals	CB7-32 1/ 1 2/	CB7-47 2	CB7-48 3	CB7-51 4	CB7-53 5	CB7-82 6	CB7-88 7	CB7-93B 8
quartz	27.8	26.2	39.8	29.6	37.2	28.6	39.2	36.0
plagioclase	27.0	50.3	28.2	35.8	22.8	29.8	33.2	27.0
microcline	17.8	3.9	15.8	1.2	10.2	3.4	0.6	2.4
orthoclase	4.8	?	----	----	----	----	----	----
biotite	18.4	15.1	5.2	23.2	23.8	23.8	16.4	19.4
muscovite	3.2	0.4	4.8	2.8	1.4	2.6	5.2	14.4
Accessory minerals								
apatite	tr	0.2	tr	tr	tr	tr	tr	tr
zircon	tr	tr	tr	tr	tr	tr	tr	tr
sphene	0.4	----	----	tr	1.6	0.2	----	----
allanite	0.2	0.2	tr	tr	tr	tr	tr	----
chlorite	tr	1.2	1.8	1.4	0.8	2.4	2.6	0.4
epidote	0.2	1.4	3.8	3.2	2.0	2.8	2.0	----
opaques	0.4	1.2	0.6	2.4	0.2	6.6	0.8	0.4
rutile	----	tr	?	----	----	----	tr	----
leucoxene	tr	----	tr	tr	----	----	tr	----
clay	tr	tr	tr	tr	tr	tr	tr	tr
Total	100.2	100.1	100	99.6	100	100.2	100	100
Anorthite content	36	34-38	?	34	?	31	28	?

1/ Contains inclusions of microcline gneiss.

2/ Numbers refer to plot on Q-A-P diagram (Figure 14).

Table 3 (cont'd).

Major minerals	CB7-107B 9	CB7-108 10	CB7-214 11	CB7-317C 12	CB7-318 13	Avg. 14
quartz	36.0	29.2	26.6	39.8	31.0	32.8
plagioclase	33.6	38.6	20.4	31.2	27.0	31.1
microcline	4.0	12.4	13.4	2.6	13.4	8.1
orthoclase	----	----	----	----	----	
biotite	19.8	15.0	28.6	0.6	21.2	17.7
muscovite	5.0	3.2	6.8	8.8	3.0	4.7
Accessory minerals						
apatite	tr	tr	tr	0.2	tr	tr
zircon	tr	tr	tr	tr	tr	tr
sphene	----	----	----	?	0.2	tr
allanite	tr	tr	tr	tr	tr	tr
chlorite	tr	0.2	1.0	11.2	0.4	1.8
epidote	tr	tr	1.2	3.0	2.4	1.7
opaques	1.6	1.4	2.0	2.6	1.4	1.7
rutile	tr	----	----	tr	tr	tr
leucoxene	----	----	----	?	----	tr
clay	tr	tr	tr	tr	tr	tr
Total	100	100	100	100	100	99.6
Anorthite content	32	29	?	32	38	33

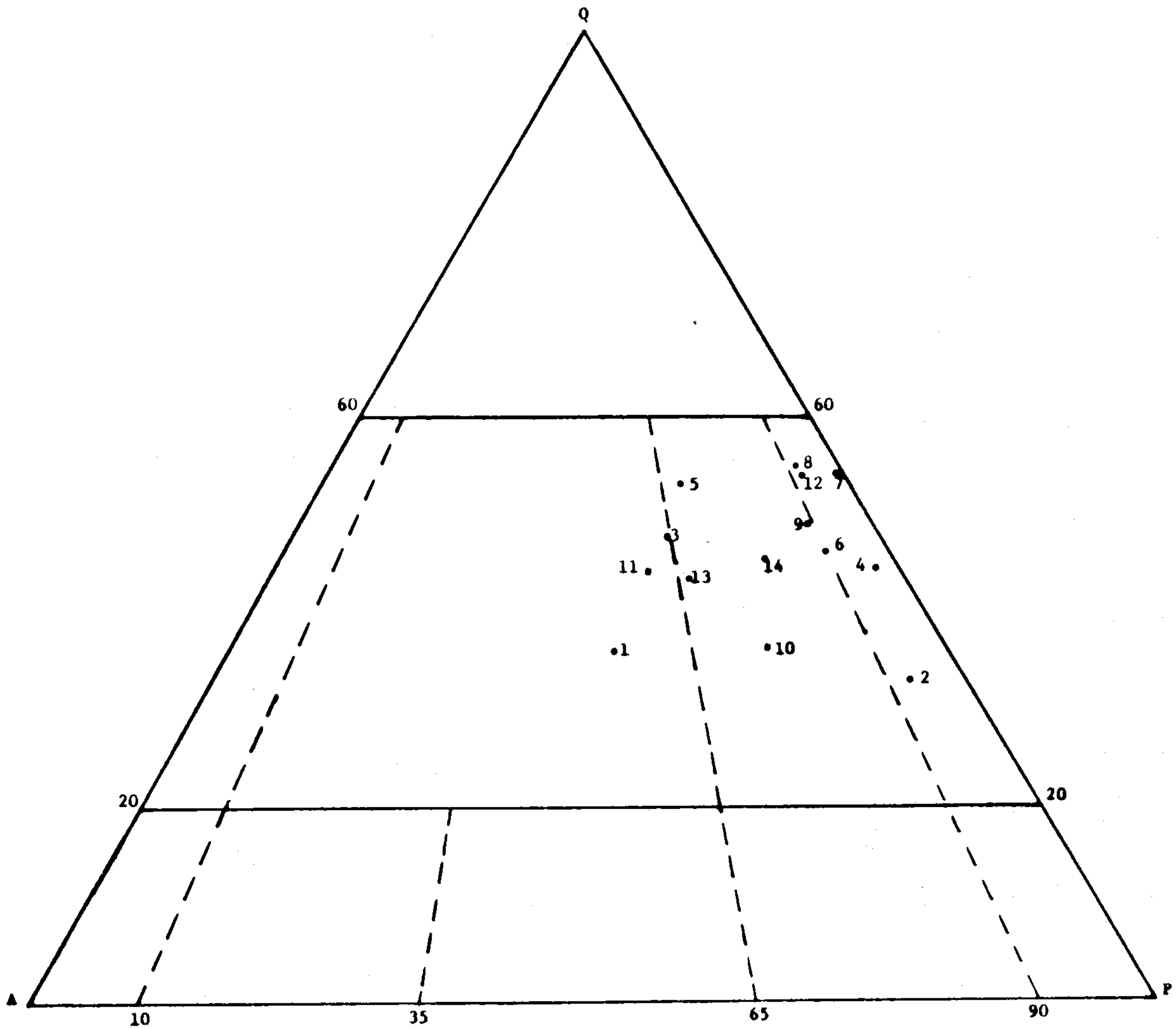

Figure 14. Q-A-P diagram for Denny Creek Granodiorite Gneiss; sample numbers are listed in table 3.

As seen in hand specimen and thin section, the texture is allotriomorphic, inequigranular, fine to medium-grained, with well-developed foliation. Lineation is produced by lensoid aggregates of biotite and quartz-feldspar. Gneissic foliation results from the segregation of quartz-feldspar and biotite-rich layers (figures 15, 16 and 17). Figures 18 and 19 show Denny Creek granodiorite gneiss with poorly developed foliation and cataclastic texture.

Cataclastic textures are common, as shown by bent micaceous plates and plagioclase twin lamellae, broken grains of quartz and plagioclase, and polycrystalline quartz with undulatory extinction and mortar texture. Cataclasis has resulted in various degrees of comminution of quartz and feldspar crystals, usually forming fine mortar texture between the more resistant crystals. Microfractures are locally abundant, usually filled by quartz and potassium feldspar.

Two types of quartz, apparently of different generations, are present in the granodiorite gneiss. Primary anhedral crystals of quartz occur as irregular masses and granular lenses, which show undulatory extinction and sutured borders. This quartz shows an abundance of inclusions of several varieties. These include: (1) fine dust-sized particles and vapor bubbles, commonly arranged in definite lines which possibly define invisible fractures; (2) euhedral zircon crystals; and (3) fine hair-like needles (rutile?) are seen in some slides. Much of the quartz shows mortar texture formed by intensely crushed or granulated zones around intact crystals. Elongate quartz, parallel to the foliation exhibits sutured borders along with other signs of recrystallization. The second type of quartz occurs as unstrained blebs in myrmekite and along microfractures, indicating a late palagenesis.

Anhedral crystals of plagioclase average 1-2 mm in maximum diameter. The plagioclase is dominantly calcic an-

Figure 15. Denny Creek granodiorite gneiss outcrop. Augen of feldspar and quartz in a schistose matrix.

Figure 16. Hand sample of typical Denny Creek granodiorite gneiss, a moderately foliated plagioclase-quartz-biotite gneiss.

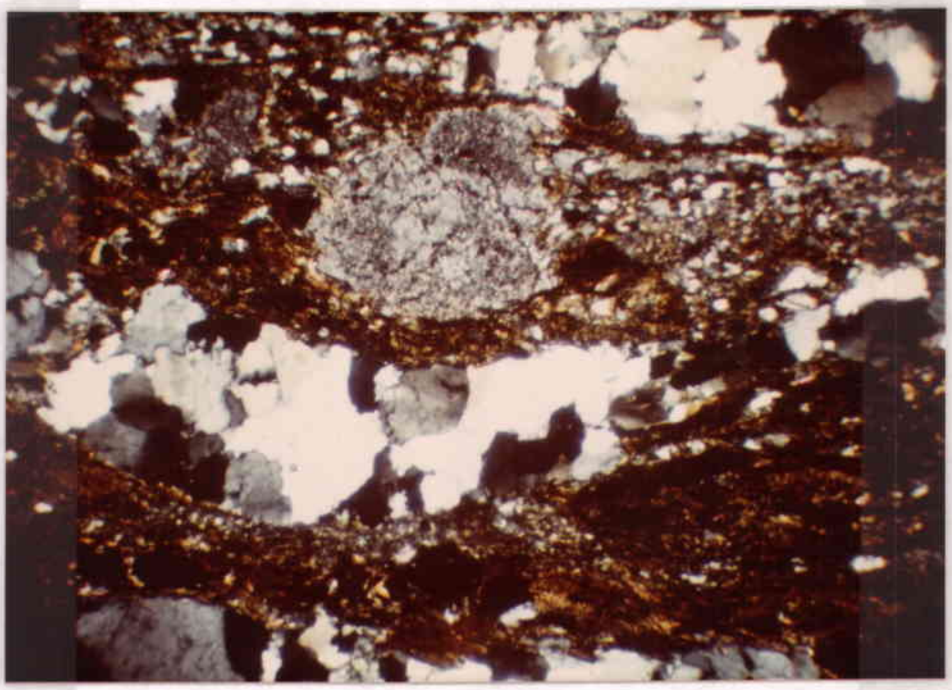

Figure 17. Photomicrograph of highly foliated Denny Creek granodiorite gneiss. Lenticular quartz bands and relict ovoid crystals of plagioclase augen interlayered with biotite, quartz and magnetite.

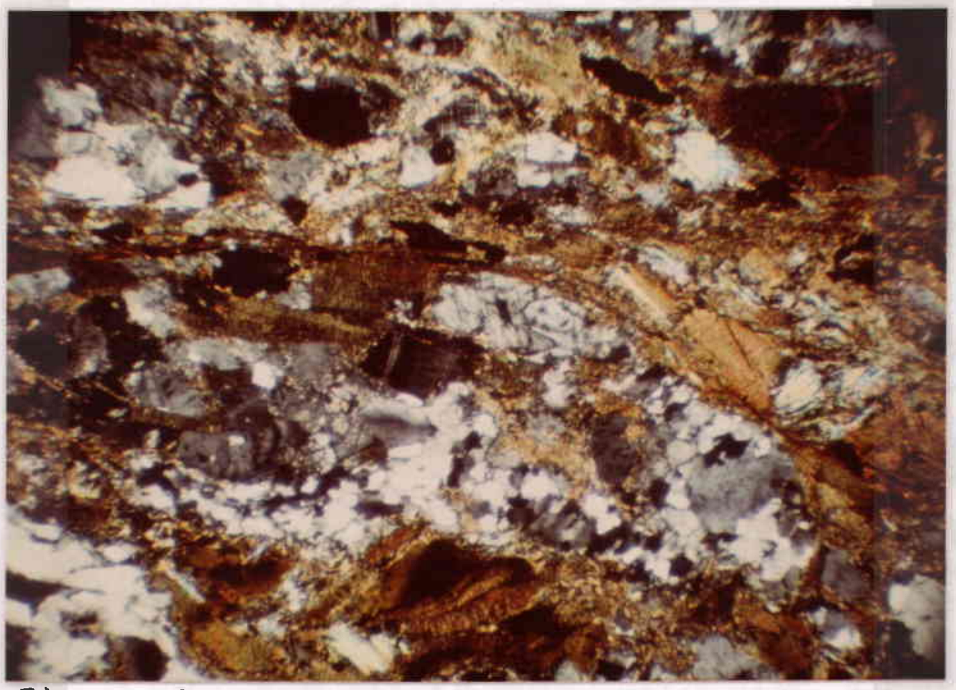

Figure 18. Variation of Denny Creek gneiss is less foliated than that shown in figure 17 although still gneissic. Major minerals are quartz, plagioclase, microcline, biotite and muscovite.

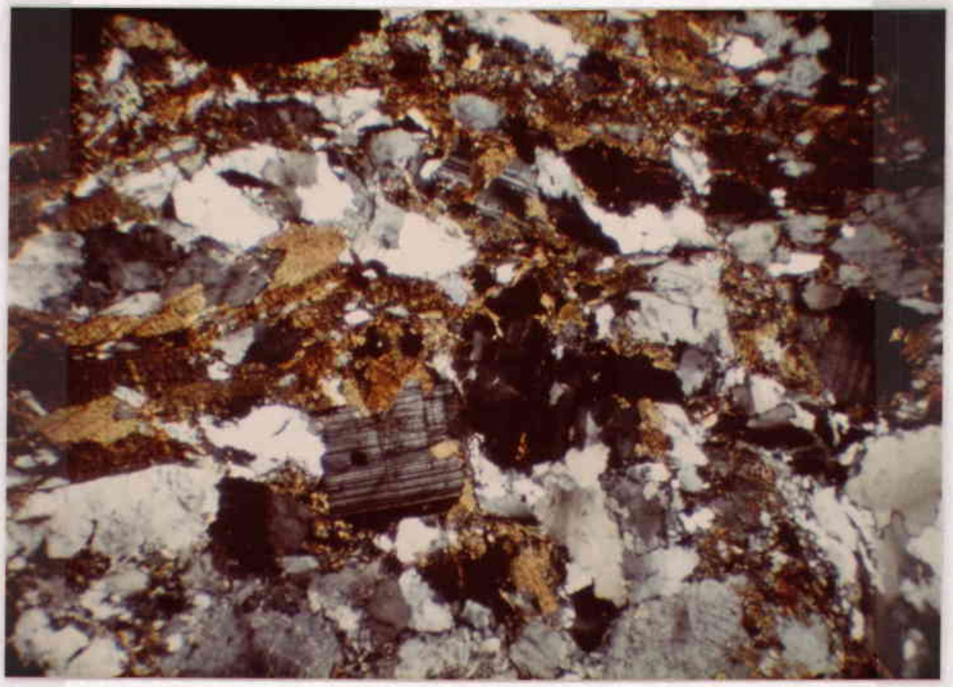

Figure 19, Example of Denny Creek granodiorite gneiss? exhibiting poor foliation. Deformation and recrystallization are still evident.

desine with an average anorthite content of 33 percent. Zoned plagioclase was not present in the slides studied. Moderate to poorly developed albite and carlsbad twins are observed in thin section. Mild cataclasis is evident in most slides by bent and offset polysynthetic twins. Borders of plagioclase grains are commonly embayed by quartz, and locally by microcline. Minor myrmekite is observed in some slides occurring along boundaries between plagioclase and microcline crystals. Hydrothermal alteration of plagioclase formed sericite and saussurite. The sericite is inferred to be muscovite from evidence of fine white mica along cleavage planes grading into coarse plates of muscovite. In some slides alteration has completely obscured twinning.

Microcline forms anhedral crystals with moderately to poorly developed gridiron twinning. Crystal borders are highly irregular forming embayments into plagioclase and quartz, possibly indicating late crystallization of the microcline. Inclusions of biotite, plagioclase, quartz, muscovite, epidote and opaques are common in crystals of microcline.

Subhedral plates of biotite, exhibiting yellowish-tan to dark-brown or greenish-brown pleochroism, occur as subparallel plates and aggregates. Segregation of biotite into layers defines the gneissic texture. Inclusions in biotite include apatite, zircon, opaques, quartz and sphene. Zircon is commonly surrounded by pleochroic halos. Much of the biotite is partially altered, usually to chlorite, magnetite, epidote and occasionally sphene.

Two generations of muscovite are visible in thin section. Primary muscovite occurs as subhedral plates commonly intergrown with and subparallel to biotite. Secondary muscovite is an alteration product of plagioclase, and biotite, forming fine wisps and aggregates in the cores of plagioclase and invading biotite plates along cleavage planes and rims.

Chlorite occurs as an alteration product along cleavage planes and crystal borders of biotite. In some rocks biotite is completely replaced by chlorite.

Microscopic subrounded crystals and aggregates of epidote occur as alteration products of biotite and plagioclase. Epidote is also common as a rim around crystals of allanite.

Sphene is a minor constituent usually associated with magnetite in altered biotite.

Subhedral to euhedral crystals of apatite are ubiquitous in these samples. They are usually associated with biotite, but also occur as inclusions in feldspars.

Opaque minerals were tentatively identified by reflected light in thin section. They are titaniferous magnetite which is locally altering to hematite and leucoxene. A titaniferous composition is inferred from the close association with sphene.

Metamict allanite crystals are seen in most thin sections. Crystal shapes are subhedral to anhedral, commonly rimmed by epidote.

Minor clay (unidentified) is probably an alteration product of plagioclase, due to weathering processes.

Kroenke Granodiorite

One small pluton of Kroenke granodiorite crops out in section 26, T13S, R82W. A contact with biotite schist is seen along the southeast border of the pluton and small outcrops of paragneiss and migmatites crop out around the granodiorite. Mixed, glacially derived, float of Kroenke granodiorite, paragneisses and Denny Creek granodiorite gneiss obscure bedrock relations at many locations in the eastern portion of the field area. Although mapped as a large body extending from the Mount Harvard quadrangle into the thesis area the exact distribution of Kroenke granodiorite is impossible to delineate without subsurface data in this glacially covered eastern portion of the map area.

Kroenke granodiorite is a leucocratic, fine to medium-grained, equigranular rock. In outcrop, it is grayish-orange-pink (5YR 7/2) to moderate orange (10R 7/4) in color. A well defined primary joint pattern, trending N 50 E and dipping 22 degrees to the north transects the outcrop. A second, less well-defined joint pattern trends N 60 W and has a vertical dip. Visible minerals in hand specimen are quartz, plagioclase, biotite and minor muscovite. Biotite occurs as fine wisps and plates. Locally, biotite segregation occurs giving a moderate foliation to the rock. Thin sections were not prepared for this rock type so modal analyses are not available.

Age and Correlation

Correlation of metaigneous rocks in the Taylor Park area with the Denny Creek granodiorite gneiss and Kroenke granodiorite of the Mount Harvard quadrangle is based on the proximity and lithology of the units.

Kroenke granodiorite, cropping out in the Mount Harvard quadrangle, has been dated by a Rb/Sr isochron at about 1700 m.y. old, with an initial $^{87}Sr/^{86}Sr$ ratio of $.7027 \pm .0003$ (Barker and others, 1974). Denny Creek granodiorite gneiss is intruded by the Kroenke granodiorite and is believed to be the same age as the Cross Creek granite of the Sawatch and Gore Ranges, that is, about 1715 m.y. (Tweto, 1977).

Rocks in the thesis area that are lithologically similar and spatially continuous to the Denny Creek granodiorite are given the same informal name and age. A similar correlation exists for the Kroenke granodiorite.

Biotite Tonalite

Field Description

Rocks mainly of tonalite composition are interpreted to be equivalent in age to the 1700 m.y. igneous rocks of the region. Biotite tonalite is exposed along both sides of Taylor River in section 32, T13S, and section 5, T14S R82W, cropping out to the west over an area of approximately five square miles. The tonalite is medium to coarsely crystalline and has an overall salt and pepper appearance. Outcrops weather to rounded or subrounded bodies and fragments ranging in size from boulders more than six feet in diameter to sand-sized particles forming grus. Weathered surfaces are light brownish-gray (5YR 6/1) to medium dark-gray (N4). Fresh surfaces are medium-gray (N5).

Xenoliths of mica schist were observed in several small outcrops at scattered locations. Fine aplite and pegmatite dikes of Precambrian age cut this pluton as well as Tertiary rhyolite and andesite dikes.

The dominant jointing trend is north-northeast and steeply dipping west. A secondary, nearly horizontal joint pattern is locally observed.

Petrography

Modal analyses of four thin sections listed in table 4 and plotted on figure 20 indicate this massive Denny Creek equivalent age pluton is tonalite to granodiorite in composition. The average percentage of major minerals is about 31 percent quartz, 33 percent plagioclase, 24 percent biotite, with lesser amounts of muscovite and potassium feldspar. Accessory minerals and alteration products include apatite, zircon, sphene, allanite, chlorite, epidote, opaques and rutile. In thin section, this rock appears hypidiomorphic, inequigranular and medium to coarse-grained

Table 4. Modal analyses (volume percent) of biotite tonalite (500 points counted for each slide).

Major minerals	CB7-5 1 1/	CB7-148 2	CB7-151 3	CB7-315 4	Avg. 5
quartz	29.0	29.4	32.4	31.8	30.7
plagioclase	36.7	29.4	32.3	33.0	32.9
microcline	1.0	tr	8.8	----	3.1
orthoclase	----	----	----	2.0	
biotite	24.0	30.0	20.0	23.0	24.3
muscovite	3.2	4.3	2.6	1.2	2.8
Accessory minerals					
apatite	0.4	0.6	0.4	0.2	0.4
zircon	tr	tr	tr	tr	tr
sphene	1.3	1.2	1.2	----	0.9
allanite	0.4	0.2	----	0.2	0.2
chlorite	1.7	1.2	0.6	2.6	1.5
epidote	1.1	0.4	1.0	2.4	1.2
opaques	1.5	3.5	0.6	3.6	2.3
rutile	tr	tr	tr	?	tr
leucoxene	----	----	----	----	----
clay	tr	tr	tr	tr	tr
Total	100.3	100.2	100	100	100
Anorthite content	38-42	30-40	28-42	36	36

1/ Numbers refer to plot on Q-A-P diagram (Figure 20).

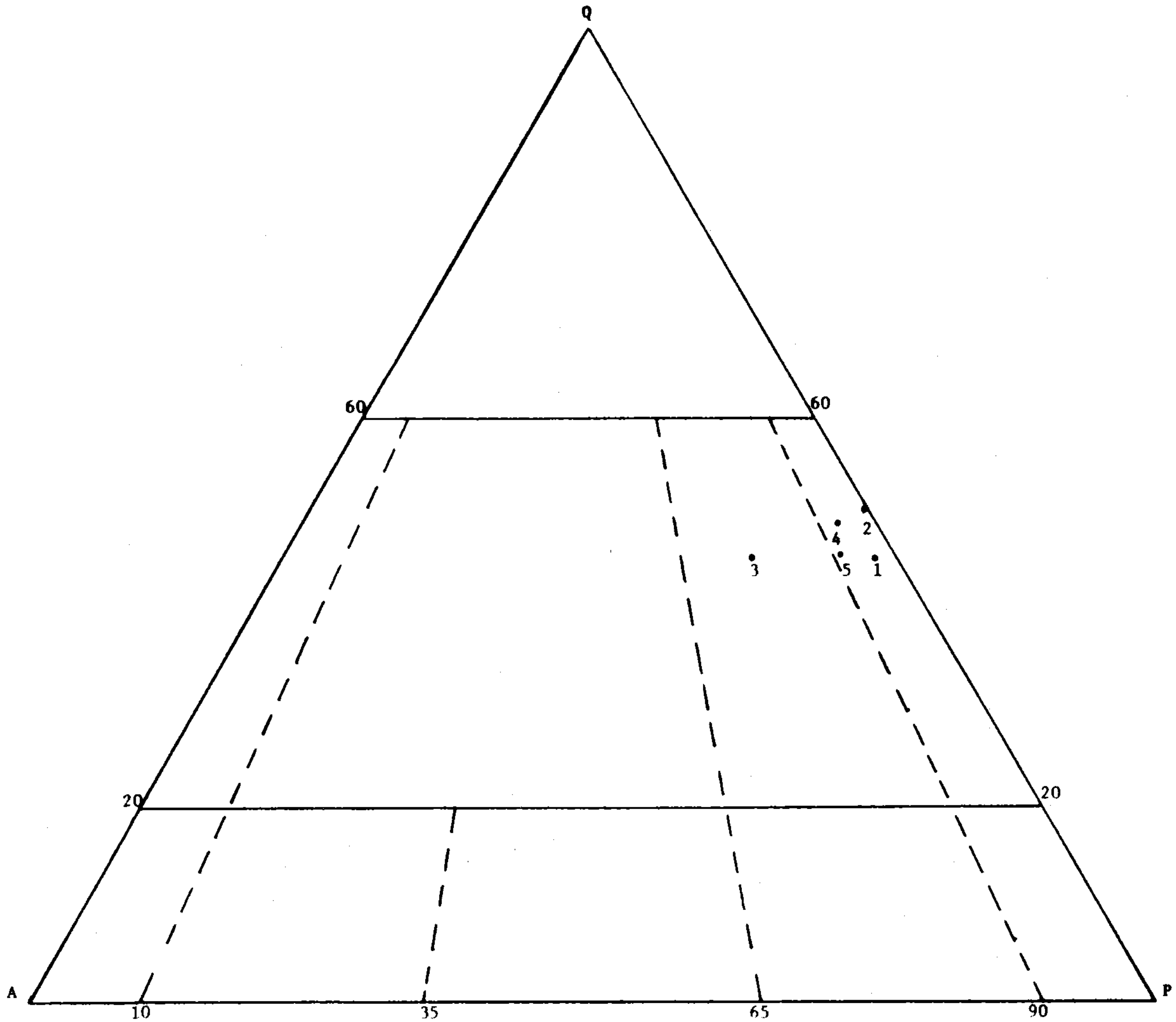

Figure 20. Q-A-P diagram for Biotite Tonalite samples listed on table 4.

(figure 21). One sample (CB7-315) has undergone extreme cataclasis which reflects its location near a large shear zone. Various degrees of microfracturing of individual crystals are visible in all the slides studied.

Anhedral crystals of quartz range from fine interstitial masses, less than 1 mm in diameter, up to large subrounded masses 7 mm in diameter. Inclusions observed in quartz include all the major constituents, indicating a late paragenesis for the quartz. Apatite, zircon and fine hair-like needles of rutile occur along crystallographic planes in the quartz. Sutured borders are common and undulatory extinction is present in all samples. One sample (CB7-315) is cataclastic with highly strained quartz exhibiting undulatory extinction and comminution. Quartz is the last mineral to crystallize, usually forming large crystals and interstitial blebs which embay earlier formed minerals.

Plagioclase feldspar is sodic andesine (An_{40}). Zoning is rare, occurring only in one slide. Here, it occurs as concentric bands around a more calcic core which is altered to sericite. Crystals are subhedral averaging about 2.5 mm in length with some longer crystals reaching 7 mm. Inclusions in the plagioclase consist of quartz, biotite, muscovite and fine needles of rutile(?). Alteration products include sericite, epidote and clay (kaolin?). Twinning is well developed in most plagioclase crystals, consisting of sharp albite, carlsbad and occasionally pericline twins.

There appear to be two generations of plagioclase: (1) An earlier anhedral, poorly twinned, zoned and highly altered plagioclase which is corroded and included in biotite and quartz; and (2) a late magmatic or deuteric plagioclase with subhedral crystals exhibiting good twinning, minor alteration and a lower An content of between 28 and 32 percent. Where plagioclase is in contact with microcline, poorly developed myrmekitic intergrowths and

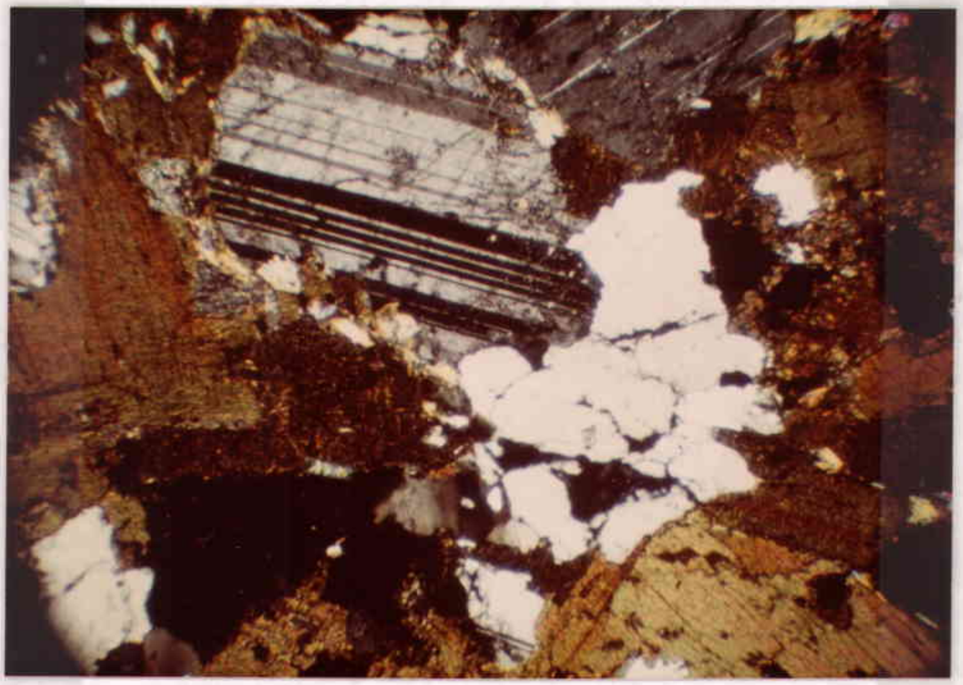

Figure 21. Photomicrograph of typical Denny Creek Biotite Tonalite. Quartz, plagioclase, biotite, sphene, apatite and muscovite are visible in this section.

faint sodic rims are formed. Plagioclase also exhibits corroded borders when in contact with microcline or quartz.

Potassium feldspar is a minor constituent of this unit, except for one sample (CB7-315) of granodiorite which has nearly 9 percent microcline. Gridiron twinning is moderately developed in most grains. Microcline is clear (unaltered) compared to the altered plagioclase feldspar. Minor inclusions of altered plagioclase, sphene, quartz, zircon and magnetite occur in microcline. Crystal shapes are anhedral to subhedral. Microcline commonly embays plagioclase, quartz and biotite and locally occurs along fractures in quartz, indicating a late magmatic or deuteric origin for at least some of the microcline.

Biotite is pleochroic light tan to dark-greenish brown. Many of the larger crystals are bent. The crystals are subhedral to anhedral, ranging in size from less than 1 mm up to 4 mm. In the cataclastic biotite tonalite sample, biotite flakes are smaller, more deformed, and form clusters with faint subparallel alignment. Apatite, sphene, zircon, allanite and rarely quartz occur as inclusions in biotite. Granular aggregates of magnetite commonly occur along cleavage planes intergrown with biotite. Alteration products are chlorite, muscovite and epidote which commonly occur as intergrowths along cleavage planes or rims around plates of biotite. Alteration was probably a result of activity from hydrothermal solutions.

Muscovite occurs as a secondary alteration product of biotite and plagioclase. It forms subhedral flakes and shards less than 1 mm in length. Aggregates of fine muscovite plates obliterate the cores of some plagioclase crystals.

Euhedra and subhedra of apatite commonly occur as inclusions in quartz and biotite. Some crystals contain fine dust-sized opaque particles giving them a cloudy core.

Euhedral zircon crystals, usually exhibiting birefringent halos due to radioactive decay, are included in biotite and less commonly in feldspars and quartz.

Sphene occurs as anhedral inclusions in biotite and as aggregates surrounding magnetite.

Anhedral crystals of metamict allanite occur as inclusions in biotite and plagioclase and as irregular shaped interstitial masses. Epidote rims are common around allanite crystals.

Chlorite is ubiquitous as an alteration product of biotite, usually occurring along cleavage planes or crystal borders.

Epidote is an alteration product of both biotite and plagioclase. It forms fine aggregates in the latter. Concentration of epidote in the cores of some plagioclase crystals indicates normal zoning with the more calcium rich core altering to epidote first. Pervasive epidozation of plagioclase is more common indicating a homogeneous calcium content.

The primary opaque is tentatively identified in reflected light as magnetite, with minor amounts of pyrite visible in one slide (CB7-5). Both magnetite and pyrite are oxidizing to hematite.

Fine hair-like needles of rutile are abundant as inclusions in quartz, often seen in distinct parallel alignment.

Age and Correlation

The lack of good intrusive contacts between biotite tonalite, Denny Creek granodiorite gneiss and Forest Hill granite make correlation of the biotite tonalite problematic. Field characteristics of the various rock types as well as petrographic and chemical evidence indicates the biotite tonalite is younger than Denny Creek granodiorite gneiss and older than Forest Hill granite. Three possible ages may be inferred from this: (1) The tonalite may be an early differentiate of the Forest Hill granite and, therefore, equivalent to the 1000 m.y. orogenic episode; (2) it is of an intermediate age equivalent to the 1400 m.y. old igneous rocks of Colorado; (3) it is equivalent to rocks of Kroenke granodiorite age or slightly younger and, therefore, equivalent to the 1700 m.y. orogenic episode of Colorado. The biotite tonalite does not crop out in contact with the Forest Hill granite and there is no indication from lithologic, petrographic or chemical data of its being related to the granite. Besides the obvious petrographic and chemical differences (see descriptions in text), the tonalite locally displays weak foliation, deformation and more intense alteration than the granite. The unit is unlikely to be equivalent to rocks of the 1400 m.y. old orogenic pulse in Colorado because of the restricted occurrence, lack of other 1400 m.y. rocks in the immediate vicinity and similarity to the Denny Creek granodiorite gneiss. I tentatively correlate the biotite tonalite with the Denny Creek granodiorite gneiss. Lithological, petrographic and chemical similarities with Denny Creek granodiorite gneiss indicate the biotite tonalite is probably equivalent in age. The informal designation used in this report will be Denny Creek biotite tonalite, although exact correlation with the 1700 m.y. old rocks in the thesis area is inconclusive. A final correlation may be made only when a more detailed study, including a radiometric age date, has been undertaken.

Forest Hill Granitic Rocks

Three rock types of the same orogenic event are discussed separately in the following sections. The correlation of the three (Forest Hill porphyritic granite, Forest Hill cataclastic granite and Forest Hill hornblende granodiorite) is presented here to avoid repetition.

A tentative absolute age for the porphyritic granite and cataclastic granite is established by Rb/Sr isotopic analyses. Three fresh samples from each granite were sent to Teledyne Isotopes in New Jersey for analysis. The results are shown in table 5 and the analytical methods used are presented in appendix I.

The combined analyses of the six samples define an apparent isochron age of 1030 ± 40 m.y. with an initial ratio of 0.7111 ± 0.0019 (figure 22). Uncertainties are 1σ of ± 1%. Ages for the samples are calculated in three ways as shown on table 5. The first two ages are calculated for the separate granitic phases and the third is a combined calculation.

The age calculation for group I is not meaningful because the samples are very close together in composition.

The separation of group II is sufficient to permit calculation of an age but the error is large (1000 ± 390 m.y.), due primarily to sample number CB7-202, which is either high in radiogenic strontium or low in rubidium content.

If the rocks in the two groups are cogenetic (which I interpret them to be based on field mapping) the age calculation is improved considerably with the statistical error being reduced to about ± 4%. If sample #202 is excluded, the age is 990 ± 10 m.y., so the statistical error is considerably reduced with a relatively small change in calculated age.

A tentative age correlation may be made with the Pikes Peak orogenic event. A lithological correlation is not attempted in this report due to the distance separating the intrusions. This is a very significant and unique age for Precambrian igneous rocks in the Sawatch Range. The only other rocks of this age identified in Colorado are the rocks which compose the Pikes Peak batholith located in the Front Range.

Correlation of the hornblende granodiorite is based on intrusive relationships with the porphyritic granite. Two small plugs intrude the granite on Forest Hill and are interpreted to be a late pulse of early differentiated mater-

Table 5. Rb-Sr isotope dilution data for Forest Hill porphyritic and cataclastic granites.

Sample	Rb,ppm	Sr,ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Forest Hill cataclastic granite				
CB7-44	203.3	144.8	3.985	.7675
CB7-127	102.2	54.7	5.314	.7871
CB7-202	230.3	142.8	4.584	.7827
Forest Hill porphyritic granite				
CB7-117	173.5	480.3	1.021	.7249
CB7-242	113.7	354.5	0.9066	.7258
CB7-248	159.3	469.9	0.9062	.7242

Samples included	Group I (44, 127, 202)	Group II (117,242,248)	Group III (all six samples)
Age (b.y.)	1.00 ± .39	.76 ± .37	1.03 ± .04
$^{87}Sr/^{86}Sr$ (Initial)	0.7132 ± 0.0257	0.7146 ± 0.0050	0.711 ± 0.0019

Group I - Adequate range of composition but error is large.

Group II - Not meaningful because samples are very close together in composition.

Group III - Two rock types cogenetic - use all six samples and the statistical error is reduced to ± 4%. If sample #202 is left out then age is .99 ± .01 b.y.

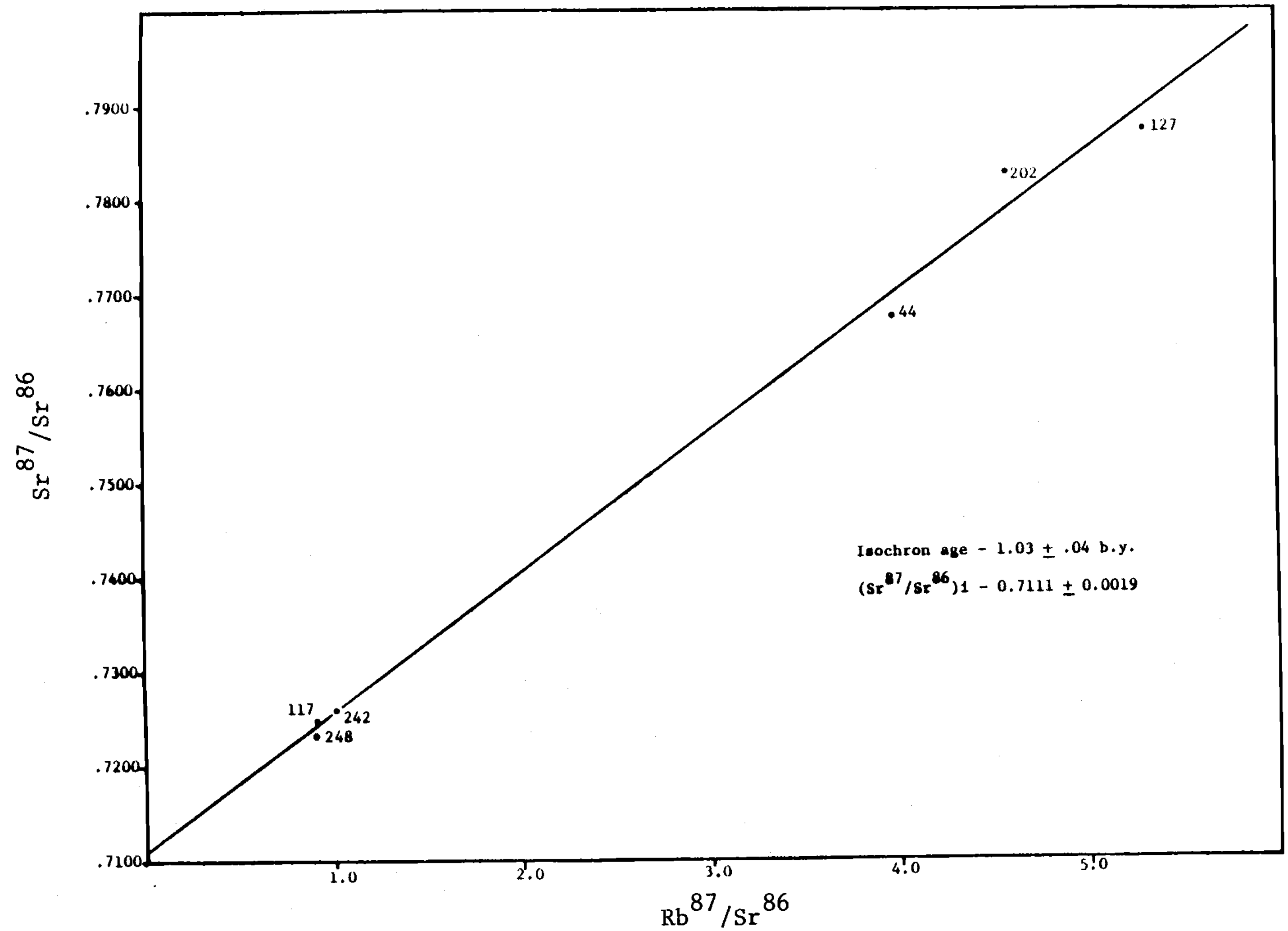

Figure 22. Rb/Sr isochron plot for samples of the Forest Hill porphyritic and Forest Hill cataclastic granites. Analytical results are listed in table 5.

ial, probably from the same magma chamber.

Forest Hill Porphyritic Granite

Field Description

Forest Hill porphyritic granite is the most extensive Precambrian igneous unit mapped in the Taylor Park area. Outcrops are limited in exposure, but in conjunction with float the pluton is believed to underlie the western half of the map area. The spatial distribution is defined on the west and south by Paleozoic rocks. Cataclastic granite of equivalent age to the porphyritic granite and older Denny Creek age rocks crop out to the east across Trail Creek. The northern limit of the porphyritic granite is uncertain as it extends beyond the map area and is covered by Tertiary volcanics.

In outcrop, the Forest Hill porphyritic granite is generally light-gray (N7) to medium-gray (N6) (figure 23). Weathered surfaces range in color from medium dark-gray (N4) to brownish-gray (5YR 4/1), with local zones of moderate-red (5R 4/6) coloration due to oxidation of ferromagnesian minerals. The granite exhibits a seriate porphyritic texture in hand specimen, with phenocryst size ranging from less than 1 mm to 4 cm in length (figure 24). Potassium feldspar phenocrysts are very light-gray (N8) to grayish-pink (5R 8/2), commonly containing visible inclusions of biotite and magnetite. Carlsbad twinning is visible in some of the larger phenocrysts. Other minerals identified in hand specimen are quartz, plagioclase, biotite and occasionally muscovite. Megascopically visible alteration minerals consist of chlorite, epidote and occasionally sericite.

Shearing has occurred throughout the region and was mapped where the scale permitted. The most intense shearing of porphyritic granite is seen along Trail Creek form-

Figure 23. Outcrop of Forest Hill porphyritic granite located on the east side of Forest Hill. Outcrop is cut by pegmatite dike and contains xenoliths of metasedimentary rocks.

Figure 24. Close up of porphyritic granite, phenocrysts of microcline and plagioclase are visible.

ing a microbreccia zone shown in figures 41a and 41b (page 111). Many smaller shear zones were observed throughout the area but their size did not permit mapping.

Xenoliths are a common sight in many outcrops of porphyritic granite as shown in figure 9. These inclusions of older Precambrian metasedimentary rocks consist predominantly of quartz-biotite-schist and quartz-biotite-sillimanite schist and are widespread in the area west of Trail Creek. The xenoliths range in size from a few inches to hundreds of feet. Many of the larger bodies retain original structures and textures. Figure 25 shows the discordant contact between a metasedimentary roof pendant and the porphyritic granite. Smaller, partially resorbed xenoliths which retain the near vertical foliation of the roof pendant are seen in the granite below the contact. The contact between the metasedimentary roof pendant and the granite is fairly sharp. Other similar roof pendants of metasedimentary rocks occur along the ridge northwest of Forest Hill.

Exposures of Forest Hill porphyritic granite display various degrees of weathering from relatively fresh outcrops to completely decomposed granite forming a regolith composed of grus and fragments of granite.

Jointing is prominent in some outcrops but distinctively lacking in many others. No regional joint patterns could be identified. Where jointing is seen it usually consists of one prominent set of steeply dipping joints trending either northwest or northeast (figure 26), and a less pronounced set of joints trending approximately 90 degrees from the first with a near vertical dip. At a few locations, poorly developed horizontal jointing was observed. The near vertical sets may have developed as tensile fractures from cooling of the intrusion. The horizontal set possibly formed due to unloading. The strikes of the joints varied greatly over the area without discernible pattern.

Figure 25. Roof pendant of quartz-biotite sillimanite schist. Discordant contact with porphyritic granite is sharp. Xenoliths of biotite schist are also visible in the granite.

Figure 26. Near vertical jointing in the Forest Hill porphyritic granite trending broadly northwest or northeast.

Field relationships with the other Precambrian rocks indicate the Forest Hill porphyritic granite is younger than the metasedimentary rocks and Denny Creek age rocks, but older than the medium-grained cataclastic granite and pegmatites. Outcrops along Trail Creek exhibit the age relations of these rock types very well showing porphyritic granite with inclusions of biotite schist and cut by dikes of cataclastic granite along with pegmatite and aplite dikes.

Petrography

Under the microscope, the texture of the granite is seen to be inequigranular, hypidiomorphic, porphyritic and locally modified by secondary structures due to crushing and recrystallization.

Porphyritic granite has an average modal composition based on eight thin sections of 33 percent quartz, 24 percent plagioclase, 23 percent potassium-feldspar, 8 percent biotite, 6 percent muscovite and approximately 6 percent other constituents. These other constituents include apatite, zircon, allanite, sphene, magnetite, epidote, chlorite, rutile and locally monazite and flourite. The large range in modal composition shown by the field of compositions in figure 27 and modal analyses listed on table 6 partly reflects the coarse-grain size of the granite. Point counting of such coarse-grained rocks gives only a crude approximation of the abundance of major minerals.

Two types of quartz, apparently of different generations, are seen in thin section. Quartz occurring as anhedral crystals showing undulatory extinction, sutured borders and elongation of some crystals are of an earlier generation than the clear unstrained quartz that occurs as myrmekitic blebs and subrounded crystals in microcline. The large irregular masses of strained quartz contain minute inclusions of dust-size particles and vapor bubbles

Table 6. Modal analyses (volume percent) of Forest Hill porphyritic granite (minimum of 500 points counted for each slide).

Major minerals	CB7-22 1[1/]	CB7-115 2	CB7-179 3	CB7-242 4	CB7-265 5	CB7-272 6	CB7-274 7	CB7-311 8	Avg. 9	CB7-271 10[2/]
quartz	26.4	33.4	31.6	43.5	23.4	29.8	45.0	26.8	32.5	14.2
plagioclase	21.2	21.8	23.0	15.4	29.8	27.6	21.8	34.0	24.3	36.2
microcline	27.8	12.4	23.0	28.3	27.6	26.6	24.8	14.8	23.3	7.0
orthoclase	----	----	----	----	0.8	----	----	----	----	----
biotite	0.8	12.0	13.6	6.4	9.6	9.2	1.4	12.0	8.1	20.0
muscovite	10.6	9.2	4.6	3.2	2.8	5.8	2.8	5.4	5.6	0.8
Accessory minerals										
apatite	tr	1.2	0.4	tr	tr	tr	tr	0.4	tr	tr
zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
sphene	tr	----	tr	tr	tr	----	tr	----	tr	1.4
allanite	0.4	----	0.6	tr	1.0	tr	tr	0.6	tr	tr
chlorite	4.8	4.4	1.0	1.4	1.4	0.6	2.8	3.0	2.4	1.4
epidote	4.6	1.8	0.4	tr	1.2	tr	0.8	0.8	1.2	1.6
opaques	3.4	3.8	2.0	1.7	2.4	0.4	0.6	2.3	2.1	1.0
rutile	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
leucoxene	tr	---	---	---	---	---	---	---	---	---
clay	---	tr	---	tr	tr	tr	tr	tr	tr	tr
fluorite	---	---	---	tr	tr	---	---	---	---	---
Total	100	100	100	100	99.9	100	100	100.1	99.5	100
Anorthite content	6-10	8-14	24-28	28-30	36	26-32	36	26	25	28-30

1/ Numbers refer to plot on Q-A-P diagram (Figure 27).

2/ Number 10 is Forest Hill hornblende granodiorite and listed here and plotted on figure 27. Discussion of this rock begins on page 84.

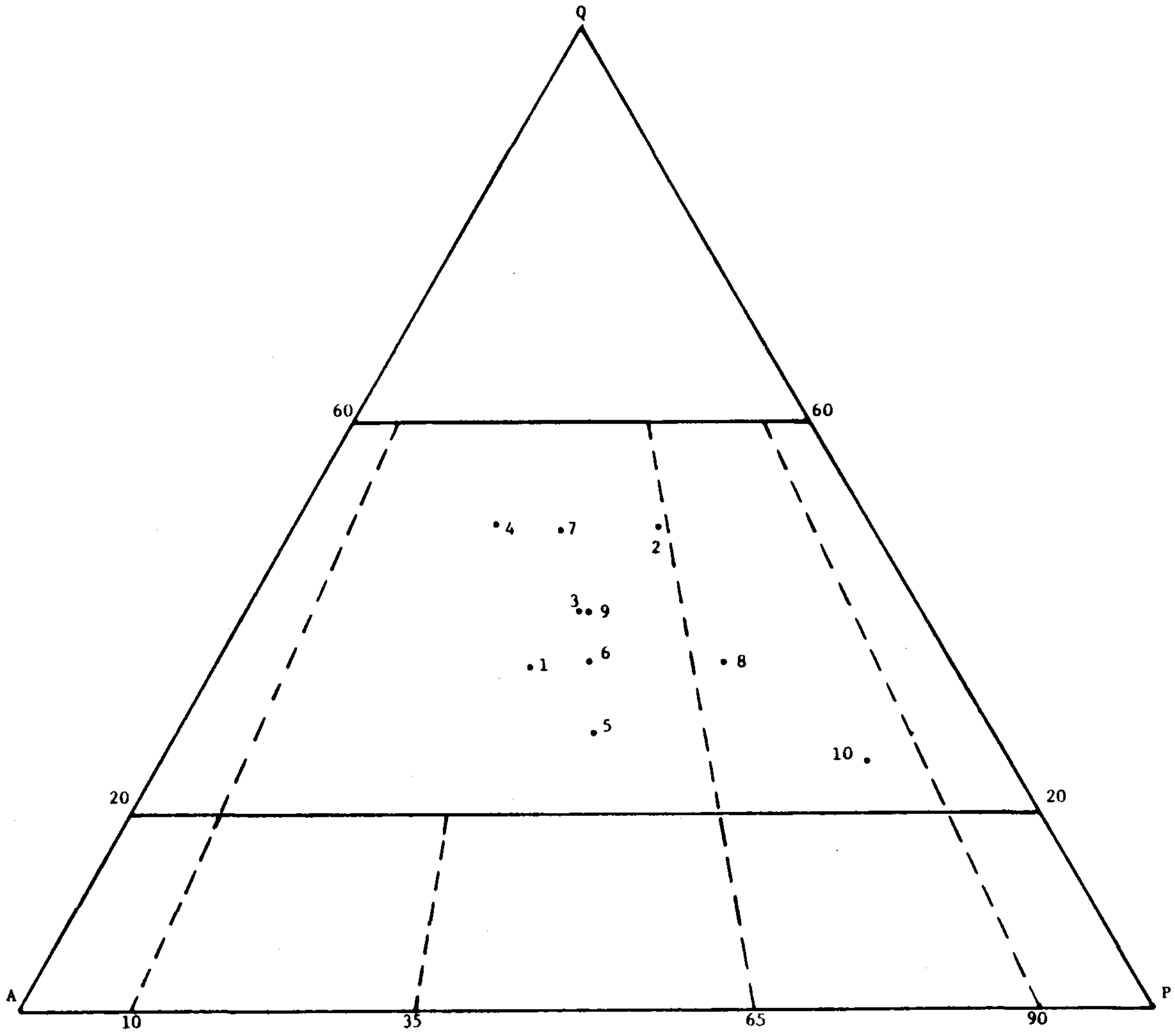

Figure 27. Q-A-P diagram for Forest Hill porphyritic granite. Samples are listed on table 6.

commonly arranged along definite invisible fractures. Fine hair-like needles of rutile are locally abundant in the quartz and similar needles are seen in microcline.

Cataclasis of these rocks is evident in the occurrence of strained, granulated and recrystallized quartz. Mortar texture is common around more resistant feldspar crystals and in fractures. In one specimen (CB7-115) quartz is recrystallized into thin stringers which undulate around feldspar grains and define a moderately-developed fluxion structure.

Plagioclase in the Forest Hill porphyritic granite is calcic oligoclase to sodic andesine in composition with an average content of 30 percent anorthite. Good crystal outlines are rare. Grains usually exhibit subhedral to anhedral form. Size ranges from less than 1 mm to 8 mm in length. Plagioclase generally has moderately to poorly formed polysynthetic twinning, dominantly of albite type but also including carlsbad and rarely combinations of albite and pericline. In all the sections studied the plagioclase is at least in part deutericly altered to saussurite, sericite and clay minerals. In some sections, the alteration minerals are large enough to be identified as plates of white mica (muscovite) and aggregates of epidote in a fine sericitic mass. Occasionally, sericite is formed as thin blades along cleavage planes in plagioclase. Many plagioclase grains exhibit a faint to moderately developed gradational zonation, identified microscopically by the higher anorthite content measured in the cores of some grains and the common sericitic alteration of plagioclase cores. Weak undulatory extinction is seen in many crystals indicating strain. Minor deformation is identified in some of the samples by the occurrence of bent and fractured polysynthetic twins in plagioclase and the strained appearance of quartz. Myrmekitic intergrowths of quartz in plagioclase appear in the form of isolated blebs, rods and dendritic varieties (figure 28). Plagioclase crystals in

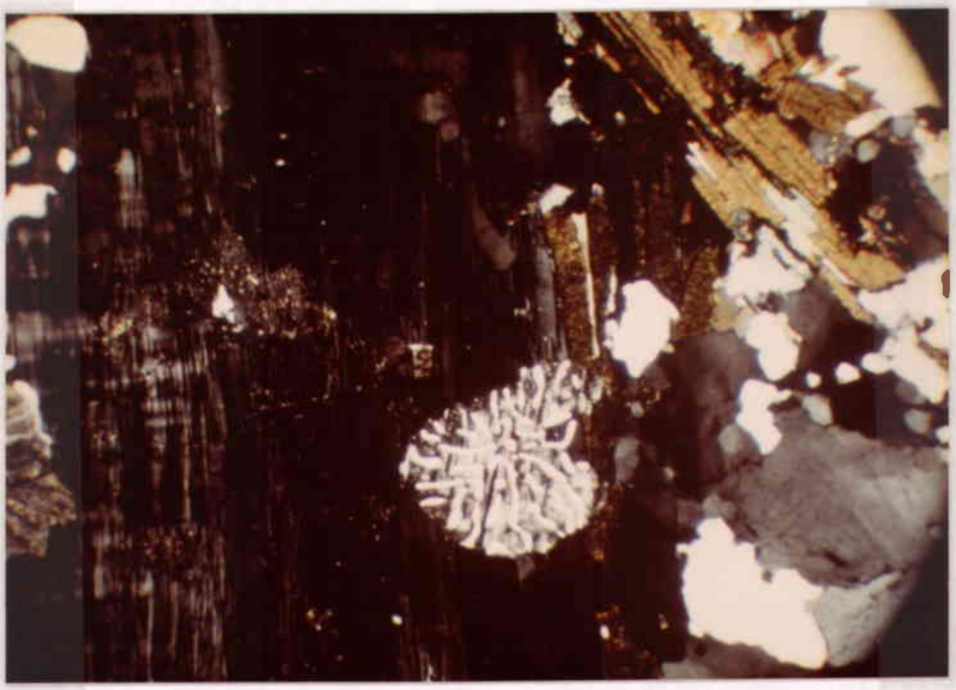

Figure 28. Photomicrograph of Forest Hill porphyritic granite. Myrmekitic intergrowths in plagioclase, when in contact with microcline. Other constituents include biotite, muscovite, quartz and sphene.

various stages of corrosion are included in microcline; often all that is visible microscopically is the alteration products.

Microcline appears fresh in thin section while plagioclase shows various degrees of saussuritization and sericitic alteration. From textural relations, microcline appears to represent at least two generations. The oldest microcline is enclosed and partially replaced by phenocrysts of younger microcline. That most microcline is late is apparent as this mineral is seen to surround, embay and penetrate other minerals, such as quartz, plagioclase and biotite (figure 29). In some crystals, microcline appears to be altered but upon closer scrutiny it is seen that a highly altered plagioclase crystal is being invaded and corroded. In many instances where microcline is in contact with plagioclase, fresh inclusion free albite rims form around the latter. Myrmekite generally occurs near grain boundaries between plagioclase and microcline although in a few specimens myrmekite is seen replacing plagioclase inclusions within a microcline crystal. The grid twinning that characterizes microcline is generally well-defined but may be irregular and blotchy in some cases. Carlsbad twinning is observed in some of the larger phenocrysts. Subhedral to anhedral crystals of microcline range from less than 1 mm to phenocrysts of approximately 16 mm in length. Microperthite is seen locally in microcline phenocrysts as strings and blebs.

Orthoclase is present in one rock on the basis of its negative sign, lower 2V than microcline and refractory index. Microcline appears to be replacing orthoclase by the occurrence of patches and embayments of twinned microcline within the orthoclase.

Biotite averages a little over 8 percent of the rock but is quite varied in abundance ranging from 1 to 15 percent. Seldom is the biotite entirely fresh, but when it is it exhibits strong pleochroic colors from tan to deep-brown

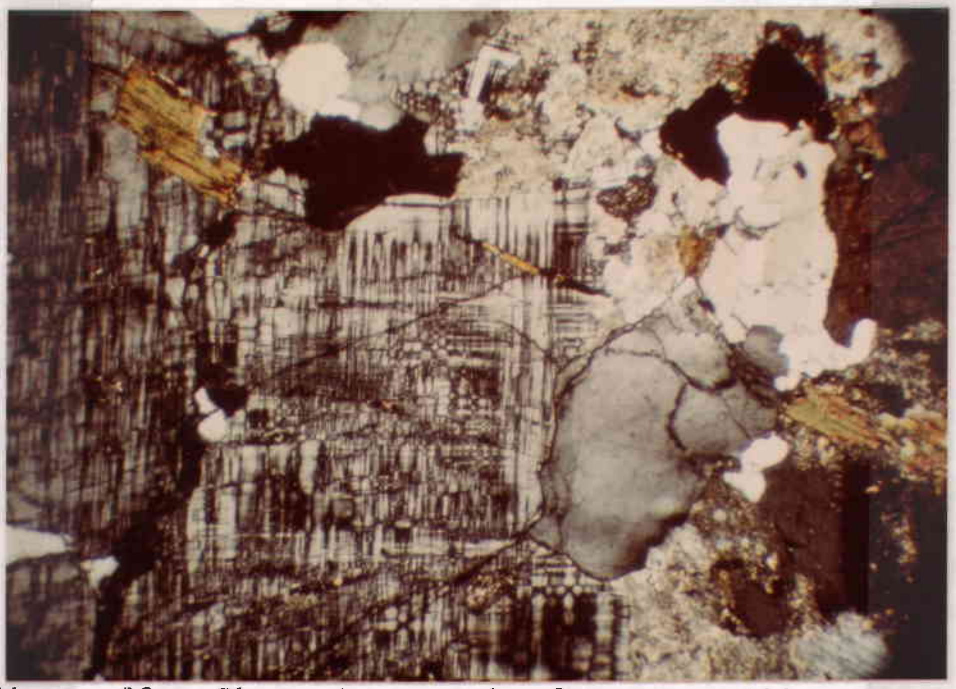

Figure 29. Photomicrograph of Forest Hill porphyritic granite. Microcline embaying quartz and plagioclase. Microcline exhibits good gridiron twinning and is fresh relative to plagioclase. Biotite and sphene are also present.

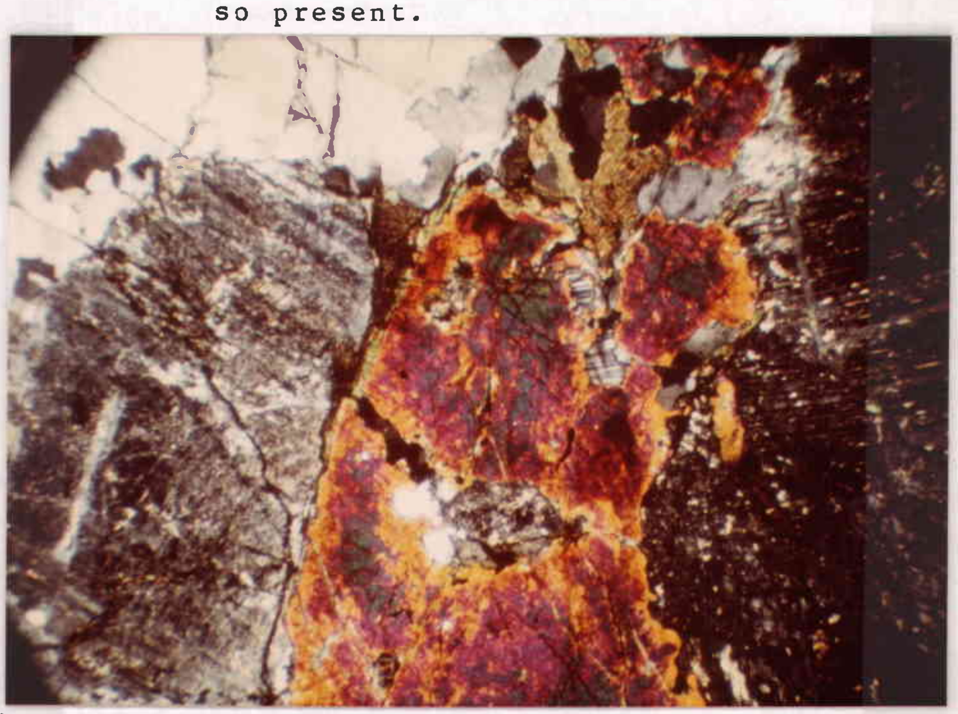

Figure 30. Large allanite crystal, rimmed by epidote in Forest Hill porphyritic granite. Also visible are quartz, plagioclase, biotite and microcline.

or greenish-brown. Biotite is present as anhedral to subhedral plates ranging in size from less than 1 mm to 3 mm in length. Plates of biotite form random clusters without preferred orientation in the least deformed specimens, while in granite demonstrating more intense cataclasis biotite flakes tend to exhibit well-defined planar orientations with increased deformation. Sometimes, larger plates appear bent as the result of strain. Inclusions of zircon, apatite, magnetite and quartz are common in biotite. Muscovite is locally intergrown with biotite along cleavages. Pleochroic halos due to radioactive decay surround the zircon crystals. Chlorite is ubiquitous as an alteration product of biotite. Magnetite, epidote and occasionally sphene also form as alteration products of biotite.

Subhedral to anhedral muscovite flakes appear to be of two generations. Early muscovite plates from less than 1 mm to 2 mm in length are intergrown with biotite. Thin wisps of muscovite rim and locally invade biotite plates. Some plates of white mica included in plagioclase grade into sericite shards along cleavage planes indicating a deuteric origin for much of the muscovite. In samples where biotite is substantially altered to chlorite, anhedral muscovite plates are commonly intercalated with epidote and magnetite in the chloritized biotite flakes. Where cataclasis and alteration are more intense deformed muscovite plates contain opaque material along their cleavage planes.

Chloritic alteration of biotite occurs along cleavage planes, rims and in some specimens completely replaces biotite. In slide CB7-311, chlorite is seen invading the biotite plates from the ends pervasively changing the color of the biotite to green, although the biotite partially retains its birds-eye extinction.

Magnetite is visible in all the specimens studied occurring as subhedral to euhedral crystals. In some slides, magnetite is partially altered to hematite, leucoxene or both. Magnetite is usally associated with biotite, sphene, apatite and epidote.

Sphene occurs as granular masses surrounding magnetite and in close association with biotite plates. Alteration to leucoxene is apparent in some masses while others are unaltered and display faint cleavage planes. Sphene is identified by its high birefringence, low 2V, positive sign, crystal form (wedge shape) and association with titaniferous magnetite.

Allanite is prominent in some slides attaining lengths of up to 3 mm (figure 30). Crystals are subhedral to anhedral in most thin sections although in one slide crystal shapes are predominantly euhedral. Epidote crystals rim most of the allanite, especially between allanite and biotite crystals. The close association of allanite with epidote may indicate a late paragenesis. Metamict allanite is isotropic in thin section but not all allanite displays a metamict texture. Pleochroism of yellow-brown to brown is common.

Monazite has tentatively been identified in some slides but because of the difficulty in distinguishing zircon from monazite, data for the two minerals are combined in table 6.

Euhedra to subhedra of apatite are closely associated with biotite plates but are also seen as inclusions in feldspars. In some samples, apatite reaches 1 mm in diameter.

Epidote is locally abundant, as an alteration mineral in plagioclase and along cleavage fractures or rimming biotite. Epidote is also associated with allanite, sphene and opaque minerals. Epidote generally occurs as aggregates of anhedral crystals of less than .5 mm and up to 2 mm across. Individual subhedra of epidote up to 1 mm in diameter are present in some slides. A faint yellow pleochroism is visible in most crystals.

Fine acicular hair-like needles of rutile are seen in quartz crystals and occasionally in microcline. Some rutile may also be present as opaque material along cleavage planes in altered biotites.

Fluorite was identified in two thin sections (CB7-242 and CB7-265). The fluorite exhibits a faint purplish color and is present as a single crystal in biotite and as an aggregate of crystals along a cleavage plane in biotite.

Leucoxene occurs as an alteration product of titaniferous minerals, such as biotite, magnetite and sphene.

Clay is ubiquitous as a very minor constituent in the altered plagioclase grains.

Forest Hill Cataclastic Granite

Field Description

A small stock of granite, approximately three square miles in area, is located between Trail Creek and Taylor Park. Poor exposure makes the exact distribution of this stock questionable. Small outcrops of cataclastic granite and associated float indicate the granite occupies a rather narrow northeast-trending zone between the Forest Hill porphyritic granite and the Denny Creek granodiorite gneiss.

Contact relations and Rb/Sr data indicate the porphyritic granite and the cataclastic granite are of the same general age. A Rb/Sr isochron of 1030 $\pm$ 40 m.y. was determined using the combined Rb/Sr data for both types of granite (table 5, figure 22 and appendix I). In many locations along both sides of Trail Creek, the cataclastic granite is seen in dikes cutting the porphyritic granite (figures 31a and 31b). Sharp, intrusive contacts are visible between these two granitic phases. The textural habit of the cataclastic granite represents the emplacement of granite along a major northeast-trending shear zone that had later movement resulting in the cataclastic texture. A similar mode of emplacement is presented by Higgins (1971) as an explanation for gneissic intrusive bodies.

Figure 31a. Forest Hill cataclastic granite dike intruding porphyritic granite along Trail Creek. Jointing is abundant in the dike rock but less obvious in the host.

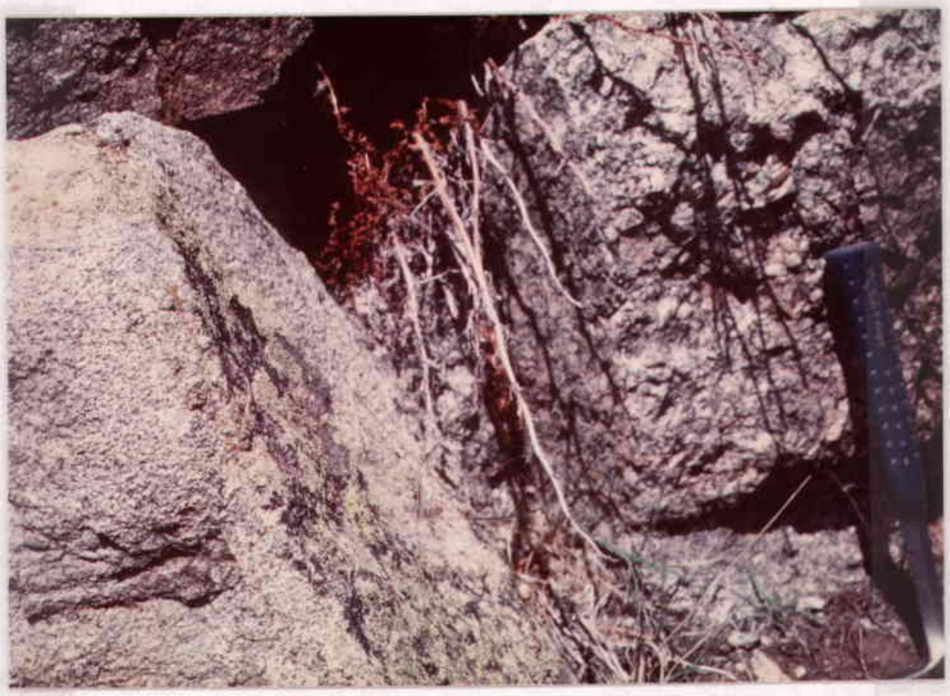

Figure 31b. Close up of sharp contact between cataclastic granite dike and porphyritic granite host.

The most important feature of this cataclastic granite is that it defines a major northeast-trending Precambrian shear zone that is approximately one mile wide. Smaller en echelon shears occur to the northwest and southeast of the major cataclastic zone. The close relationship of this northeast-trending cataclastic zone and en echelon shear zones is coincident with other Precambrian shear zones that define the Colorado mineral belt of Tweto and Sims (1963). Cross faults and shear zones, trending north-northwest, were mapped in the area and others may be hidden.

Megascopically, this rock is a fine to medium-grained, equigranular granite having a faint but distinct foliation. Foliation is defined by fine bands of biotite interlayered with feldspar and quartz. Color varies with mafic content, ranging from medium-gray (N5) to very light-gray (N8) or pinkish-gray (5YR 8/1). Minerals visible in hand sample are quartz, potassium-feldspar, plagioclase, biotite and, in a few samples, a fine white mica believed to be muscovite. Cataclastic granite is holocrystalline, allotriomorphic to hypidomorphic depending on the degree of cataclasis. In the specimens showing extreme cataclasis, augen texture is developed with augen of feldspar and lenses of elongate quartz. Subparallel alignment of elongate feldspars and micaceous plates is more pronounced as the degree of cataclasis increases.

Petrography

Under the microscope, the cataclastic granite displays a poorly developed gneissic texture. Cataclasis has affected all the samples resulting in crushed, broken and bent crystals.

The average modal analyses of fourteen thin sections (table 7) are quartz 31 percent, plagioclase 23 percent, microcline 27 percent, orthoclase 2 percent (total potassium feldspar is about 28 percent), biotite 5 percent and

Table 7. Modal analyses (volume percent) of Forest Hill cataclastic granite (minimum of 500 points counted for each slide).

Major minerals	CB7-7 1 1/	CB7-27 2	CB7-28 3	CB7-31 4	CB7-44 5	CB7-89 6	CB7-92 7	CB7-116 8
quartz	28.2	30.4	26.4	34.4	33.0	30.6	34	28.8
plagioclase	18.6	27.8	29.8	23.2	12.6	29.0	27.6	15.0
microcline	33.0	32.4	31.0	21.4	27.2	17.6	12.2	37.2
orthoclase	0.4	----	----	----	1.4	1.8	2.8	----
biotite	3.2	tr	4.2	----	2.0	2.0	4.4	5.2
muscovite	10.6	8.8	5.6	21.0	12.4	8.8	5.4	9.0
Accessory minerals								
apatite	tr	tr	tr	tr	tr	0.4	0.4	tr
zircon	tr	tr	tr	tr	tr	tr	0.2	tr
sphene	----	----	tr	----	----	0.2	tr	tr
allanite	0.2	tr	tr	tr	0.2	0.6	0.8	0.2
chlorite	2.0	----	1.8	----	3.8	4.0	8.0	1.2
epidote	2.2	----	tr	tr	6.0	2.6	1.6	2.0
opaques	1.6	0.8	1.2	0.2	1.2	1.2	2.2	1.4
rutile	----	tr	tr	tr	tr	tr	tr	----
leucoxene	----	tr	tr	tr	tr	tr	tr	----
clay	tr	tr	tr	tr	tr	1.2	0.4	tr
fluorite	----	----	----	----	----	----	----	----
Total	100	100.2	100	100.2	99.8	100	100	100
Anorthite content	27	30	35	37	26	28	?	28

1/ Numbers refer to plot on Q-A-P diagram (Figure 32).

Table 7 (cont'd).

Major minerals	CB7-139B 9	CB7-141 10	CB7-202 11	CB7-205 12	CB7-226A 13	CB7-304 14	Avg. 15
quartz	28.4	27.4	34.5	33.2	37.4	31.6	31.3
plagioclase	17.8	13.6	27.3	23.8	35.4	20.6	23.0
microcline	36.2	34.2	22.6	17.0	15.6	34.4	26.1
orthoclase	----	----	2.5	3.2	2.8	----	1.1
biotite	6.8	4.8	----	5.6	----	7.8	4.2
muscovite	8.6	13.0	2.0	6.6	8.2	5.4	8.9
Accessory minerals							
apatite	tr	tr	0.2	0.2	tr	tr	tr
zircon	tr	tr	tr	tr	tr	tr	tr
sphene	tr	----	----	0.2	tr	tr	tr
allanite	tr	0.2	tr	0.2	tr	----	tr
chlorite	0.6	1.6	6.4	4.8	0.2	tr	2.8
epidote	1.0	4.2	4.0	3.0	0.2	tr	2.0
opaques	0.6	1.2	tr	2.2	0.2	0.2	1.0
rutile	tr	----	----	tr	----	----	tr
leucoxene	----	----	tr	----	tr	----	tr
clay	tr	tr	0.8	tr	0.2	tr	tr
fluorite	----	----	----	----	----	----	----
Total	100	100.2	100.3	100	100.2	100	100.9
Anorthite content	29	?	34	28	28	24	29

muscovite 9 percent. Accessory and alteration minerals are dominated by chlorite 3 percent, epidote 2 percent and opaques 1 percent. The other accessory minerals include apatite, zircon, monazite(?), sphene, allanite, rutile, leucoxene, and clay. When plotted on a ternary Q-A-P diagram (volume percent), the results fall in the granite field (figure 32). In thin section, the cataclastic granite appears to range from microbreccia to protomylonite and even mylonite in some slides. In all the slides of cataclastic granite, feldspar crystals have broken, crushed and subrounded borders. Quartz on the other hand have underwent more intense comminution than the feldspars, as shown by the scarcity of large grains, most having been reduced in size.

Quartz displays the most intense cataclastic textures. The quartz crystals are commonly elongate parallel to foliation, have crenulated borders and undulatory extinction. With increasing cataclasis, quartz forms fine granular masses arranged in bands, between grains and in fractures (figure 33). Inclusions of fine dust-sized particles and vapor bubbles are present along invisible fractures. Quartz also contains inclusions of hair-like needles (rutile?) and euhedral zircon crystals.

Plagioclase feldspar is the most common porphyclast in the granite. The average plagioclase feldspar composition taken from 12 thin sections is An_{30}. The majority of plagioclase is calcic oligoclase although in four slides the plagioclase is sodic andesine. In thin section plagioclase appears as elongate subhedral laths and subrounded crystals. Due to cataclasis of the granite, plagioclase ranges from crystals with slightly corroded margins to granulated subrounded grains. Moderate to intense sericitic alteration has partially obscured twinning in most crystals, although both albite and carlsbad twins are still visible in some thin sections. The twins are commonly bent or displaced along microfractures in individual crystals. Altera-

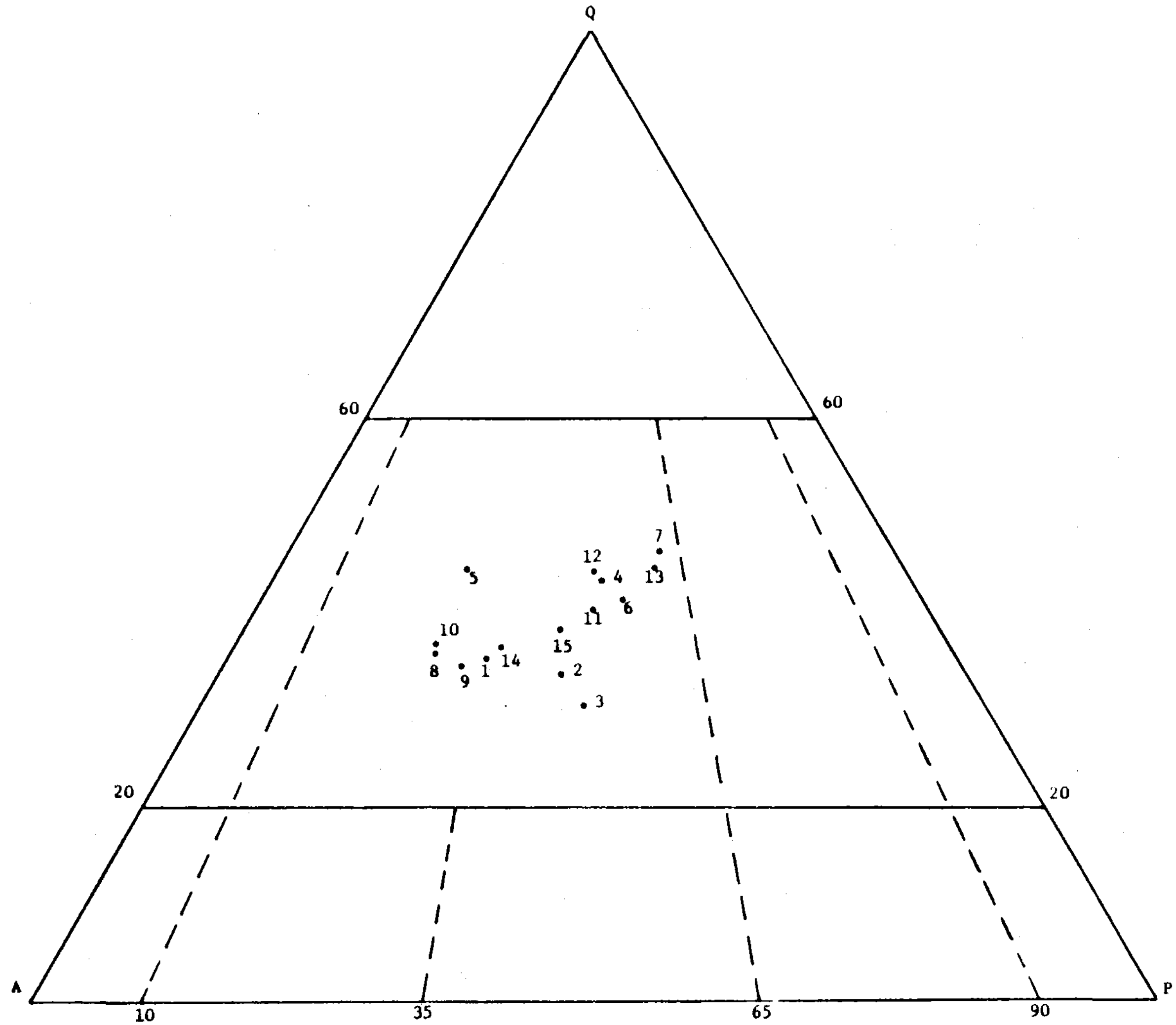

Figure 32. Q-A-P diagram for the Forest Hill Cataclastic Granite. Samples are listed in table 7.

tion minerals besides white mica (muscovite?) are epidote and clay (kaolinite?). Where plagioclase crystals are in contact with microcline, faint sodic rims occur around the clouded plagioclase crystals. Myrmekite is also common in plagioclase crystals that are in contact with microcline.

Potassium feldspar is most commonly in the form of microcline, although in some specimens both orthoclase and microcline are present. Gridiron twinning is well developed in most crystals although a few display patchy twinning. Carlsbad twinning is also present in some crystals. Microperthitic stringers, rods and blebs are moderately developed in many of the larger microcline crystals. Subhedral to anhedral microcline displays increasing degrees of rounding, comminution and fracturing with increasing cataclasis (figure 33). Phenocrysts of microcline in a pulverized groundmass of quartz, mica and feldspars have inclusions of round (secondary) quartz, partially resorbed myrmekitic plagioclase crystals and chloritized biotite. Later secondary microcline is seen along microfractures that cut feldspar porphyclasts and quartz.

Minor biotite occurs as subhedral to anhedral plates averaging less than 1 mm in length. In some slides, it has been hydrothermally altered to chlorite with epidote, rutile and opaques often accompanying the chlorite. All slides exhibit some degree of chloritic alteration of biotite, usually along cleavage planes. Other accessory minerals associated with biotite include apatite, zircon and allanite. Biotite is pleochroic tan to dark greenish-brown. In samples where extreme cataclasis has occurred biotite and muscovite shards, along with epidote and chlorite, define foliation planes.

Muscovite occurs both as a primary mineral and as a hydrothermal alteration mineral after the breakdown of plagioclase feldspar. Primary muscovite, in plates up to 2.5 mm in diameter, are seen in the least deformed samples which crop out along Taylor River in the southeast 1/4 of section 19, T13S, R82W. Aggregates of fine muscovite, commonly with biotite and quartz, define a foliation in the extremely cataclastic rocks (figure 34). Secondary muscovite forms fine shards and plates in cores and along cleavage planes in plagioclase. Large poikilitic plates of muscovite contain quartz, magnetite and zircon crystals.

Chlorite is ubiquitous as an alteration product of the ferromagnesian minerals totally replacing biotite in some specimens. Chlorite forms mattes and spheriodal clusters where biotite crystals once defined foliation.

Epidote occurs along fractures in biotite and as a pervasive alteration product of plagioclase-feldspars. A faint yellow pleochroism is visible in most epidote crystals.

Euhedral crystals of zircon commonly occur in quartz and biotite.

Anhedral allanite occurs as single crystals and as aggregates of crystals showing various stages of metamict texture. Epidote usually forms rims around the allanite crystals.

Magnetite occurs as both primary crystals and as secondary mineral constituents where it is an alteration product of ferromagnesian minerals.

Sphene, where present, is closely associated with magnetite, usually occurring as rims around the magnetite grains.

Rutile occurs as thin needles in quartz crystals in most of the slides studied. A faint parallel alignment of rutile needles is seen in some quartz crystals indicating a possible crystallographic control to their orientation.

Subhedral crystals of apatite occur in close association with biotite and magnetite. Apatite crystals are clear and average less than .5 mm in cross section and less than 1 mm in length.

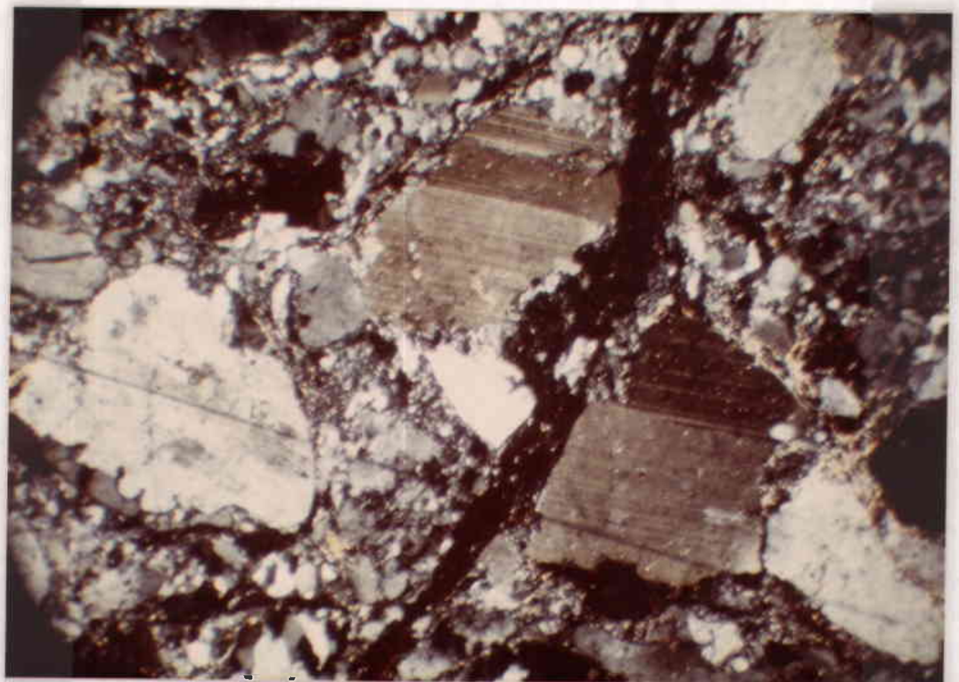

Figure 33. Forest Hill cataclastic granite. Cataclastic texture exhibits comminution of quartz and the rounding of plagioclase crystals. Microfractures contain isotropic minerals.

Figure 34. Cataclastic granite exhibits gneiss foliation, comminution of quartz and the rounding of plagioclase and microcline crystals. Biotite, muscovite, epidote and opaque minerals form parallel bands that define a weak foliation.

Forest Hill Hornblende Granodiorite

Field Description

A massive hornblende granodiorite crops out in two small plugs less than 1/2 mile apart along the ridge trending northwest from Forest Hill. The larger plug is approximately 540 feet wide and 1000 feet long while the smaller plug is only about 150 feet in diameter. These two plugs are the only hornblende-rich Precambrian igneous rocks in the field area.

The hornblende granodiorite weathers into subrounded to angular fragments from several meters in diameter to less than 1 cm. Weathered surfaces are medium light-gray (N6) to grayish-pink (5 R 8/2). Fresh surfaces are greenish-gray (5 G 6/1) to medium dark-gray (N4). In both plugs, the rock is fairly fresh with only minor chloritic alteration visible in hand specimen. Hornblende, biotite, feldspar and quartz can be recognized megascopically along with alteration products. The ferromagnesian minerals occur in distinct clusters.

The contact between the larger plug and porphyritic granite is near vertical and sharp along its northern edge; the remaining contacts are poorly exposed. A small pink pegmatitic dike cuts the smaller plug at its southern contact with the porphyritic granite. The remaining contacts are obscured by cover. No xenoliths of metasedimentary rocks were visible at either outcrop although small lenses and a roof pendant of biotite schist occur nearby.

Petrography

Modal analysis of one sample taken from the larger of the two granodiorite bodies indicates this rock is a hornblende granodiorite according to the 1973 I.U.G.S. classification (figure 27 and table 6). Whole rock chemical analysis of one sample from the smaller plug is shown on figure 37 and listed in table 9. In thin section, the rock is medium-grained, equigranular, hypidiomorphic and displays a syneusis-type texture consisting of aggregates of biotite, hornblende, sphene and magnetite. The absence of cataclasis and the random orientation of grains is very distinctive of this rock (figure 35). The major constituents of this rock are: plagioclase 36 percent; biotite 20 percent; hornblende 16 percent; quartz 14 percent; microcline 7 percent; and lesser amounts of muscovite, sphene, chlorite and epidote. Accessory minerals include apatite, zircon, allanite, rutile and clay. The low amount of modal microcline and muscovite in this rock is consistent with the low K_2O content determined by whole rock chemistry.

Anhedral crystals of quartz are clear with only minor inclusions of dist-sized particles, rutile and vapor bubbles. Other minerals locally included in quartz are apatite and zircon. Quartz crystals range in size from less than .5 mm to 2.5 mm in diameter, but average less than 1 mm overall. Undulatory extinction is faint to moderate in the larger grains and absent in the rounded to subrounded quartz inclusions. A late paragenesis is suggested for the quartz that occurs as interstitial masses and locally embaying or containing inclusions of biotite, hornblende and plagioclase. The occurrence of unstrained quartz blebs as inclusions in biotite and hornblende and forming poorly developed myrmekitic texture is also evidence for a late or secondary origin for some of the quartz.

Subhedral to anhedral plagioclase crystals range from less than 1 mm to 5.5 mm in length and average about 2 mm. From extinction angles of combined albite and carlsbad twin lamellae, the anorthite content was determined identifying the plagioclase to be calcic oligoclase (An_{28-30}). Twinning is moderately developed consisting of polysynthetic albite and carlsbad twin lamellae. Pericline twinning was identified in one grain. Inclusions in plagioclase include biotite, quartz, and opaques. A few crystals exhibit slight

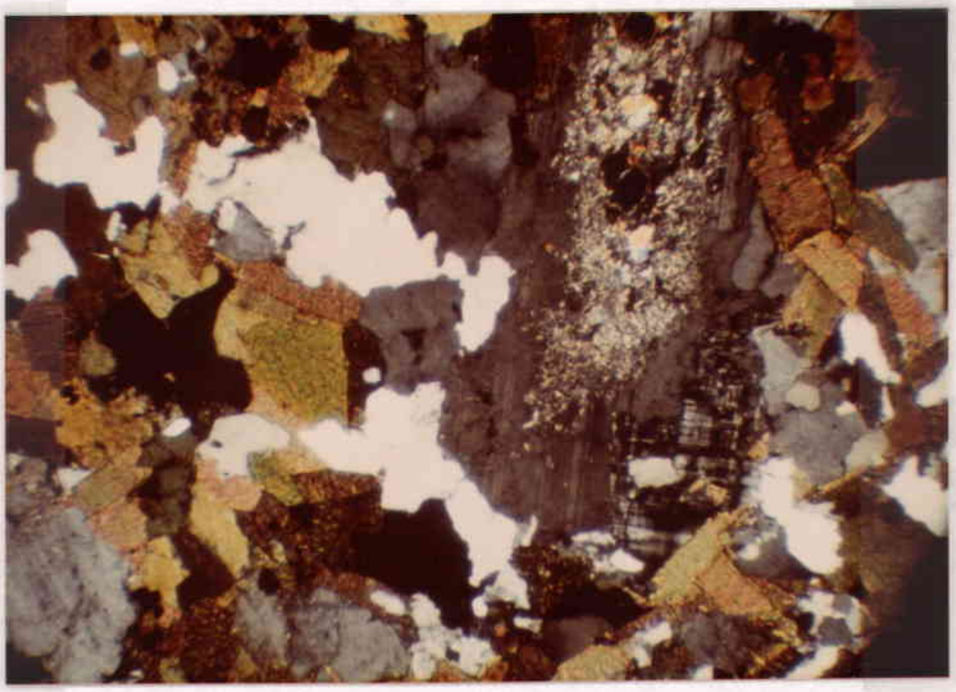

Figure 35. Forest Hill hornblende granodiorite. Syneusis texture shown by aggregates of biotite and hornblende is common. Altered core of plagioclase indicates normal zoning. Quartz, microcline, muscovite (alteration product), sphene, apatite and opaque minerals are also present.

bending of albite twin lamellae indicating minor strain. The slightly more calcic centers of oliogoclase crystals are altered to white mica, epidote and clay minerals. Where alteration products are too fine to identify in thin section they are interpreted to be sericite or saussurite. Faint rims of sodic plagioclase occur around oligoclase crystals that are in contact with microcline. A few crystals in contact with microcline exhibit poorly developed myrmekitic textures. Irregular crystals of microcline commonly corrode and replace plagioclase crystals. Blebs of microcline included in plagioclase grains may be replacing plagioclase instead of exsolving from it. Gridiron twinning is well-developed in most grains. What appears to be sericitic alteration of microcline is probably remnant alteration products from a plagioclase grain.

Subhedral to anhedral crystals of hornblende occur in aggregates with biotite, sphene and opaques defining a syneusis texture. Characteristic cleavage angles are seen in end sections, which commonly exhibit tan to olive-green pleochroism, while in long sections hornblende exhibits a blue-green to olive-green pleochroism. The extinction angle is about 15 degrees. Grain boundaries are highly irregular due to quartz embayments. Poikilitic hornblende contains inclusions of quartz, biotite, apatite, sphene and magnetite. Minor alteration of hornblende to biotite, epidote and chlorite has affected some grains.

Subhedral to anhedral biotite crystals display tan to dusky-brown or dark greenish-brown pleochroism. Grain sizes vary from less than 1 mm to 3 mm in length. Inclusions of apatite, sphene, zircon and locally quartz are seen in many grains. Hydrothermal biotite forms smaller, ragged plates associated with hornblende along fracture and cleavages.

Irregular plates of muscovite as altering from plagioclase are a minor constituent of this rock.

Sphene is an important accessory mineral occurring as subrounded and wedge shaped grains and aggregates averaging .5 mm in length. Sphene is interstitial between biotite and hornblende and surrounds magnetite crystals. Sphene also occurs as inclusions in hornblende, biotite and occasionally in plagioclase. Inclusions of subhedral to euhedral zircon srystals occur in biotite, plagioclase, hornblende and quartz. Pleochroic halos surround zircon grains in biotite and hornblende.

Chlorite is an alteration product of biotite and occurs along cleavage planes and in a few instances biotite is completely replaced. Minor chloritic alteration of some hornblende grains is also observed.

Epidote is common as an alteration product of plagioclase, hornblende and biotite. Rims of epidote enclose metamict crystals of allanite.

Apatite occurs as subhedral to euhedral grains that are up to .7 mm in length and .2 mm in cross section. Apatite is present as inclusions in biotite, quartz and plagioclase.

Magnetite is the dominant opaque mineral with hematite and pyrite less common. Hematite occurs as an oxidation product of both magnetite and pyrite.

Euhedral to anhedral allanite crystals display a metamict appearance and are usually rimmed by epidote.

PEGMATITES

Pegmatites intrude all the Precambrian rocks except the Denny Creek biotite tonalite where they were not seen. They appear as dikes and irregular masses, commonly subparallel to the regional structure. Size of the dikes ranges from two inches to approximately 25 feet. The large mass located between Forest Hill and Spring Creek is approximately 4500 feet long and 2500 feet wide. Pegmatitic material, occurring as float, is present in unusual abundance over much of the area mapped as Forest Hill granite.

All the pegmatite bodies (and float) are essentially the same composition, consisting of coarse-grained milky quartz, pink microcline, white plagioclase and muscovite plates (figures 36a and 36b). Biotite is characteristically absent or a very minor constituent in most pegmatite bodies.

Petrographic analysis was not attempted due to the very coarse-grained nature of these pegmatites. Feldspar crystals range from one to six inches in diameter. Irregular quartz crystals average one inch in diameter and it is common to see books of muscovite ranging from one to three inches in length. Biotite flakes, when present, are usually less than one inch in length and rimmed by muscovite.

Some of the coarse-grained leucosomes occurring in the migmatite zones of the Denny Creek gneiss may be considered pegmatitic, but in this report these are interpreted as mineral segregations rather than late stage pegmatitic injections.

Figure 36a. Pegmatite outcrop in road along the west side of the map area. The massive pegmatite body mapped in this area consists of microcline, quartz and muscovite.

Figure 36b. Close up of pegmatite showing microcline, quartz and muscovite.

CHEMISTRY

Chemical analyses of 19 samples, representing the major rock units are given in tables 8 and 9 (see appendix II for the analytical procedures used). Sample locations are shown on Plate 2. Jeffery (1975) states that 13 major oxides account for 99 percent or more by weight of most silicate rocks. Values for 10 of these 13 major oxides were determined for these samples with manganese and water (water evolved above and below 105° C) being excluded. Water and manganese are not considered to be important components of these rocks, probably totaling one percent or less (sample CB7-219 which is a biotite schist may contain more water). Typical granite, such as U.S.G.S. G-2 contains about .08 percent MnO and .5-1 percent H_2O (Flanagan, 1969). The low results (below 97% total oxides for 10 of the 19 samples analyzed) are believed to be due to errors in silica and alumina determinations. Low silica values could be caused by: (1) loss of silica by volatization, (2) contamination from glass (when silica reacts with molybdate, an equal quantity of fluoride is released which could react with the glass of the flask or absorption cell causing contamination of the solution), or (3) slight errors in preparing the master solution of a reference sample. This has a noticeable effect on determining silica values. The low total percentages for the major oxides is probably a result of erroneous preparation of the master solution. At the time these analyses were done, the analyst (Geolabs) did not have much experience in whole rock chemical analysis. When questioned about the low values, they reported having problems with their silica and alumina determinations. Small errors in preparing the master solution from a standard can noticeably affect silica determination while not affecting the other oxides. Reworking the data to have it total closer to 100 percent is not consider-

Table 8. Major element analyses[a,b].

	CB7-242 (1)[c]	CB7-220 (2)	CB7-127 (3)	CB7-133 (4)	CB7-209 (5)	CB7-248 (6)
SiO_2	71.0	59.5	56.5	66.0	70.5	63.0
Al_2O_3	11.7	13.0	18.3	14.0	12.8	15.3
K_2O	5.1	4.9	2.1	4.2	4.3	4.0
Na_2O	2.3	2.4	5.9	2.7	2.7	2.8
CaO	1.5	1.8	1.0	1.8	1.6	2.7
MgO	0.8	1.4	1.9	0.75	0.75	1.5
FeO	1.6	2.7	2.7	1.0	1.0	3.2
Fe_2O_3	2.4	5.3	3.6	3.7	2.9	6.1
TiO_2	0.59	1.1	0.32	0.77	0.68	1.2
P_2O_5	0.19	0.05	0.15	0.28	0.23	0.38
Total	97.18	92.15	92.47	95.20	97.46	100.18

[a]Analyses were done by Geolabs, Lakewood, Colorado 1977.

[b]Samples CB7-242, 220, 127, 133, 209 and 248 are Forest Hill Porphyritic Granite.

Samples CB7-321, 202, 223, 226A, 117 and 89 are Forest Hill Cataclastic Granite.

Sample CB7-267 is Forest Hill Hornblende Granodiorite.

[c]Numbers refer to plot on AFM diagram.

[d]Letters are the average for the four major rock types. (A) Forest Hill porphyritic granite, (B) Forest Hill cataclastic granite, (C) Denny Creek granodiorite gneiss, (d) Biotite Tonalite.

Table 8. (Cont'd.)

	CB7-321 (7)	CB7-202 (8)	CB7-223 (9)	CB7-226A (10)	CB7-117 (11)	CB7-89 (12)	CB7-267 (18)
SiO_2	75.0	71.0	69.5	74.0	63.5	67.5	54.5
Al_2O_3	12.3	13.6	12.1	13.2	14.4	12.8	13.4
K_2O	4.6	4.6	6.0	5.0	4.1	5.0	2.0
Na_2O	2.9	3.2	2.4	3.1	2.4	2.8	2.2
CaO	0.75	0.9	0.85	0.2	2.2	0.85	3.3
MgO	0.25	1.0	0.5	0.2	1.2	0.8	5.1
FeO	0.4	0.9	1.0	0.2	2.3	1.2	5.9
Fe_2O_3	0.8	1.6	1.9	0.7	4.2	2.6	9.0
TiO_2	0.23	0.55	0.43	0.28	0.84	0.54	1.4
P_2O_5	0.07	0.2	0.13	0.1	0.35	0.2	0.39
Total	97.3	97.37	94.81	95.98	95.49	94.29	97.99

Table 9. Major element analyses[a,b].

	CB7-54 (13)[c]	CB7-339 (14)	CB7-148 (15)	CB7-156 (16)	CB7-308 (17)	CB7-219 (19)
SiO_2	57.0	56.5	65.0	61.0	59.5	60.5
Al_2O_3	15.1	13.6	12.1	14.0	14.0	13.4
K_2O	1.9	2.6	2.6	2.6	3.1	4.4
Na_2O	2.4	2.1	2.5	2.5	2.2	0.95
CaO	3.9	1.4	3.1	3.0	2.9	0.15
MgO	2.2	3.0	1.8	1.8	1.5	1.3
FeO	5.5	4.2	4.2	4.3	3.7	4.4
Fe_2O_3	9.8	9.8	6.6	7.1	6.6	5.9
TiO_2	2.1	1.9	1.1	1.4	1.4	1.0
P_2O_5	0.43	0.24	0.28	0.28	0.23	0.37
Total	100.33	95.34	99.28	97.88	95.13	92.37

[a]Analyses were done by Geolabs, Lakewood, Colorado 1977.

[b]Samples CB7-54 and CB7-339 are Denny Creek Granodiorite gneiss.

Samples CB7-148, CB7-156 and CB7-308 are Denny Creek age Biotite Tonalite.

Sample CB7-219 is a Biotite Schist.

[c]Numbers refer to plot on AFM diagram.

ed justified because the exact nature of the analytical error is uncertain. As pointed out by Jeffery (1975), negative errors in silica determination can be balanced by positive errors in alumina content and, therefore, even a good total is not evidence of a good analysis. Because of the low values for the major oxide totals of 10 samples, the "good totals" are considered problematic at best.

Figure 37 is an AFM plot of oxide values for the major igneous rock types analyzed. The alkalies ($Na_2O + K_2O$), iron ($FeO + Fe_2O_3$), and magnesia (MgO) are recalculated to 100 percent and plotted on the AFM diagram. Four areas are distinguished by plotting the data. The areas appear to separate the major rock types as well as the two Precambrian age groups.

The Denny Creek age rocks plot at the iron rich end of the trend with the Denny Creek granodiorite gneiss more iron enriched than the Denny Creek biotite tonalite. The biotite tonalite was interpreted on the basis of field evidence to be younger than the granodiorite gneiss. The possibility of it being a late differentiate from the same magma that formed the granodiorite gneiss is supported by the AFM plot. A break between the Denny Creek age rocks and the Forest Hill age rocks is defined by the clustering of Denny Creek rocks at the iron end and the separate linear trend of Forest Hill rocks towards the alkali apex. Although the chemical variation between Denny Creek age rocks and Forest Hill granites is significant, a more important variation shown on figure 37 is that between the cogenetic granite phases of the Forest Hill intrusion. The cataclastic granite was interpreted as slightly later than the porphyritic phase on the basis of field evidence. The chemical variation between these two granites suggests differentiation from a similar magma source with the cataclastic granite being a later differentiate than the porphyritic granite.

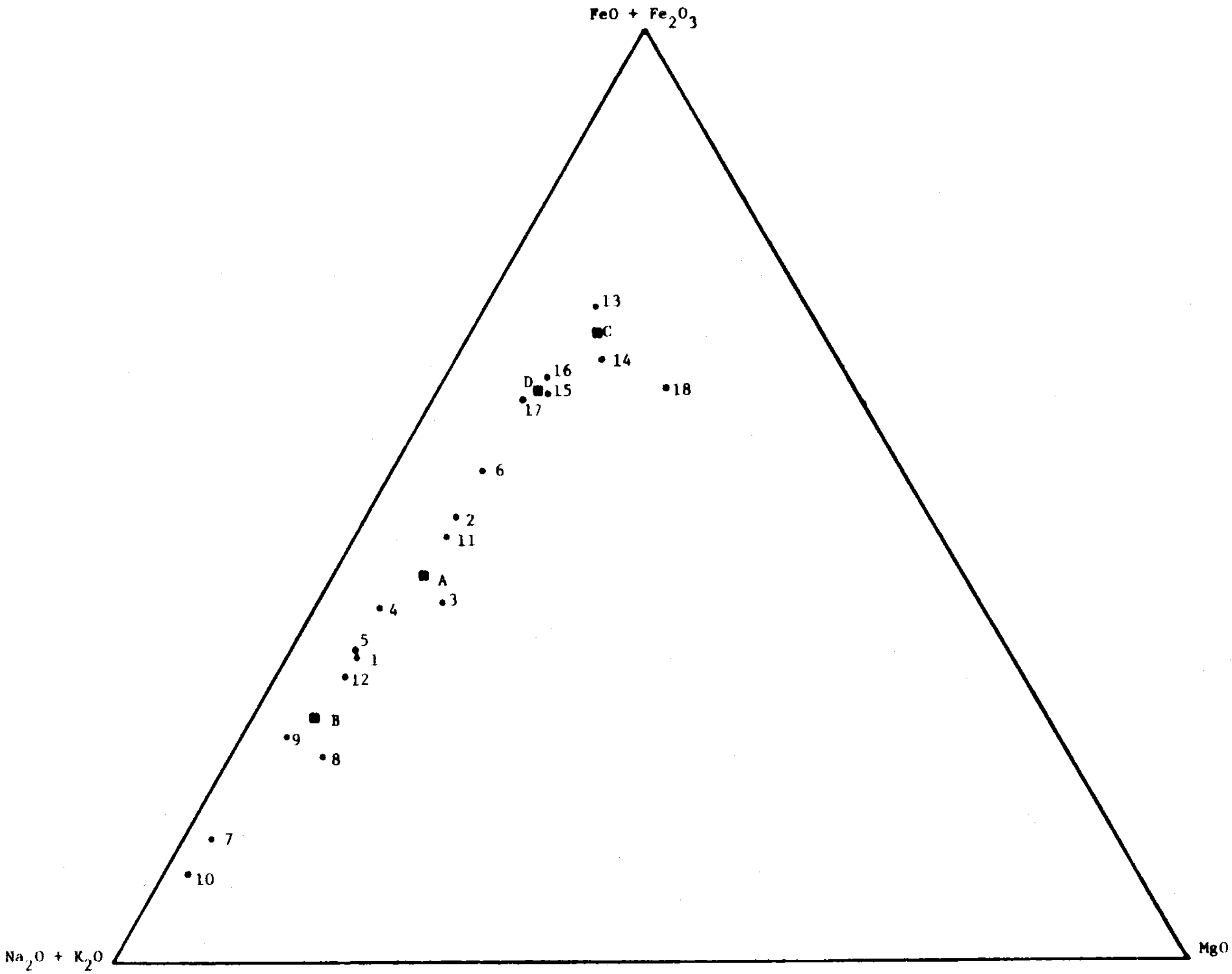

Figure 37. A-F-M plot of recalculated oxide values for the major igneous rock types.

Comparisons of weight percent of each oxide against silica (Harker variation diagram) is presented in figure 38. Variations shown on figure 38 correspond to the trend seen on figure 37 and reveal a general distinction between the rocks of Denny Creek age and Forest Hill age. Denny Creek age rocks have a higher content of refractory minerals such as MgO, CaO, TiO_2, and total iron as Fe_2O_3 than do the Forest Hill granitic rocks. Especially noteworthy are: (1) the virtually constant amount of Na_2O in all the rocks except for a slight increase in the Forest Hill granitic rocks; (2) the nearly constant K_2O and CaO content of the Denny Creek rocks while the Forest Hill rocks increase in K_2O and decrease in CaO content with increasing silica; and (3) the similar trends of decreasing TiO_2, Fe_2O_3 and MgO with increasing silica for both rock types.

Sample CB7-267 (#18) is a hornblende granodiorite which crops out as two plugs intruding the Forest Hill porphyritic granite. Contact relationships and petrographic and chemical data suggest that this rock is younger and possibly from a different source. Until more detailed work is done on these rocks, such as more chemical analyses and age dating, they will be considered to be age equivalent to the Forest Hill granites.

Sample CB7-219 (#19) is a biotite schist that was analyzed for the purpose of comparing with the Denny Creek age rocks. The low total percentage of major oxides may be a result of not analyzing for H_2O which may be high in the biotite schist. Highly foliated Denny Creek granodiorite gneiss is often very similar in megascopic and microscopic appearance to the biotite schist; however, their major oxide concentrations are significantly different.

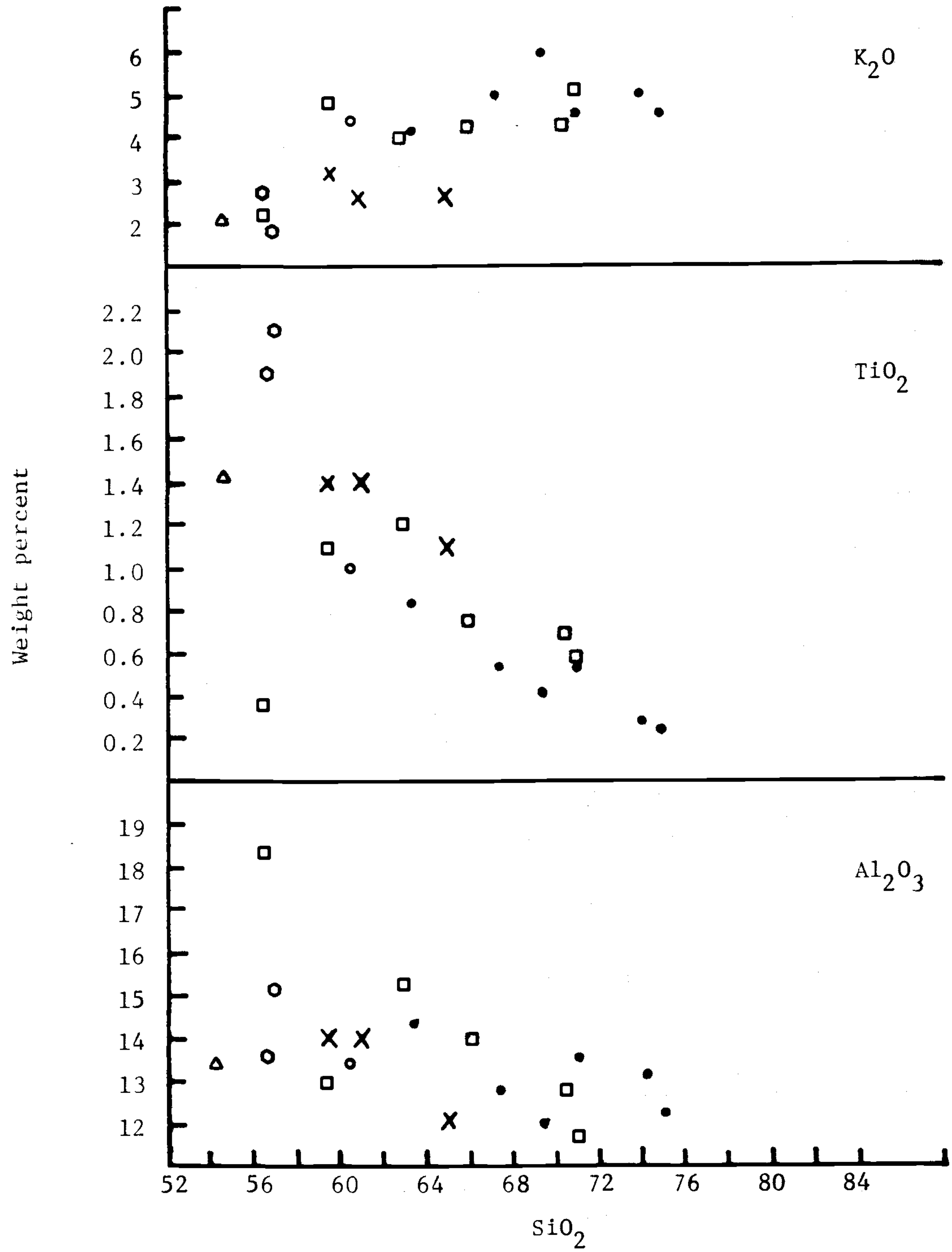

Figure 38. Harker variation diagram of each major oxide versus silica. (O)= Denny Creek granodiorite gneiss; (X)= Denny Creek biotite tonalite; (□)= Forest Hill porphyritic granite; (•)= Forest Hill cataclastic granite; (Δ)= Forest Hill hornblende granodiorite; (o)= Biotite schist.

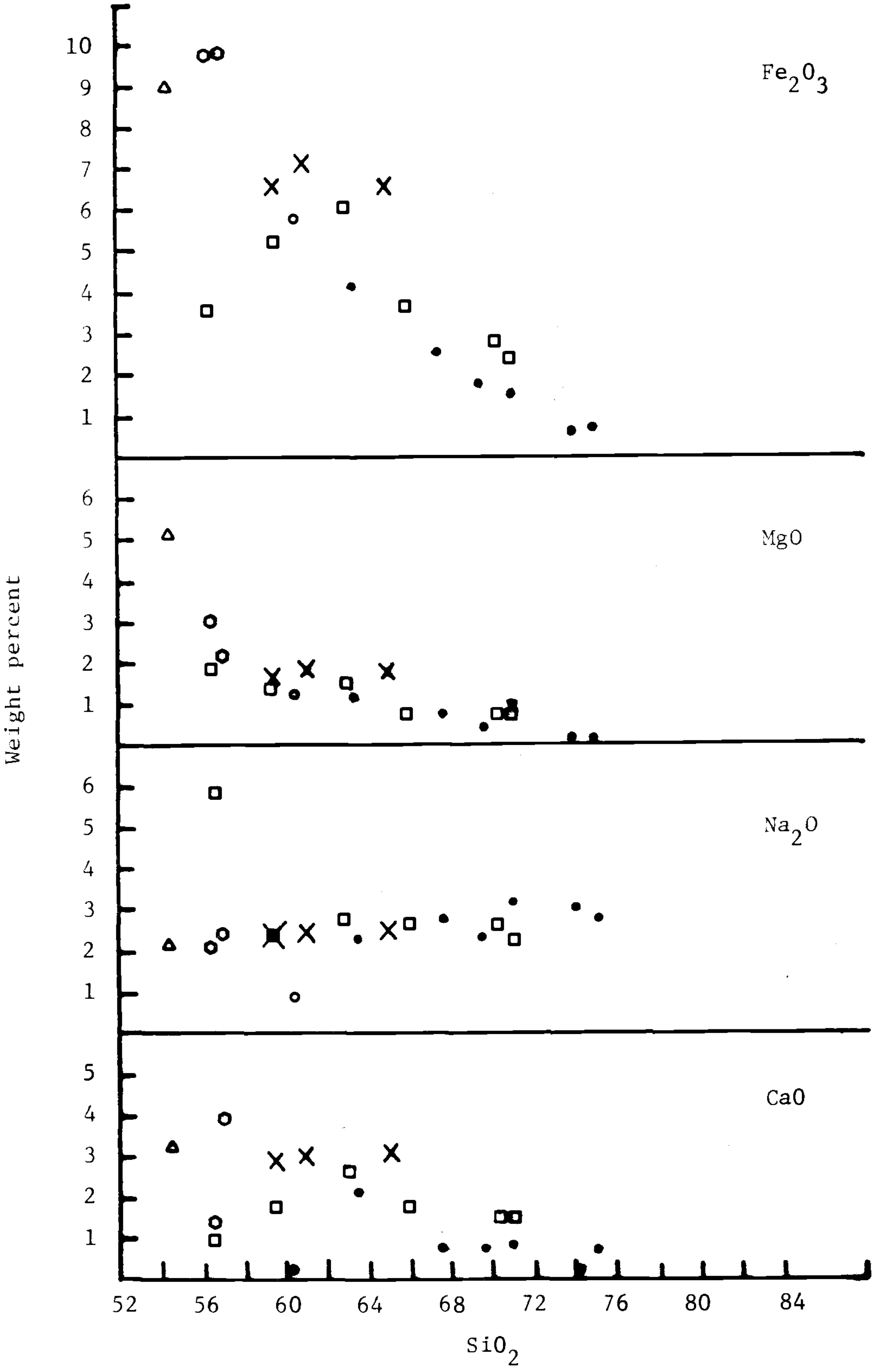

Figure 38 continued. Fe_2O_3 = total iron.

PALEOZOIC STRATIGRAPHY

General Statement

The Paleozoic rocks received only a cursory inspection to determine their contact relationship with the Precambrian rocks and to help determine structural trends. The Paleozoic systems were tentatively identified by lithologic correlation to rocks mapped in the immediate vicinity of the thesis area. Silurian rocks are not found in this region of Colorado. The lower Paleozoic formations (Cambrian through Mississippian) are well exposed in the cliffs along the southern margin, west of Taylor Park Reservoir. Upper Paleozoic formations are less well exposed and crop out at scattered locations along Spring Creek and Trail Creek. Detailed measurements of sections were not carried out as they were not a concern of this report (published and unpublished reports including Johnson, 1944, Meissner, 1954, O'Connor 1961, Prather 1961 and Cunningham, 1973, give detailed stratigraphic sections).

The lower Paleozoic rocks are mostly marine shelf carbonates while the upper Paleozoic rocks are mostly clastics recording the initiation of the Colorado Trough.

Cambrian

Sawatch Quartzite

The term Sawatch Quartzite was first applied by Eldridge (1894) to Cambrian deposits cropping out in the Crested Butte quadrangle. The term has now been extended to include all late Cambrian deposits of similar characteristics in central Colorado.

The Sawatch Quartzite unconformably overlies the Forest Hill porphyritic granite along the western margin of the map area and to the south between Rocky Point and Taylor Park Reservoir (plate 1 in pocket). The basal portion of the lower member of the Sawatch formation is conglomeratic consisting of well-rounded quartz pebbles ranging from fine sand size up to two inches in length and minor feldspar grains averaging less than 1/2 inch in diameter. Minor crossbedding was observed in quartz arenite sandstones in the lower member. A basal conglomerate varies in thickness from five to twenty feet and grades into a dense fine-grained, white (N9) to very light-gray (N8) quartzite layer. Above this massive quartzite is a transition to a grayish-orange (10YR 7/4) to grayish-brown (5YR 3/2) glauconitic and calcareous sandstone member. This unit contains bands of ferruginous material, which upon weathering exhibit a very distinctive solution pitted surface. No fossils were found in any of the outcrops studied.

Thickness of the Sawatch formation is from 170 to 270 feet thick (Johnson 1944, Prather 1961 and O'Connor 1961).

Ordovician

Manitou Dolomite and Fremont Limestone

The Ordovician system is made up of the Lower Ordovician Manitou Dolomite (Cross, 1894) and the Upper Ordovician Fremont Limestone (Walcott, 1892). These two rock types were not differentiated in the field but were both identified along the east side of Spring Creek and at two locations east of Rocky Point. The contact between the Sawatch Quartzite and the Manitou Dolomite appears to be gradational although this is based on only a few cursory observations. The contact between the Manitou Dolomite and the Fremont Limestone was not observed.

The Manitou grades from a basal medium-grained, sandy dolomite to a fine-grained massive, light-pale-green (5G 8/2) dolomite towards the top. Abundant chert nodules and stringers are concentrated at certain horizons near the top of the Manitou Dolomite.

The Fremont Limestone is a gray to dark-gray, medium-grained, massive dolomitic limestone of varying thickness. The beds are quite thick along Spring Creek often forming cliffs below the overturned Cambrian Sawatch Quartzite and Manitou Dolomite.

Devonian

Chaffee Formation

The Chaffee formation (Kirk, 1931) consists of two members (the Upper Dyre and the Lower Parting) and crops out at American Flag Mountain and along Spring Creek in the overturned Paleozoic rocks. One small outcrop was seen in a road cut along Rocky Brook road. No outcrops were observed in close proximity to the southern boundary of the map area. The best exposures are at American Flag Mountain where the Chaffee formation is seen in a cliff unconformably overlying the Fremont Limestone and unconformably overlain by the Leadville Limestone.

Lithologically, the Chaffee formation is brightly colored grayish-orange (10YR 7/4) sandstones and pale-brown (5YR 5/2) sandy dolomites in the Lower Parting Member and gray (N6) dolomitic limestones in the Dyer Member.

Mississippian

Leadville Limestone

Kirk's (1931) restricted usage of the term Leadville Limestone to the Mississippian limestones in western Colorado is generally followed by stratigraphers. In the immediate vicinity of this study, the Leadville Limestone was observed cropping out on top of American Flag Mountain and at two locations along Rocky Brook road. In all observed locations, the Leadville Limestone was a fossiliferous dark-gray (N4) to grayish-blue (5PB 4/2) which when freshly broken emitted a distinctive odor. The limestone appears as massively-bedded, finely-crystalline rock in outcrop. Fossil crinoidal stems and corals are present.

Pennsylvanian

The Pennsylvanian formations in the map area are the Belden Shale, Gothic formation and the lower part of the Maroon formation.

The Belden is a distinctive black carbonaceous shale with interbeds of fine-grained sandstone and limestones. The limestone beds are dark-gray and contain abundant fossils of bryozoans, crinoids and brachiopods. Thickness of the shale in the area is approximately 80 feet with the limestone interbeds locally reaching 100 feet thick.

The Gothic formation crops out only in the southwest portion of the field area and consists of a brown arkosic sandstone overlying a thick lense of red conglomerate, which contains large pebbles of Mississippian limestone and fragments of Precambrian igneous rocks. Many beds show well developed crossbedding.

The Maroon formation is easily identified by its distinctive red color and abundant conglomerate beds and is only found along the western margin of the map area. The Maroon formation is classified as Pennsylvanian-Permian in age and is the only Permian rock unit found in the thesis area. Total thickness is estimated to be over 10,000 feet of sandstones, sandy shales and conglomerate lenses, with most beds having a distinctive red weathering color.

TERTIARY IGNEOUS ROCKS

General Statement

Tertiary igneous activity in the Sawatch Range included the emplacement of the Mount Princeton and Twin Lakes batholiths during the Laramide orogeny 80-50 m.y. ago. A second major episode of igneous activity during mid-Tertiary time (Oligocene) intruded most of the rocks of the Elk Mountains, including the Italian Mountain stock immediately northwest of the map area (Cunningham 1973). The Grizzly Peak cauldron complex was also formed during this period, as were the vast volcanic fields of southwest Colorado.

Laramide and younger igneous activity is believed to have been localized by Precambrian structures that define the Colorado mineral belt (Tweto 1963). Taylor Park is located in the center of the mineral belt where it crosses the Sawatch Range.

Local Tertiary Rocks

Tertiary igneous rocks in the thesis area include ash-flow tuff, rhyolite porphyry and dikes of andesite and felsite (rhyolite?). The ash-flow tuff originated from the Grizzly Peak cauldron, located approximately four miles northeast of the map area. The flow consists of poorly welded crystal-rich rhyolite and overlies the Forest Hill granite on the northern edge of the area. The Grizzly Peak volcanic field is equivalent in age to the Oligocene San Juan, 39-mile and Bonanza volcanic fields of southern Colorado (Cruson 1973).

A rhyolite porphyry intruded the Paleozoic rocks along the southwest border of the area. It forms a discordant plug along the axis of the Wheelbarrow anticline (Conyers, 1954) cutting the Paleozoic formations.

Two rhyolite dikes trending northeast crop out in the southern portion of the field area and are inferred to have originated from the South Matchless Mountain laccolith located 4 miles to the southwest.

Andesite dikes are more numerous and widespread in the region than the silicic dikes. The andesite dikes in the map area contain abundant phenocrysts of euhedral hornblende and plagioclase in a holocrystalline groundmass. The groundmass consist of plagioclase and hornblende with secondary chlorite and epidote also present.

STRUCTURE

Regional Structure

The Rocky Mountains of Colorado are composed of four major north-trending, elongate mountain belts. The Front Range lies to the east, the Park Range in the center, the Sawatch Range to the west and the Sangre de Cristo Range lies south of the Park Range. To the west of the Sawatch Range are two subcircular groups, the Elk and West Elk Mountains (see figure 4). The Taylor Park area lies near the junction of the Elk Mountains and the Sawatch Range. The three dominant structural trends of this area are: (1) Northeast-trending Precambrian shear zones and faults; (2) north-trending anticline; and (3) the northwest-trending folding and faulting.

Regional Precambrian shear zones cut diagonally to the northeast across the dominant north-trending mountain belts and northwest-trending foliation of the basement rocks in Colorado. The Homestake shear zone in the northern Sawatch Range trends approximately N 55 E and other zones south at Independence Pass, Clear Creek (Tweto and Sims, 1963) and Quartz Creek (Staatz and Trites, 1955) have similar trends. The Idaho Springs-Ralston shear zone of the Front Range (Tweto and Sims, 1963) is one of many shear zones occurring in the central Front Range system (Lovering and Goodard, 1950, Tweto and Sims, 1963). Warner (1978) has assigned the term "Colorado Lineament" to the northeast-trending belt of Precambrian shearing and faulting that transects Colorado. According to Warner, the "Colorado Lineament" is a belt 685 miles long and 100 miles wide, extending from the Front Range in Colorado to the Flagstaff-Grand Canyon area of Arizona. He also suggested a possible extension to the northeast across the great plains to the Canadian shield in Minnesota.

The Colorado mineral belt is coextensive with these northeast-trending shear zones. Tweto and Sims suggested that this zone of weakness in the Precambrian rocks is responsible for localizing the Tertiary intrusives and the mineral belt.

The Sawatch Range, a north-trending anticline 90 miles long and 40 miles wide, with a core of Precambrian rocks, is bordered on the east and west sides by fault zones. The Arkansas river valley, located on the east side, is a graben (Tweto and Case, 1972). This feature is the northward extension of the Tertiary Rio Grande Rift system, a basin and range structure in New Mexico. The west edge of the Sawatch Range is bordered along much of its length by the Castle Creek fault zone. West of the Castle Creek fault zone is the Elk Mountain fault zone, a group of thrust and normal faults. These two fault zones coalesce north near Glenwood Springs (figure 39) into the Grand Hogback fold (Vanderwitt, 1937). At its northern end, the Sawatch Range plunges into the Eagle basin while its southern end is buried by Tertiary volcanic rocks of the San Juan and Bonanza volcanic fields.

Taylor Park, a large northwest-trending structural low, on the west flank of the Sawatch Range is interpreted to be a block faulted feature (figure 40). Although the evidence of block faulting is not conclusive, topography, sheared and fractured rocks along the west side of Taylor Park, and a similar trend to other Tertiary grabens in the region, suggests that block faulting may have occurred. Offset is considered to be minor with most of the topographic expression due to glacial activity.

Local Structure

Only a general examination of the structures of the Precambrian rocks in the map area was made. A detailed

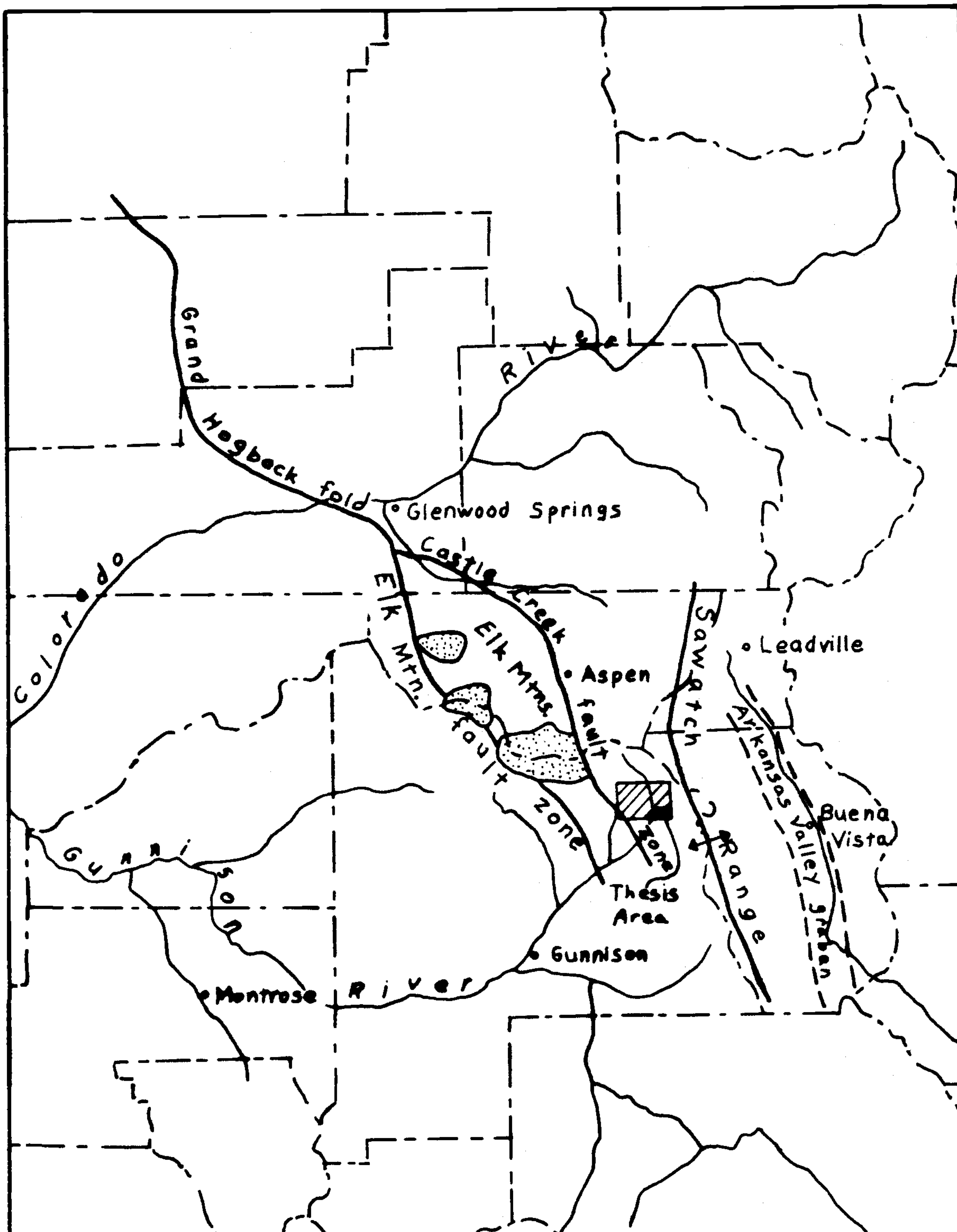

Figure 39. Regional structures, adapted from Prather 1961.

Figure 40. Photograph looking north along the west side of Taylor Park (a possible graben). Dinner Station campground is in the center of the photo, adjacent to the Taylor River.

study was not possible because the extensive colluvial, glacial and soil cover make it difficult to identify and trace structural trends and the large poorly exposed areas exhibiting intense shearing resulted in further uncertainty.

Folding

Folding was evident locally, on a small scale, as plastic folds in migmatite and crenulations in metasedimentary rocks. I was unable to identify any mappable folds in the Precambrian rocks. An overturned fold is exhibited by the Paleozoic rocks along the west side of the map area and parallel to the trend of the Sawatch Range. A northwest-trending syncline is visible in the cut above the Taylor Park dam. Synclines and anticlines, described by O'Connor (1961) are visible in the Paleozoic rocks between the Taylor Park Reservoir and the thesis area.

Faulting

The northwest-trending Castle Creek fault zone is reflected by overturned folding of the Paleozoic rocks bordering the map area on the west (Prather, 1971). This fold is broken along its strike by three tear faults (two trending east-west and one trending northeast). These tear faults, offsetting the Paleozoic and Precambrian rocks along the east side of Spring Creek, disappear in the Forest Hill granite to the east. A northwest-trending normal fault cuts the Paleozoic and Precambrian rocks along the southern border of the map area. This fault is poorly defined because of lack of outcrop.

A major northeast-trending fault zone, shown on the map as strike slip but probably oblique, transects the center of the map area. This fault borders the Forest Hill granite along the southwest margin of the thesis area. The fault bends to a northeast trend where it enters the Trail Creek drainage. The central portion of the fault is either buried by Quaternary sediments or obscured by a wide zone of cataclastic and mylonitic rocks. The northern end of the fault entering Taylor Park is uncertain because of the lack of outcrop and surface expression.

A wide northeast-trending shear zone identified by sheared cataclastic and mylonitic rocks parallels the above fault. Figures 41a and 41b shows sheared Forest Hill granite along Trail Creek. This shear zone, over a mile wide, trends approximately N 53 E. Numerous smaller en echelon shear zones occur outside of the main body. Shear zones trending north-northwest occur locally. This zone of shearing is here informally called the Trail Creek shear zone and is believed to extend under Taylor Park to the northeast and to continue outside of the map area to the southwest. Tertiary intrusive centers to the southwest along Rocky Brook and at Grizzly Peak to the northeast are on line with the Trail Creek shear zone and are interpreted to indicate that structural weakness controlled the location of these intrusive bodies.

Foliation

The Precambrian rocks in the region have a generally well-defined foliation. The foliation is conspicuous in the layered rocks being defined by preferred mineral orientation and compositional layering. Similar foliations are visible in the Denny Creek granodiorite gneiss, where dimensional platy minerals are aligned. The foliation in layered rocks appears to be subparallel to the original bedding although plastic deformation has obscured this relationship in most outcrops. Slickenside striae, resulting from shearing, were measured and mapped as shear zones where significant surface exposure occurred. In some cases, the size of individual outcrops was such that they could not be mapped. Linear elements formed by secondary flowage accompanied plastic deformation.

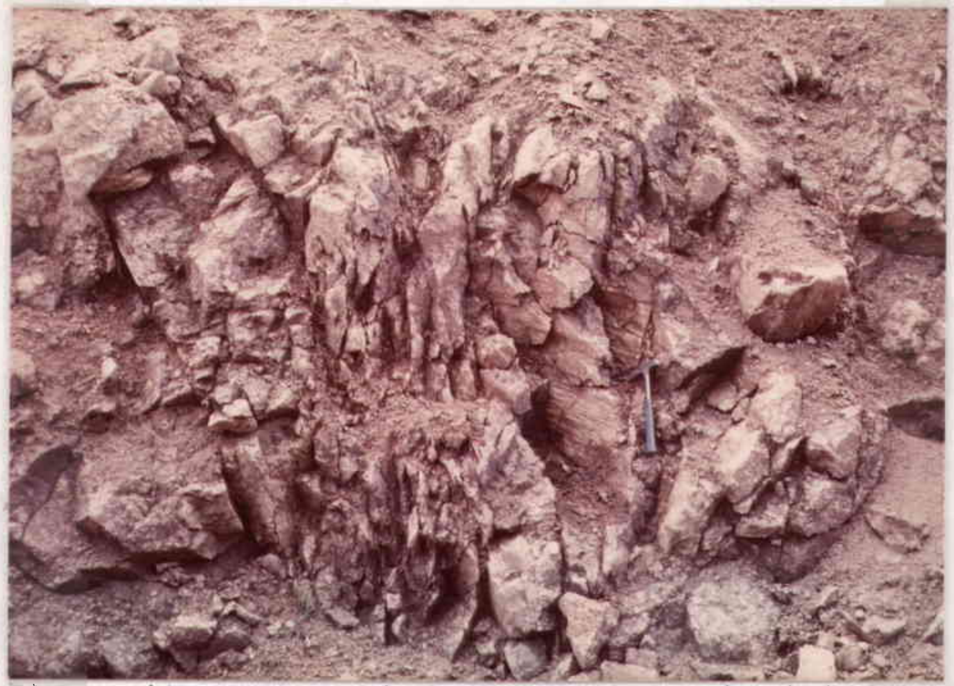

Figure 41a. Sheared Forest Hill porphyritic granite along Trail Creek.

Figure 41b. Close up of figure 41a showing slickensides and epidotization along fractures.

PRECAMBRIAN GEOLOGIC HISTORY

The metasedimentary units are the oldest rocks in the thesis area. These units are similar to the widespread metasedimentary complex of Colorado. Parent material consisted of sedimentary and possibly volcanic rocks. A minimum age for these metasedimentary rocks is established by the intrusion of granitic rocks that have been dated at about 1700 m.y. Regional metamorphism peaked between 1775 and 1700 m.y. ago in Colorado (Hedge and others, 1967, 1968, Peterman and others, 1968). Age of the parent rocks are tentatively placed in the range 1750-1820 m.y. by U-Pb isotopic ratios of zircon in metaigneous rocks (Silver and Barker, 1968). Rb/Sr ratios indicate the rocks were derived from rocks of mantle origin, no more than 2000 m.y. ago (Tweto, 1977).

Metasedimentary rocks of the Taylor Park area are considered to be similar in origin to the other pre-1700 m.y. metasedimentary rocks of Colorado.

Regional metamorphism preceded and occurred during the widespread emplacement of deep-seated igneous bodies 1700 m.y. ago. These rocks include the Boulder Creek granite of the Front Range and the Denny Creek granodiorite gneiss of the Sawatch Range. Detailed relationships between the intrusive rocks and the metasedimentary rocks are largely obliterated by metamorphism and deformation. Early greenschist metamorphism was probably upgraded to amphibolite facies during this orogenic period (1750-1650 m.y.). Migmatization and gneissic textures were also formed during this event.

The second major orogenic pulse in Colorado occurred about 1400 m.y. ago resulting in the emplacement of granitic batholiths such as the Silver Plume granite in the Front Range and the St. Kevin granite in the Sawatch Range. This period of intrusive activity was apparently not accompanied by strong tectonic movements since the characteristic habit of the intrusives is discordant. Rocks of this age are not identified in the thesis area although some effects from this orogeny may be present.

Post-tectonic emplacement of the Pikes Peak batholith is considered to be the last major event of the Precambrian in Colorado, occurring 1000 m.y. ago. Igneous activity of this age is considered to be restricted to the Front Range, but with dating of the Forest Hill granite at 1030 m.y. igneous activity of this period may be more widespread than previously believed.

REFERENCES

Barker, F. and Brock, M.R. 1965, Denny Creek Granodiorite Gneiss, Browns Pass Quartz Monzonite, and Kroenke Granodiorite, Mount Harvard quadrangle, Colorado: U.S. Geol. Survey Bull. 1224-A, p. A23-A26.

Barker, F., Peterman, Z.E., Henderson, W.T., and Hildreth, R.E., 1974, Rubidium-Strontium dating of the trondhjemite of Rio Brazos, New Mexico, and of the Kroenke Granodiorite, Colorado: U.S. Geol. Survey Jour. Research, v. 2, no. 6. p. 705-709.

Barker, F., Arth, J.G., Peterman, Z.E., and Friedman, I., 1976, The 1.7-1.8 b.y. old trondhjemites of southwestern Colorado and northern New Mexico, Geochemistry and depth of genesis: Geol. Soc. America Bull., v. 87, no. 2, p. 189-198.

Barnes, f. F., 1935, The Precambrian rocks of the Sawatch Range, Colorado: unpublished Ph.D. thesis, Northwestern University.

Brock, M.R., and Barker, Fred, 1972, Geologic map of the Mount Harvard quadrangle, Chaffee and Gunnison Counties, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-952.

Church, S.E., and Bickford, M.E., 1971, Spontaneous Fission-Track Studies of accessory Apatite from granitic rocks of the Sawatch Range, Colorado: Geol. Soc. America Bull. v. 82, p. 1727-1734.

Conyers, W.F., 1957, Geology of the Upper Spring Creek area, Gunnison County, Colorado: unpublished Masters thesis, University of Kentucky.

Crawford, R.D., 1913, Geology and Ore deposits of the Monarch and Tomichi districts, Colorado: Colorado Geol. Survey Bull. no. 4.

Crawford, R.D., and Worcester, P.G., 1916, Geology and Ore deposits of the Gold Brick district, Colorado: Colorado Geol. Survey Bull. no. 10.

Crawford, R.D., 1924, A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., v. 7, p. 365-388.

Cross, W., 1894, U.S. Geol. Survey Geological Atlas: Pikes Peak Folio 7.

Cruson, M.G., 1973, Geology and ore deposits of the Grizzly Peak cauldron complex Sawatch Range, Colorado: unpublished Ph.D. thesis, Colorado School of Mines.

Cunningham, C.G., Jr., 1973, Multiple intrusion and venting of the Italian Mountain Intrusive Complex, Gunnison County, Colorado: unpublished Ph.D. thesis, Stanford University, Stanford, Calif., 168 p.

Deer, W.A., Howie, R.A., and Zussman, J., 1966, An introduction to the Rock-Forming minerals. London: Longman Group Limited.

Dings, M.G. and Robinson, C.S., 1957, Geology and Ore deposits of the Garfield quadrangle, Colorado: U.S. Geol. Surv. Prof. paper, 289, 110 p.

Edwards, J., 1966, The petrology and structure of the buried Precambrian basement of Colorado: Colorado School of Mines Quart., v. 61, no. 4, 436 p.

Eldridge, C.H., 1894, U.S. Geol. Survey Geological Atlas, Anthracite-Crested Butte Folio 9.

Flanagan, F.J., 1969, U.S. Geological Survey standards-II. First compilation of data for the new U.S.G.S. rocks: Geochimica et Cosmochimica Acta, v. 33, p. 81-120.

Garrett, H.L., 1950, The geology of Star Basin and Star Mine, Gunnison County, Colorado: M.S. thesis, Colo. Sch. Mines, 45 p., unpublished.

Giffin, C.R., and Kulp, J.L., 1960, K-A ages in the Precambrian basement of Colorado: Bull. Geol. Soc. Am., 71, p. 219-222.

Goddard, E.N., 1935, The geology and ore deposits of the Tincup mining district, Gunnison County, Colorado: Colo. Sci. Soc. Proc., 13, p. 551-595.

Hayden, F.V., 1873, United States geological survey of the territories, 7th annual report, p. 56-61 and p. 249-252.

Hayden, F.V, 1874, United States geological survey of the territories, 8th annual report, p. 55-58 and p. 71.

Hedge, C.E., Peterman, Z.E., and Braddock, W.A., 1967, Age of the major Precambrian regional metamorphism in the northern Front Range, Colorado: Geol. Soc. America Bull., v. 78, p. 551-557.

Hedge, C.E., Peterman, Z.E., Case, J.E., and Obradovich, J.D., 1968, Precambrian geochronology of the northwestern Uncompahgre Plateau, in Geological Survey research 1968; U.S. Geol. Survey Prof. Paper 600-C, p. C91-C96.

Hedge, C.E., 1970, Whole-rock Rb-Sr age of the Pikes Peak batholith, Colorado: U.S. Geol. Survey Prof. Paper 700-B, p. B86-89.

Higgins, M.W., 1971, Cataclastic rocks: U.S. Geol. Survey Prof. Paper 687, 97 p.

Howell, J.V., 1919, Twin Lakes district of Colorado: Colorado Geol. Survey Bull. 17, 106 p.

James, H.L., 1972, Note-40-Subdivision of Precambrian: an interim scheme to be used by U.S. Geological Survey. Am. Assoc. Petrol. Geol. Bull., 56, p. 1128-1133.

Jeffery, P.G., 1975, Chemical methods of rock analysis, New York: Pergamon Press, Inc.

Johnson, J.H., 1944, Paleozoic stratigraphy of the Sawatch Range, Colorado: Geol. Soc. America Bull., v. 55, p. 303-378.

Kirk, E., 1931, Devonian of Colorado: Am. Jour. Sci., v. 22, p. 222-240.

Koksoy, Mumin, 1961, Geology of the northern part of Tincup Mining District, Gunnison County, Colorado: unpublished M.S. thesis, Colorado School of Mines.

Lovering, T.S., and Goddard, E.N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 p.

McCord, W.R., 1957, Geology of the Upper Spring Creek area, Gunnison County, Colorado: unpublished Masters thesis, University of Kentucky.

Meissner, F.F., 1954, The geology of Spring Creek Park, Gunnison County, Colorado: unpublished Masters thesis, Colorado School of Mines.

Miyashiro, A., 1975, Metamorphism and Metamorphic Gelts. New York, Halsted Press.

Moorhouse, W.W., 1959, The study of rocks in thin section, New York: Harper and Row.

Navarro, E., 1974, Metamorphic Precambrian rocks, Gunnison County, The Metasedimentary rocks, Neues Jahrb. Mineral Abr., v. 122, no. 3, p. 246-267.

Nockolds, S.R., 1954, Average chemical composition of some igneous rocks: Geol. Soc America Bull., v. 65, no. 10.

Nockolds, S.R., and Allen, R.L., 1954, The geochemistry of some igneous rock series: Geochimica et Cosmochimica Acta, v. 4, p. 105-142.

O'Connor, T.E., 1961, The structure and stratigraphy of an area west of Taylor Park: Northeast Gunnison County, Colorado: unpublished M.S. thesis, University of Colorado.

Pearson, R.C., and Tweto, O., 1958, Precambrian rocks of the northern Sawatch Range, Colorado (Abstract): Geol. Soc. America Bull., v. 69, p. 1738-1739.

Pearson, R.C., Hedge, C.E., Thomas, H.H., and Stern, T.W., 1966, Geochronology of the St. Kevin Granite and neighboring Precambrian rocks, northern Sawatch Range, Colorado: Geol. Soc. America Bull., v. 77, no. 10, p. 1109-1120.

Peterman, Z.E., Hedge, C.E., and Braddock, Q.A., 1968, Age of Precambrian events in the northeastern Front Range, Colorado: Jour. Geophys. Research, v. 73, no. 6, p. 2277-2296.

Prather, T.L., 1961, Geology of the North Italian Mountain area, Gunnison County, Colorado: M.S. Thesis, Univ. of Colo., unpublished.

Silver, L.T., and Barker, Fred, 1968, Geochronology of Precambrian rocks of the Needle Mountains, southwestern Colorado - Part 1, U-Pb zircon results (abs.): Geol. Soc. America Spec. Paper 115, p. 204-205.

Staatz, M.H., and Trites, A.F., 1955, Geology of the Quartz Creek pegmatite district, Gunnison County, Colorado: U.S. Geol. Survey Prof. Paper 265, 111 p.

Stark, J.T., and Barnes, F.F., 1932, The structure of the Sawatch Range: Am. Jour. Sci., 5th. ser., v. 24, p. 471-480.

Stark, J.T., 1934, Reverse faulting in Sawatch Range, Geol. Soc. America Bull., v. 45, p. 1001-1016.

Stark, J.T., 1935, Migmatites of the Sawatch Range, Colorado: Jour. Geology, v. 43, no. 1, p. 1-26.

Stark, J.T., 1935, Geology of the Sawatch Range, Colorado: Colorado Sci. Soc. Proc., v. 13, no. 8, p. 467-479.

Stark, J.T., and Barnes, F.F., 1935, Geology of the Sawatch Range, Colorado: Colo. Sci. Soc. Proc., v. 13, p. 467-474.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth-science Reviews, No. 12, p. 1-33.

Turner, F.J., 1968, Metamorphic Petrology. Mineralogical and Field aspects. New York: McGraw-Hill Book Co.

Tweto, O., and Sims, P.K., 1963, Precambrian ancestry of the Colorado Mineral Belt: Geol. Soc. America Bull., v. 74, p. 991-1014.

Tweto, O., and Case, J.E., 1972, Gravity and Magnetic features as related to geology in the Leadville 30-minute quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 726-C, 31 p., 1973.

Tweto, O., Steven, T.A., Hail, W.J., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1x2 degree quadrangle southwestern Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-761.

Tweto, O., 1977, Nomenclature of Precambrian rocks in Colorado: U.S. Geol. Survey Bull. 1422-D.

Urbani, F., and Blackburn, W.H., 1974, Basement rocks, Precambrian, Gunnison County, Neues. Jahrb. Mineral Abr., v. 121, no. 3, p. 272-292.

Vanderwilt, J.W., 1937, Geology and mineral deposits of the Snowmass Mountain area, Gunnison County, Colorado: U.S. Geol. Survey Bull., 884, 184 p.

Walcott, C.D., 1892, Preliminary notes on the Discovery of a vertibrate fauna in Silurian (Ordovician) strata: Bull. Geol. Soc. Amer., v. 3, p. 153-172.

Warner, L.A., 1978, The Colorado Lineament: A middle Precambrian wrench fault system: Geol. Soc. America Bull., v. 89. p. 161-171.

Wetherill, G.W., and Bickford, M.E., 1965, Primary and metamorphic Rb-Sr chronology in central Colorado: Jour. Geophys. Res., v. 70, p. 4669-4686.

Zoerner, F.P., 1973, Stratigraphy and structural geology west-central Sawatch Range, Elk Mountains, Italian Creek, and Pearly Pass quadrangles: In Rocky Mountain section, 26th. ann. meeting, Geol. Soc. Am. (Abstract), v. 5, no. 6.

APPENDICES

APPENDIX I

Rb-Sr Analyses done by Teledyne Isotopes of New Jersey

Fresh, representative portions of the rock samples were crushed and sieved to obtain a #30-100 mesh fraction. This fraction was ground in a hand mortar to powder of grain size smaller than 200 mesh. A weighed aliquot of this powder was spiked with ^{87}Rb and ^{84}Sr, then dissolved in hydrofluoric, nitric and perchloric acids in teflon beakers. The solution was fumed to dryness, taken up in the acid mixture again and again evaporated. The residue was then taken up in 1:1 HCl:H_2O and centrifuged to separate the strontium-containing solution from the rubidium-bearing precipitate. The solution was evaporated to dryness and taken up in 2.4 N HCl. Radioactive ^{85}Sr was added as a tracer and the solution was placed on a cation exchange column and eluted with 2.4 N HCl. Strontium-containing fractions were collected by counting ^{85}Sr. The most active fractions were combined and evaporated to dryness. A few drops of HNO_3 were added to convert Sr to a nitrate medium. The rubidium-bearing precipitate from the centrifugation procedure was dissolved in deionized water, evaporated to dryness and treated with a few drops of HNO_3.

Mass spectrometry was done on an NBS-type, 12 inch 90° solid source thermal ionization unit. The strontium fraction was taken up in a few drops of 2% HNO_3 and applied to baked rhenium filaments in a triple-filament assembly. The rubidium fraction was run similarly on rhenium filaments. Strontium was ionized at 1710°C and rubidium at 1600°D. Measured ratios of $^{86}Sr/^{88}Sr$ were normalized to 0.1194 and the observed $^{87}Sr/^{86}Sr$ ratios were adjusted by half the amount of the $^{86}Sr/^{88}Sr$ correction to allow for mass discrimination. Isotopic ratios can be measured to a precision (1σ) of $\pm$ 0.1% and elemental concentrations to

± 1%.

The $^{87}Sr/^{86}Sr$ ratio was plotted against $^{87}Rb/^{86}Sr$. The age was calculated from the slope of a line fitted to the data by the method of least squarea. The intercept of this line gives the initial ratio. The constants used for the calculations are $\gamma = 1.42 \times 10^{-11}/y$, ^{87}Rb isotopic % = 27.83. These are the constants recommended by the Subcommission on Geochronology, 25th International Geological Congress, 1976.

The ^{84}Sr spike is National Bureau of Standards isotopic standard 988 (99.892 atom % ^{84}Sr, 0.059% ^{86}Sr, 0.010% ^{87}Sr, 0.039% ^{88}Sr). The ^{87}Rb spike is 99.211 atom % ^{87}Rb, 0.789% ^{85}Rb.

The calculations involved in isotope dilution analysis and the basic assumptions involved in Rb/Sr dating may be found in standard works on the subject, such as:

York, D., and Farquhar, R.M., 1972, The Earth's Age and geochronology, Pergamon Press, Inc., Elmsford, N.Y., 178 p.

Faure, G., and Powell, J.L., 1972, Strontium Isotope Geology, Springer-Verlag, N.Y., 188 p.

APPENDIX II

Methods used by Geolabs, A Division of Natural Resources Laboratory Inc., for whole rock geochemical analyses of 19 samples from the thesis area.

Fresh samples were trimmed and then crushed in a jaw crusher to -1/4 inch or less. The sample was then run through a Jones riffle splitter where a representative split was taken and pulverized in a Braun-Bico Rotating ceramic pulverizer to - 150 mesh. Rapid decomposition by fusion at high temperature with lithium-metaborate in platinum crucibles formed a bead which was then analyzed.

Direct aspiration atomic absorption, using either a Perkin-Elmer model 560 or 603 atomic absorption instrument, was used to determine the following major oxides, Al_2O_3, K_2O, Na_2O, CaO, MgO and total iron as Fe_2O_3.

Visible UV spectrophotometric methods were used to determine SiO_2, FeO, TiO_2 and P_2O_5.

APPENDIX III

Modal Estimates of the Metasedimentary Rocks

Minerals	qu-peb. congl.	qtzite 1	qtzite 2	qtzite 3	avg.	qu-musc schist 1	qu-musc schist 2	qu-musc schist 3	avg.
quartz	68-80	92	95	72	86.3	32	55	45	44
plag.	5-20	3	1	16	6.7	5	10	20	11.7
K-spar	--	--	--	--	--	--	--	--	--
biotite	3.5	2	1	5	2.7	8	3	tr	3.9
musc.	tr-3	1	1	1	1	40	20	25	28.3
chlorite	tr-3	1	tr	3	1.4	5	7	9	7
epidote	tr-1	tr	tr	1	0.6	tr	2	tr	1
sill.	--	--	--	--	--	--	--	--	--
zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr
opaque	1-5	tr	tr	1	0.8	9	2	1	4
cord.	--	--	--	--	--	tr	tr	--	--
tour.	--	--	--	--	--	tr	--	tr	tr
rutile	?	--	tr	tr	tr	tr	tr	tr	tr
sphene	--	--	--	tr	tr	--	--	--	--
allanite	--	--	--	--	--	--	--	--	--
garnet	--	--	--	--	--	--	--	--	--
TOTAL	99-100	99.6	99.8	100.1	100.3	99.7	99.9	100.4	100.4

APPENDIX III (Cont'd.)

Minerals	qu-ep schist 1	qu-ep schist 2	qu-ep schist 3	avg.	qu-bio schist 1	qu-bio schist 2	qu-bio schist 3	avg.	qu-bio-sill schist 1	qu-bio-sill schist 2	qu-bio-sill schist 3	avg.
quartz	47	48	58	51	40	59	48	49	18	45	28	30.3
plag.	16	1	5	7.3	35	10	30	25	1	1	tr	0.7
K-spar	1	tr	2	1.2	--	--	--	--	30	10	15	18.3
biotite	1	5	3	3	24	28	21	24.3	30	9	40	26.3
musc.	3	15	16	11.3	tr	tr	--	tr	tr	--	--	tr
chlorite	1	13	5	6.3	tr	tr	tr	tr	tr	tr	tr	tr
epidote	25	18	10	17.7	tr	--	tr	tr	--	--	--	--
sill	--	--	--	--	--	--	tr	tr	20	35	16	23.7
zircon	tr	tr	tr	tr	tr	tr	tr	tr	--	tr	tr	tr
opaques	5	tr	tr	1.8	tr	tr	tr	tr	tr	tr	tr	tr
cord.	--	--	--	--	--	--	tr	tr	--	--	--	--
tour.	--	tr	--	tr	--	--	--	--	--	--	--	--
rutile	--	--	--	--	--	--	--	--	--	--	--	--
sphene	tr	tr	tr	tr	--	--	--	--	--	--	--	--
allanite	tr	--	tr	tr	--	tr	--	tr	--	--	--	--
garnet	--	--	--	--	--	--	tr	tr	tr	--	tr	tr
TOTAL	99.9	100.2	100	100	100	99.1	99.9	100	99.9	100.1	100	100.1