OPEN-FILE REPORT 01-5

Geologic Map of the Georgetown Quadrangle, Clear Creek County, Colorado

By Beth L. Widmann and Ulrike Miersemann

Colorado Geological Survey
Division of Minerals and Geology
Department of Natural Resources
Denver, Colorado / 2001

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Description of Map Units, Geologic Hazards, Structural Geology, Economic Geology, and References

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This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey STATEMAP component of the National Cooperative Geologic Mapping Program, Agreement No. 00HQAG0119.

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 01-5, *Geologic Map of the Georgetown Quadrangle, Clear Creek County, Colorado* is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located along the I-70 corridor about 40 miles west of Denver. Beth L. Widmann, staff geologist at the Colorado Geological Survey, and Ulrike Miersemann, graduate student at Colorado School of Mines completed the field work on this project in the summer of 2000.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 00HQAG0119, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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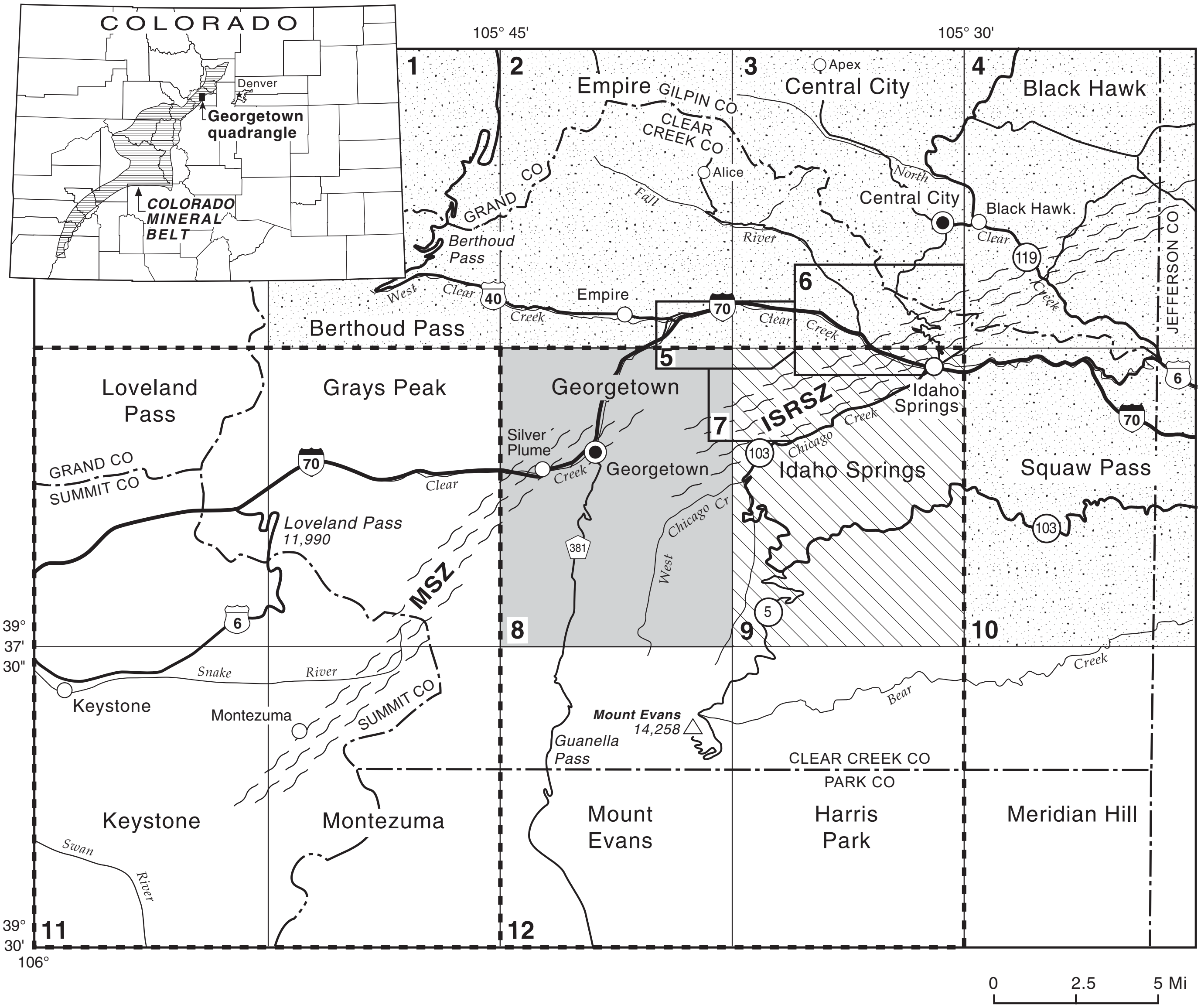
INTRODUCTION

The Georgetown quadrangle is located in Clear Creek County in the Colorado Front Range. It is characterized by rugged terrain ranging in elevation from about 8,400 ft in Georgetown to 13,040 ft at the southern edge of the quadrangle. The Interstate Highway 70 transportation corridor (I-70) passes through Georgetown and Silver Plume in the northern part of the quadrangle. The Georgetown-Silver Plume mining district, known primarily for its silver production, generally extends throughout the western and northern parts of the quadrangle.

Geologic mapping of the Georgetown 7.5 minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program, authorized by the National Geologic Mapping Act, which is administered by the U.S. Geological Survey. Partial funding for this project came from Colorado Severance taxes, which are derived from the production of oil, gas, coal, and metals. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource development, and ground-water exploration.

The Georgetown 15-minute quadrangle, which includes the Georgetown 7.5-minute quadrangle, was previously mapped by Spurr and others (1908). The Montezuma 15-minute quadrangle to the west was mapped by Lovering (1935). Other previously mapped 7.5-minute quadrangles adjacent to the Georgetown quadrangle include Berthoud Pass (Theobald, 1965), Empire (Braddock, 1969), Central City (Sims, 1964), and Idaho Springs (Widmann and others, 2000). Figure 1 shows the current status of geologic mapping in the Georgetown area.

Proterozoic metamorphic and igneous rocks crop out beneath most of the quadrangle. The oldest are Early Proterozoic metasedimentary and metavolcanic rocks that were originally deposited up to 1,800 Ma (Tweto, 1987) and later metamorphosed during a period of intense deformation about 1,726 Ma (Selverstone and others, 1997). This metamorphic complex was subsequently intruded by granitic rocks of the Berthoud plutonic suite (Tweto, 1987) between about 1,448 and 1,420 Ma (Aleinikoff and others, 1993; Peterman and others, 1968). Multiple pulses of igneous intrusion from 65 to about 20 Ma resulted in the emplacement of numerous porphyry dikes and other small intrusive bodies throughout the Colorado Mineral Belt (Figure 1). Porphyry bodies in the Georgetown quadrangle are predominantly associated with a magmatic pulse occurring between 43 to 35 Ma (Bookstrom and others, 1987). The ore minerals of the Georgetown-Silver Plume mining district were precipitated during the later stages of this 43 to 35 Ma intrusive event. The youngest deposits in the quadrangle include glacial till of Pinedale and possibly Bull-Lake age, as well as other Quaternary surficial deposits.



Explanation

Current CGS 1:24,000-scale map

Completed CGS 1:24,000-scale map

Completed USGS 1:24,000-scale map

Completed USGS 1:62,500-scale map

Completed USGS 1:6,000-scale map

Shear zone

Index Map No.	Map Area and Reference
1	Berthoud Pass quadrangle (Theobald, 1965)
2	Empire quadrangle (Braddock, 1969)
3	Central City quadrangle (Sims, 1964)
4	Black Hawk quadrangle (Taylor, 1976)
5	Freeland-Lamartine mining district (Harrison and Wells, 1959)
6	Idaho Springs mining district (Moench and Drake, 1966)
7	Chicago Creek mining district (Harrison and Wells, 1956)
8	Georgetown 15-minute quadrangle (Spurr and others, 1908)
9	Idaho Springs quadrangle (Widmann and others, 2000)
10	Squaw Pass quadrangle (Sheridan and Marsh, 1976)
11	Montezuma 15-minute quadrangle (Lovering, 1935)
12	Georgetown quadrangle (this publication)

Figure 1. Location map and index of published geologic maps in the vicinity of the Georgetown quadrangle and the Montezuma (MSZ) and Idaho Springs-Ralston (ISRSZ) shear zones. Inset map shows location of the Georgetown quadrangle within the Colorado Mineral Belt.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than about 5 ft thick but may be thinner locally. Residuum and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally include deposits of another type. Divisions of the Pleistocene correspond to those of Richmond and Fullerton (1986). Age assignments for surficial deposits are based primarily upon the degree of erosional modification of original surface morphology, height above modern streams, and relative degree of clast weathering and soil development. Clast size is based on the modified Wentworth scale.

HUMAN-MADE DEPOSITS—

af

Artificial fill (latest Holocene)— Unsorted silt, sand, and rock fragments from alluvial, debris-fan, and rockfall deposits, mine and mill waste, and recycled construction materials deposited by humans to facilitate development in Georgetown, particularly at the turn of the century and during the construction of I-70 and several dams located along South Clear Creek and downstream of Georgetown. Artificial fill underlying structures in Georgetown is probably less than about 10 ft thick. Elsewhere, the average thickness of the unit is less than 30 ft, although the dam west of Clear Lake Campground may exceed 150 ft. Artificial fill may be subject to settlement when loaded if not adequately compacted.

mw

Mine and mill waste (latest Holocene)— Waste rock excavated from mines and prospecting pits and mill tailings resulting from milling operations. Mine waste typically consists of pebble- to cobble-size angular fragments of altered granite, biotite gneiss, and intrusive porphyry and may be as much as 50 ft thick. Mill tailings are composed of smaller fragments and are usually only a few feet to a few tens of feet thick. There may be environmental problems, such as contamination of ground and surface water, associated with mine and mill waste.

ALLUVIAL DEPOSITS— Silt, sand, and gravel deposited in stream channels, on flood plains, terraces, and minor debris fans, and in sheetwash areas.

Qa

Stream-channel, flood-plain, and low-terrace alluvium (Holocene)— Clast-supported, interbedded sandy to bouldery pebble and cobble gravel commonly overlain by silty sand, organic-rich sandy silt, and minor peat in prominent drainages, adjacent flood plains, and low terraces up to about 10 ft above modern stream level. Clasts are subangular to well rounded, and their varied lithology reflects the diverse types of bedrock within their provenance. This unit may be interbedded with colluvium or debris-fan deposits where the distal ends of fans extend into modern river channels and flood plains. Areas mapped as alluvium may be prone to flooding and sediment deposition. The unit is a potential source of sand and gravel.

Qao

Older alluvium (late Pleistocene)— Poorly sorted, matrix-supported, pebble and cobble gravel in a sandy matrix. Includes deposits of stream alluvium and sheetwash underlying a single small terrace remnant about 40 ft above modern stream level. The terrace is located between Green and Clear Lakes on South Clear Creek and may represent a paleo-stream channel that was abandoned because of landslide activity on either side of Green Lake following retreat of glacial ice. Thickness is probably less than 10 ft.

COLLUVIAL DEPOSITS—Silt, sand, and gravel on valley sides and floors. Material mobilized, transported, and deposited primarily by gravity, but commonly assisted by sheetwash, freeze-thaw action, and water-saturated conditions that affect pore pressure.

Qc

Colluvium (Holocene and late Pleistocene)— Includes weathered bedrock fragments that have been transported downslope primarily by gravity. Colluvium ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy matrix to matrix-supported gravelly, silty sand. It is generally unsorted to poorly sorted and contains angular to subangular clasts. Clast lithology is variable and dependent upon types of rocks occurring within the provenance area. Locally, this unit may include debris-fan deposits that are too small or too indistinct on aerial photography to be mapped separately. Colluvium commonly grades into and interfingers with alluvium (Qa), alluvium and colluvium (Qac), and debris-fan deposits (Qf). Maximum thickness of this unit is probably about 30 ft but may be greater, particularly in the broad basin east of Woodchuck Peak. Areas mapped as colluvium are susceptible to future colluvial deposition and locally are subject to debris flows, rockfall, and sheetwash. Colluvial deposits are a potential source of medium-quality aggregate.

Qls

Landslide deposits (Holocene and late Pleistocene)— Clast-supported, heterogeneous deposits consisting primarily of large rock fragments and lesser amounts of sand- to boulder- size debris in a silty-sand matrix. Major translational landslide complexes occur along the valley walls of South Clear Creek and Clear Creek, and on the northern flank of Sherman and Republican Mountains. These landslides are characterized by numerous linear scarps, hummocky terrain, interrupted drainages, and substantial toreva blocks, which are essentially massive slabs of intact rock exceeding hundreds of feet in size that have detached from the source area. Landslides near Georgetown Reservoir have more of a teardrop morphology, generally lack toreva blocks, and may have a rotational slide element. The presence of numerous fresh scarps and interrupted drainages indicates many of the slides are currently active. Landslide deposits may be prone to settlement when loaded or wetted. Large rock fragments within this deposit are a potential source of riprap and aggregate.

Qt

Talus deposits (Holocene and late Pleistocene)— Angular, cobbly and bouldery rubble derived from bedrock that was transported downslope by gravity principally as rockfalls, rock avalanches, rock topples, and rockslides. Downslope movement may have been locally aided by water and freeze-thaw action. This unit typically lacks matrix material. The largest talus deposits may exceed 30 ft in thickness. They occur within or immediately adjacent to major landslide complexes along South Chicago Creek and Chicago Creek. Areas where talus deposits have been mapped are subject to severe rockfall, rock-topple, and rockslide hazards. This unit may be a source of medium- to high-quality riprap and aggregate, but vehicular access to most talus deposits in the mapped area is limited.

ALLUVIAL AND COLLUVIAL DEPOSITS— Gravel, sand, and silt in debris fans, stream channels, flood plains, and lower reaches of adjacent hillslopes. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes are predominant on debris fans and along the hillslope/valley floor boundary.

Qf

Debris-fan deposits (Holocene and late Pleistocene)— Sediments deposited by debris flows, hyperconcentrated flows, streams, and sheetwash on active fans. Debris-fan deposits range from poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported, pebble and cobble gravel in a sandy silt or silty sand matrix. Clasts are mostly angular to subround with varied lithologies dependant upon local source rock. The maximum estimated thickness for debris fans along Clear Creek is as much as 60 ft. Elsewhere, fan thickness is typically less than 30 ft.

In recent time, numerous depositional events have occurred on debris fans along the north and west sides of I-70. Conversely, the last major phase of deposition on debris fans on the south and east sides of the highway generally occurred between 750 to 950 years ago (Coe and others, 1998). Extraordinary precipitation events may trigger large-scale mobilization of many of these fans. Debris-flow deposits may be prone to collapse when wetted or loaded, and piping (underground erosion) may occur where the deposits are fine grained and low in density.

Qac

Alluvium and colluvium, undivided (Holocene and late Pleistocene)— Includes stream-channel, low-terrace, and flood-plain deposits along valley floors, and colluvium and sheetwash on valley sides, where adjacent units are too small to be mapped or contacts are poorly defined. Locally, this unit may also include small debris-fan deposits or lacustrine deposits associated with human-made reservoirs and lakes and topographic depressions dammed by glacial deposits. Alluvial deposits are typically composed of poorly sorted to moderately sorted, moderately stratified, interbedded sand, pebbly sand, and sandy gravel, but colluvium ranges to very poorly sorted, unstratified or poorly stratified, silty sand and bouldery sand. The clast lithologies are varied, depending on the type of rocks within the source area. This unit is typically less than about 15 ft thick. Low-lying areas are subject to flooding. Valley sides are prone to small debris flows, rockfall, and sheetwash. The unit is a potential source of aggregate.

Qcs

Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)— Colluvium ranges from clast-supported, pebble to boulder gravel in a sandy matrix to matrix-supported gravelly sand. It is generally unsorted to poorly sorted and contains angular to subangular clasts. Sheetwash deposits typically consist of pebbly, silty sand, and sandy silt. Colluvium occurs on steeper slopes and sheetwash deposits are on gentler slopes. The deposits are typically gradational or intertonguing and range in thickness up to about 15 ft.

PERIGLACIAL DEPOSITS—Deposits formed in cold environments by solifluction, frost action, and nivation.

Qs

Solifluction deposits (Holocene and late Pleistocene)— Consist primarily of reworked Proterozoic bedrock fragments deposited in alpine and sub-alpine basins near Otter Mountain, in the upper regions of West and South Chicago Creeks, on the east flank of Woodchuck Peak, and near Republican Mountain. The deposits consist of angular to subrounded pebbles, cobbles, and large boulders in a chiefly sandy matrix and are characterized by hummocky terrain, ground cracks and fissures up to several inches wide, and numerous seeps and springs. Solifluction deposits result from the slow downslope flowage of surficial deposits that are water saturated and subject to seasonal freezing. Frost creep and melt-water transport are also important factors in the formation of solifluction deposits in the quadrangle. They are typically less than about 15 ft thick. Shallow groundwater and future, small-scale slope movement may be associated with these deposits.

GLACIAL DEPOSITS— Gravel, sand, silt, and clay by ice.

Qti

Till (late and late middle Pleistocene)— Heterogenous deposits of gravel, sand, silt, and clay deposited by ice in lateral, end, and ground moraines in prominent drainages throughout the quadrangle. The deposits are characterized by unsorted, unstratified, matrix-supported bouldery, pebble and cobble gravel in a matrix of silty sand. Clasts are subangular to rounded, elongate to subspherical, and may reach more than 20 ft in diameter. Clast lithology is variable but granodiorite and granite predominate. Stratified drift may be locally interbedded with till. End and lateral moraines are commonly hummocky, steep sided, and bouldery. Closed depressions are common and may be areas of elevated groundwater.

Terminal moraines have generally been obliterated by stream erosion, but remnants of end moraines are found in Bard Creek and West Chicago Creek. Lateral moraine crests are rounded but fairly well preserved especially in the West Chicago Creek valley, where ice extended only a short distance beyond Lake Edith. Ice in Bard Creek, Leavenworth Creek, and South Clear Creek ultimately converged with ice in Clear Creek before reaching a lower glacial limit in the Dumont-Lawson area (Madole and others, 1998). Most of the till is of probable Pinedale age.

Spurr and others (1908) mapped two ages of till in Bard Creek and along Clear Creek. However, there is no geomorphic evidence to suggest the presence of two tills, and both are virtually indistinguishable in the field due to on-going colluvial deposition and possible post-deposition spalling of clasts. Therefore, till in Bard Creek is herein mapped as a single unit of probable Pinedale age. Furthermore, till-like deposits mapped as glacial material above 9,500 to 10,000 ft by Spurr and others (1908) along South Clear Creek and Clear Creek are well beyond Pleistocene glacial maximums mapped by Madole and others (1998). Therefore, deposits below about 9,500 ft are herein mapped as till that is predominantly Pinedale in age, and till-like material generally above 9,500 ft are mapped as diamicton (Qd). Maximum thickness of the Pinedale-age till locally exceeds 100 ft.

NONSORTED TERRIGENOUS DEPOSITS— Bouldery material of uncertain origin.

Qd

Diamicton (early to middle Pleistocene)— Nonsorted deposits consisting largely of boulders and cobbles in a sandy matrix. The deposits resemble glacial till and are found at elevations generally above about 9,600 ft, which is beyond the Pleistocene glacial maximum outlined in the area by Madole and others (1998). Although this material may have been deposited by pre-Bull Lake ice, boulders in the deposit lack the strong weathering that typical of boulders in till of that age. Spalling in response to the extreme heat of historic forest fires may be responsible for resetting the apparent age of these deposits by removing the outer weathering rinds of many boulders. Alternatively, this bouldery material may have been deposited by processes other than ice, such as landslides, earthflows, mudflows, and solifluction (Flint and others, 1960). This unit often forms only a thin veneer over bedrock but may locally be several tens of feet thick.

BEDROCK

TERTIARY AND UPPER CRETACEOUS INTRUSIVE ROCKS— There are two significant stocks of Tertiary- to Upper Cretaceous-age adjacent to the Georgetown quadrangle. To the northeast is the Empire stock, a Laramide-age intrusive emplaced between about 61 to 68 Ma (Cunningham and others, 1994; Marvin and others, 1989; Simmons and Hedge, 1978)). The 35 to 40 Ma Montezuma stock lies to the southwest (Cunningham and others, 1994). A single porphyry near Ute Creek is probably associated with the Empire stock. The rest of the porphyries in the Georgetown quadrangle appear to be related to the Montezuma stock. Many of the various porphyries are described in detail by Spurr and others (1908), Lovering (1935), Wells (1960), Braddock (1969), and Connors (1985). Age determinations for porphyries in the Georgetown-Silver Plume district are sparse, so relative ages of the porphyries are based solely on apparent cross-cutting relations observed in the field by Connors (1985). Herein, porphyries younger than 38 Ma are considered Oligocene in age on the basis of the geologic time scale in Hansen (1991). However, it should be noted that the Eocene/Oligocene boundary is currently debated and has been argued to be 33.7 Ma (Berggren and others, 1995).

Td

Dacite (Oligocene and/or Eocene)— Bluish-gray to light-purple porphyry with an aphanitic groundmass of feldspar and quartz. Feldspar phenocrysts are largely replaced by sericite, calcite, and kaolinite (Spurr and others, 1908). Less abundant phenocrysts include quartz, hornblende, and biotite. Near the wall rocks, phenocrysts and numerous xenoliths display a common flow orientation (Connors, 1985). There are two dacite bodies located south of Georgetown (SW¼, sec. 11, T. 4 S., R. 74 W.): a dike that is as much as 50 ft wide and less than half a mile long (Spurr and others, 1908), and a large intrusion breccia at the western end of the dike. The breccia is about 200 ft wide by 700 ft long and includes fragments of Silver Plume Granite. Both bodies exhibit conchoidal fracturing and are highly pitted due to the weathering of phenocrysts. Bookstrom (1993) suggests these porphyries are 35 to 36 Ma.

Tgp

Granite porphyry (Oligocene and/or Eocene)— Tan to pinkish-gray, very fine-grained porphyry with a groundmass composed of quartz and orthoclase and phenocrysts of orthoclase biotite and quartz. Where altered, granite porphyry may be chalky yellow to orange-red, and feldspars are largely altered to sericite, kaolinite, and limonite.

The largest body of granite porphyry is a stock northeast of Otter Mountain in the southwest corner of the quadrangle (T. 5 S., R. 74 W.) dated at 36.6 ± 4.2 Ma (Bookstrom and others, 1987), on the basis of a zircon fission-track date. This stock is extensively fractured and highly weathered. Dikes near Pavillion Point, south of Georgetown, are also highly weathered and contain vesicles filled with quartz and calcite.

Ta

Alaskite porphyry (Oligocene and/or Eocene)— White to light-gray porphyry composed of very fine-grained quartz and orthoclase with scattered orthoclase and plagioclase phenocrysts, and minor quartz and mica. Weathered fragments are commonly similar in appearance to shards of white pottery and may even appear to be slightly glazed. Dendrites of manganese oxide are pervasive along fracture and joint surfaces.

Alaskite porphyry occurs as numerous dikes in the Silver Plume area, as a lengthy (approximately 2.5 mi. long) dike parallel to the Silver Gulch Fault west of Georgetown, and as a large stock on the west flank of Paines Mountain. According to Bookstrom and others (1987), the stock was intruded 37.0 ± 4 Ma, on the basis of a zircon fission-track date. Alaskite dikes are about 8 to 15 ft wide.

Tqm

Quartz monzonite porphyry (Oligocene and/or Eocene)— Light- and medium-gray to pale-violet, fine-grained intrusive rock with a groundmass consisting of plagioclase, orthoclase, and quartz and phenocrysts of plagioclase, sanidine, and less commonly, amphibole and biotite. A large body of quartz monzonite porphyry occurs in the northwest corner of the quadrangle and was referred to as the Lincoln Mountain stock by Braddock (1969). Quartz monzonite porphyry dikes are found in the Silver Plume area and north of Georgetown on the east valley wall. These intrusives are associated with the 35 to 40 Ma Montezuma stock (Cunningham and others, 1994).

TKb

Bostonite porphyry (early Tertiary to Upper Cretaceous)— Includes a single light- to reddish-purple porphyry dike in the eastern part of the quadrangle near Ute Creek (sec. 2 and 11, T. 4 S, R. 74 W.). The dike is less than 10 ft wide and is intermittently exposed over a distance of about three-quarters of a mile. Bostonite porphyry consists primarily of orthoclase and plagioclase with lesser amounts of quartz and amphibole. The groundmass is aphanitic and locally faintly trachytic. Orthoclase phenocrysts are generally rhombic and commonly have tan alteration haloes about 0.1 to 0.2 in. thick. The porphyry commonly appears pitted due to weathering of feldspar phenocrysts. It is similar in texture and mineralogy to rocks of the Laramide-age Empire stock located northeast of the Georgetown quadrangle.

PROTOROZOIC INTRUSIVE ROCKS—

Proterozoic intrusive rocks of the Colorado Front Range belong to three different groups (Tweto, 1987). The oldest igneous rocks belong to the Routt plutonic suite, which was emplaced about 1,700 Ma. Igneous rocks emplaced about 1,400 Ma belong to the Berthoud plutonic suite. Those that intruded around 1,000 Ma include mafic and intermediate dikes and rocks of the Pikes Peak batholith. The majority of the Proterozoic intrusive rocks in the Georgetown quadrangle belong to the Berthoud plutonic suite. Two small bodies of granodiorite at the northern end of the quadrangle belong to the Routt plutonic suite.

Yd

Diorite and associated hornblendite (Middle Proterozoic)— Dark-gray to mottled dark-gray and white, medium- to coarse-grained intrusive rocks composed primarily of plagioclase and hornblende with minor quartz and biotite. Associated greenish-black, fine- to medium-grained granular hornblendite is composed almost entirely of hornblende. Diorite is generally equigranular, but somewhat radial concentrations of hornblende up to about an inch in diameter occur in a matrix locally devoid of hornblende. In places, the unit exhibits weak to moderate foliation defined by rounded, elongate feldspar phenocrysts up to about 0.3 in. in length. Spurr and others (1908) suggested the diorite and associated hornblendite and the Mount Evans granodiorite are differentiation products of the same magma, the diorite and associated hornblendite being on the whole slightly younger than the granodiorite. There are only three small bodies of unit Yd mapped on the quadrangle: two are west of Georgetown (SE¼ sec. 5 and SE¼ SE¼ sec. 8, T. 4 S., R. 74 W.), and the third is on Woodchuck Peak (sec. 9, T. 4 S., R. 74 W.).

Ysp

Silver Plume Granite (Middle Proterozoic)—Pink to pinkish-gray, massive to moderately foliated granite consisting primarily of microcline, plagioclase, and quartz, with minor to moderate amounts of biotite and/or muscovite. The Silver Plume Granite commonly has a seriate porphyritic texture defined by alignment of microcline phenocrysts, many of which exhibit Carlsbad twinning. The unit differs from other granitic bodies in the quadrangle (Xbc, Ygd, and Ygq) in that it has abundant porphyritic potassium feldspar crystals that are elongate and remarkably tabular. The length of these crystals generally ranges from 0.1 to 0.4 in., but larger crystals as much as an inch long are common. This granite was descriptively known as “corn rock” by local miners at the turn of the century on the basis of the large size of the feldspar crystals (Lovering, 1935). Where mineralized, off-white microcline laths contrast with a rust- to purple-stained, fine-grained matrix.

The Silver Plume Granite has a uranium-lead zicron age of 1,422 ± 2 Ma (Graubard and Mattison, 1990). It is a good source of building stone, riprap, and aggregate.

Ygq

Biotite-muscovite granite and quartz monzonite (Middle Proterozoic)— Gray to pinkish tan, massive to weakly foliated intrusive rock composed primarily of microcline, plagioclase, quartz, and biotite, with minor muscovite. It is usually fine- to medium-grained but is locally coarse-grained and gradational to pegmatite. Where weakly foliated and equigranular the unit is difficult to distinguish from some types of felsic gneiss (Xf). Similar rock units have also been described as Silver Plume Granite (Spurr and others, 1908; Braddock, 1969; Sheridan and Marsh, 1976). However, the Silver Plume Granite at the type locality of Silver Plume is texturally different and tends to have less biotite. Given the close spatial association and similarity in mineralogy, it is possible that the biotite-muscovite granite and quartz monzonite rocks are a merely finer grained phase of the Silver Plume Granite. Theobald (1965) mapped eight subunits of Silver Plume Granite in the Berthoud Pass quadrangle, which is northwest of the Georgetown quadrangle. Ygq may correspond to his “equigranular muscovite-biotite quartz monzonite, medium-grained” (spe) and “coarse-grained biotite-muscovite quartz monzonite” (spc) subunits of the Silver Plume Granite.

This unit is a good source of riprap and aggregate.

Ygd

Granodiorite of the Mount Evans batholith (Middle Proterozoic)— Weakly to moderately foliated, medium- to coarse-grained, mottled black and white granodiorite. Primary mineral constituents are plagioclase, microcline, quartz, and biotite. Hornblende, magnetite, and sphene are accessory minerals. Locally, coarse, subround feldspar crystals are weakly aligned along with biotite. Where fresh, the unit has a characteristic blue tinge.

The Mount Evans batholith is named after the 14,258-foot-high Mount Evans, which lies less than 3 mi. south of the Georgetown quadrangle. Rocks of the Mount Evans batholith were originally considered to be part of the (1,700 Ma) Routt plutonic suite (Tweto, 1987) on the basis of their mineralogical and textural similarity to the Boulder Creek granodiorite. Early rubidium-strontium dating of the granodiorite yielded an age of 1,660 ± 30 Ma (Bryant and Hedge, 1978), which seemed to coincide well with the 1,665 ± 40 Ma to 1,710 ± 40 Ma age calculated for the Boulder Creek granodiorite (Peterman and others, 1968; Bryant and Hedge, 1978). However, more recent uranium-lead dates of zircon indicate that the Mount Evans batholith was emplaced 1,422 ± 2 Ma and is not equivalent to the Boulder Creek granodiorite (Aleinikoff and others, 1993).

Where unaltered, the Mount Evans granodiorite is a good source of riprap and aggregate.

YXqm

Quartz monzonite gneiss (Middle or Early Proterozoic)— Mottled black and white, medium- to coarse-grained, locally porphyritic gneiss composed of plagioclase, orthoclase, quartz, and lesser and variable amounts of hornblende and biotite. Although similar mineralogically to the granodiorite of Mount Evans (Ygd), this unit exhibits a gneissic structure that is defined by alternating bands of aligned quartz and feldspar and aligned biotite and hornblende. In the field, this unit was referred to as “zebra rock” because of its common black and white banding. Aplite dikes and small bodies of Silver Plume granite locally intrude the quartz monzonite. The largest mass of quartz monzonite gneiss is located at Paines Mountain.

The relationship of this quartz monzonite geniss to the Early Proterozoic Boulder Creek granodiorite to the north (Peterman and others, 1968; Bryant and Hedge, 1978), and the Middle Proterozoic granodiorite of the Mount Evans batholith to the east (Aleinikoff and others, 1993) is unclear. Lovering and Goddard (1950) proposed that the quartz monzonite geniss on Paines Mountain was sheared and deformed in response to the ensuing intrusion of the granodioritic batholith to the east. However, at the time of their publication the granodiorites of Boulder Creek and Mount Evans were considered to be of the same age and genesis, which would suggest their implication to be that the quartz monzonite is early Proterozoic in age. Since subsequent age determinations have established that the granodiorite of Mount Evans is younger than the Boulder Creek Granodiorite (Aleinikoff and others, 1993), and assuming an association between the quartz monzonite gneiss of Paines Mountain and the Mount Evans batholith, it could be postulated that the quartz monzonite gneiss is middle Proterozoic in age. Because of the uncertainties in the relationship between the quartz monzonite gneiss and the granodiorites of Boulder Creek and Mount Evans, and until age determinations for the quartz monzonite gneiss of Paines Mountain are available, the age of the quartz monzonite gneiss can only be constrained to the Early or Middle Proterozoic.

This unit is a potential source of good quality aggregate and rip-rap. Where biotite content is unusually high, an associated increase in schistosity may degrade the quality of the aggregate.

YXp

Pegmatite, aplite, and related rocks (Middle and Early Proterozoic)— Includes pegmatite, granite pegmatite, and aplite, all of which are composed of feldspar and quartz and accessory biotite, muscovite, magnetite, and hornblende. Pegmatite dikes consist of light-pink orthoclase or microcline and slightly smoky quartz with and small amounts of mica. Granite pegmatite has a similar composition but has greater amounts of mica and magnetite. Biotite is more abundant than muscovite, and the two mica types usually occur in different pegmatite bodies, although they locally occur together within the same body. Aplite dikes and veinlets are light-pink and have a fine-grained sugary texture formed by quartz and feldspar crystals.

Xbc

Boulder Creek Granodiorite (Early Proterozoic)— Medium- to coarse-grained granodiorite composed of plagioclase, microcline, quartz, biotite, and accessory hornblende and sphene. Locally, numerous elongate or rounded, pinkish potassium feldspar crystals up to about 2 inches long are weakly aligned along with biotite. The granodiorite outcrops only at the north edge of the quadrangle, in the area north of Empire Pass. Within the Georgetown quadrangle, the Boulder Creek Granodiorite differs from the granodiorite of the Mount Evans batholith in its slightly more pinkish color, weaker foliation, and tendency towards larger feldspar crystals.

The Boulder Creek Granodiorite was initially termed "Boulder Creek granite gneiss" by Boos and Boos (1934), and later, "Boulder Creek Granite" by Lovering and Goddard (1938; 1950). Gable (1980) described it as granodiorite after a more detailed investigation of the batholith. Rb-Sr age determinations of several samples collected from the batholith indicate it was emplaced 1,665 ± 40 Ma (Peterman and others, 1968).

This unit is a potential source of good quality aggregate and rip-rap.

PROTEROZOIC METAMORPHIC ROCKS— Historically, these rocks have been collectively referred to as the Idaho Springs Formation (Ball, 1906), but this name was dropped decades ago because the stratigraphic sequence of the rocks remains uncertain. In his classification of the Precambrian rock units of Colorado, Tweto (1987) referred to these rocks simply as "Proterozoic layered rocks" or the "Proterozoic gneiss complex." Metavolcanic rocks in northern Colorado and Wyoming that are lithologically similar to those in Georgetown have U-Pb zicron ages ranging from 1,780 to 1,800 Ma (Premo and Fanning, 1997) and were metamorphosed about 1,726 ± 15 Ma (U-Pb zircon age, Selverstone and others, 1997).

Xm

Migmatite (Early Proterozoic)— Rocks that have been heavily intruded by granitic material and/or have been intensely deformed and heated to the point of partial melting. Most commonly, migmatite is a chaotic jumble of large, discontinuous layers, pods, or dikes of various rock types in a granitic matrix. The unit is most prevalent in the northeastern part of the quadrangle and is typically the result of Silver Plume Granite having intruded into Proterozoic metamorphic rocks around 1,420 Ma (Peterman and others, 1968). Locally, the rocks have a classic "swirled" look due to segregation and intrusion of thin layers of partially melted schist and gneiss. Hedge (1969) suggested this type of migmatite may have developed as early as 1,700 to 1,750 Ma.

This unit is a very good source of riprap and crushed aggregate.

Xf **Felsic gneiss (Early Proterozoic)—** Fine- to medium-grained, white to light-gray or tan, moderately well-foliated microcline-quartz-plagioclase-biotite gneiss. It is almost entirely white to light-gray or dark-gray where containing little biotite; tan where plagioclase and biotite are more equal in abundance; or white and dark-gray banded where composed of alternating biotite-rich and biotite-poor layers that are typically less than 0.25 in. thick. Magnetite, hornblende, and/or garnet are locally present, and chlorite, which results from alteration of biotite, locally creates light-green streaks parallel to the foliation defined by alignment of biotite crystals. Where weakly foliated and tan in color, this rock unit is similar in appearance to biotite-muscovite granite and quartz monzonite (Ygd). Discontinuous layers of biotite gneiss, amphibolite, and calc-silicate gneiss are locally common within unit Xf, but they are usually less than about 2 ft thick.

Felsic gneiss was first thought to have a magmatic origin. S.H. Ball, in Spurr and others (1908), suggested that this unit, which he called gneissoid granite, evolved from a granitic magma as irregular stock-like bodies and was subsequently "mashed" during regional metamorphism. Later, Sims and Gable (1967) postulated that the gneiss, which they called microcline gneiss, was metasedimentary and originated as an arkosic sandstone. Having evaluated other bodies of felsic gneiss throughout Colorado, Tweto (1987) stated that evidence strongly suggests the most plausible protoliths are rhyodacitic and quartz-latitic tuffs.

Felsic gneiss is a very good source of riprap and crushed aggregate.

Xh **Hornblende gneiss and amphibolite (Early Proterozoic)—** Medium- to dark-gray, fine-grained hornblende gneiss and dark-green to black, fine- to medium-grained amphibolite. Hornblende gneiss consists of hornblende and plagioclase with lesser amounts of quartz, biotite, and pyroxene. The unit is massive or well-banded with alternating thin, white layers of quartz and feldspar. Hornblende gneiss commonly grades to or is interlayered with felsic gneiss (Xf) and, less commonly, with calc-silicate gneiss (Xc). Amphibolite tends to be massive, has a higher hornblende to plagioclase ratio than hornblende gneiss, and has almost no quartz, biotite, or pyroxene. The protoliths of these rocks are probably mafic volcanic flows, sills, or tuffs, but some of the amphibolite bodies may be intrusive (Spurr and others, 1908; Sheridan and Marsh, 1976; Tweto, 1987).

Hornblende gneiss and amphibolite are potentially a minor source of riprap and aggregate.

Xc **Calc-silicate gneiss (Early Proterozoic)—** Fine- to medium-grained, dark-gray to light-green gneiss consisting of alternating light-colored layers rich in quartz and feldspar and darker colored layers rich in hornblende and diopside. Epidote, magnetite, and garnet are also common constituents. Calc-silicate gneiss usually forms layers less than about ten inches thick but is locally several tens of feet thick in exposures at Democrat Mountain and near Empire Pass. Calc-silicate rocks are believed to be metamorphosed impure limestone and calcareous sandstone (Spurr and others, 1908). Calc-silicate gneiss is commonly associated with hornblende gneiss and amphibole (Xh) and felsic gneiss (Xf).

Xfh **Interlayered felsic and hornblende gneiss (Early Proterozoic)—** Felsic gneiss (Xf) interlayered with hornblende gneiss (Xf). These two units commonly occur together; hornblende gneiss with minor felsic layering tends to grade to felsic gneiss with minor hornblende layering. Thickness of individual layers is commonly only a few feet but locally may exceed several tens of feet.

Xfhi **Interlayered felsic, hornblende, biotite, and calc-silicate gneiss (Early Proterozoic)—** Felsic gneiss interlayered with hornblende gneiss, biotite gneiss, and sparse layers or pods of calc-silicate gneiss. Felsic and biotite gneiss layers range from a few inches to several tens of feet thick, whereas hornblende and calc-silicate gneiss layers are usually less than about 18 in. thick.

Xb **Biotite gneiss (Early Proterozoic)—** Fine-grained, light- to medium-gray gneiss composed primarily of biotite, quartz, and plagioclase, and accessory magnetite, sillimanite, garnet, and/or cordierite. The rock commonly weathers to a rusty brown color. Its texture is often equigranular, which gives it a "salt and pepper" appearance in outcrop, although in places it is schistose. Foliation is generally parallel to lithologic layering. Discontinuous layers of amphibolite and felsic gneiss are common but tend to be less than about 2 ft thick. The protolith of the bioite gneiss probably is sandy shale or graywacke (Sheridan and Marsh, 1976).

This unit is a potential source of good-quality riprap and crushed aggregate, especially where it is equigranular and not schistose.

Xsb

Sillimanitic biotite gneiss (Early Proterozoic)— Medium- to dark-gray, well-foliated gneiss consisting primarily of biotite, sillimanite, quartz, and locally, garnet. Microcline, muscovite, tourmaline, and cordierite are lesser constituents. Sillimanite is easily recognizable either as cloudy white rods and bundles or small, flattened pods elongate parallel to foliation. The pods of sillimanite are slightly more resistant to weathering than the surrounding biotite and form knobby surfaces on outcrops. At some localities sillimanite pods are notably larger (up to 4 in. by 8 in.). These areas are indicated on the geologic map with a special pattern. Areas of sillimanitic biotite gneiss containing megascopic garnet that ranges from to less than 0.1 in. up to about 1 in. in diameter are also indicated on the geologic map with a special pattern.

The high concentration of sillimanite indicates that the protolith of this rock is alumina-rich mud or shale (Sheridan and Marsh, 1976). It is a potential source of riprap and crushed aggregate.

GEOLOGIC HAZARDS

Given the strong development pressures affecting much of Colorado it has become increasingly difficult to avoid conflicts between development and geologic hazards. Unfortunately, the steep topography in the Georgetown quadrangle is particularly susceptible to geologic hazards. Many residential areas in Georgetown and Silver Plume are developed in rockfall, debris-flow, and avalanche hazard areas. It is important that county planners and home owners understand the inherent risk involved in developing and living in areas subject to adverse geologic conditions and to minimize those risks. The most prevalent hazards in the Georgetown quadrangle are rockfall, landsliding, and debris flow. Snow avalanche hazards are less common but no less significant. For general information on geologic hazards and possible mitigation techniques refer to Rogers and others (1974).

The 3rd and 6th highest rated rockfall areas in the state are located along I-70 just east of Silver Plume (Andrew, 1994). Rockfall is most prevalent below cliffs or on very steep slopes in moderately jointed or foliated bedrock and is generally the result of exposure to repeated freeze-thaw cycles. Rockfall may also occur in more competent bedrock where steep cliffs are undercut by erosion of less resistant underlying material or where fractured by excavation or blasting. Local herds of bighorn sheep and mountain goats frequently graze along the north and west sides of I-70 between Georgetown and Silver Plume and often start small rockfalls as they scale the steep slopes. Vibrations from heavy vehicular traffic along I-70 may over time loosen or dislodge rock fragments.

Most of the rock types in the Georgetown quadrangle are prone to rockfall. Where metasedimentary rocks are particularly schistose or contain high percentages of biotite, rockfall is less severe, as this rock type is the least resistant to weathering and therefore less likely to be cliff-forming. Foliation and jointing also play a significant role in the development of rockfall hazards. Rockfall is more pronounced where foliation and joints dip toward valley walls and road cuts. Rockfall hazards are greatest along the steep-sided valley walls of glaciated drainages such as Clear Creek and South Clear Creek where slopes exceed 70 percent (approximately 30° or more). Where foliation and joints dip away from steep valley walls or road cuts, rockfall is less severe and slopes tend to be more stable. Areas prone to rockfall hazards can be identified on the basis of the presence of existing rockfall debris, rockfall tracks, freshly exposed faces in cliffs, and disturbed vegetation. Inherent risks in rockfall areas include loss of life and damage to structures, roads, and utilities.

There are several major landslide complexes in the Georgetown quadrangle. Many of these landslides probably originated shortly after glacial ice retreated more than 12,000 years ago. Over-steepened valley walls carved by glaciers were left without the support of the thick ice and subsequently began to fail. Steeply dipping foliation in the bedrock strongly coincides with many of the landslide complexes, thus promoting continued slope failure. Landslide areas may be subject to future movement triggered by heavy precipitation events or excavation into these deposits, thus causing significant hazards to residences, roads, septic systems, utilities, and other improvements. Rockfall hazards are coincident with most landslide areas.

Sackungen are linear features or graben-like structures occurring on mountain ridges and indicate deep-seated rock creep, ridge-spreading movements, and slope failure. In the Georgetown quadrangle several such lineaments are on Republican Mountain, Pendleton Mountain, the Sugarloaf Peak ridge, and the ridge-line east of Hells Hole. These features generally parallel ridge crest lines and have probably developed in response to gradual gravitational movement of rock masses into adjacent valleys after glacial ice retreated, leaving over-steepened valley walls without the support of the thick ice. Foliation of the bedrock in these areas is roughly parallel to and dips steeply toward (generally greater than 65°) adjacent valleys, which enhances sackungen development. Many of these features have a close spatial relationship to major landslide complexes along South Clear Creek, Clear Creek, and Bard Creek. These landslides may have resulted from sackungen features that failed completely, suggesting the potential for continued or future landslide activity wherever these features occur.

Sackungen and other linear features may be in a state of quasi-equilibrium but natural processes such as freeze-thaw cycles and heavy precipitation events may accelerate ridge spreading and trigger large-scale landsliding. Similarly, disturbance of valley walls adjacent to these features by human activities such as road construction, placement of fills, cutting of slopes, irrigation, and installation of septic systems may cause serious slope failure.

The Georgetown–Silver Plume area has a long history of debris-flow events. The worst recorded event occurred in 1899 when Brownville, a small settlement west of Silver Plume, was completely destroyed by a major debris flow carrying rock, mine tailings, and mud (Silver Plume Historical Society). As recently as 1999 a large debris flow buried parts of I-70 about 4 mi. west of Silver Plume, and many smaller flows affected portions of the highway within the quadrangle. Today, many homes in Georgetown and Silver Plume are built on debris fans formed by multiple debris-flow events. Fans on the north and west sides of I-70 have tended to be more active during recent time. Although fans on the south and east sides of I-70 have not experienced significant deposition for the past several hundred years (Coe and others, 1998), extraordinary precipitation events could certainly trigger renewed, large-scale debris-flow activity.

Debris flows can be very destructive and life-threatening. Large boulders in debris flows can cause severe damage on impact, and shear and lift forces are capable of pulling poorly anchored structures from their foundations. Both cosmetic and structural damage can result from debris-flow inundation of homes, particularly those with below-grade levels.

The I-70 corridor from Georgetown to Silver Plume has a history of fatalities, injuries, and damaged structures caused by snow avalanches. Martinelli and Leaf (1999) mapped numerous avalanche paths in the Georgetown quadrangle, the greatest density of which occur in the Silver Plume area. One of the most disastrous events occurred in 1899 when an avalanche released from Williham and Cherokee Gulches swept through the town of Silver Plume and killed ten miners (Martinelli and Leaf, 1999). Although avalanches were more frequent during the mid-1800s to the early 1900s when mining activities had denuded the local hill slopes, avalanche potential remains significant, especially north and south of Silver Plume.

During an avalanche, large slabs of snow or turbulent masses of loose snow and debris are released from the accumulation or starting zone and travel downslope with high velocities. The greater the mass of snow and velocity, the greater the risk of damage to life, structures, and roads. Avalanches typically begin on slopes ranging between 30° and 50° (70 to over 100 percent) but will often run out onto much flatter slopes (Mears, 1992). In general, north- and east facing slopes are more susceptible to snow failure than south- or west-facing slopes due to colder snow conditions and greater snow accumulations caused by strong westerly winds. Careful consideration should be given to all areas beneath steep slopes and drainages where large accumulations of snow may occur.

STRUCTURAL GEOLOGY

The Georgetown–Silver Plume mining district is located within the Colorado Mineral Belt between two northeast-trending Precambrian shear zones: the Montezuma shear zone (MSZ) to the southwest and the Idaho Springs-Ralston shear zone (ISRSZ) to the northeast (Figure 1). The MSZ is believed to extend to Silver Plume and possibly as far northeast as Saxon Mountain east of Georgetown (Bookstrom, 1993). The ISRSZ may extend as far southwest as Ute and Cascade Creeks east of Saxon Mountain. Evidence indicates a long history of both sinistral and dextral motion along the ISRSZ (Graubard and Mattinson, 1990), although deformation was probably most intense during regional peak metamorphism 1,726 ± 15 Ma (Selverstone and others, 1997). It is likely that the MSZ experienced a similar history of deformation.

This Early Proterozoic period of deformation is also characterized by deep-seated, ductile deformation, which formed large-scale, steeply-plunging folds in rocks of the Proterozoic metamorphic complex. The best example of this type of fold is exposed in a cliff exposure east of and far above Green Lake, where hornblende gneiss and garnet-bearing sillimanitic biotite gneiss are tightly folded around a fold axis plunging 65° to the southwest (Figure 2). Similar folds are suggested by alternating foliation patterns on Sugarloaf Peak. The occurrence of garnet at these localities tends to coincide with fold cores and is in close association with hornblende gneiss.

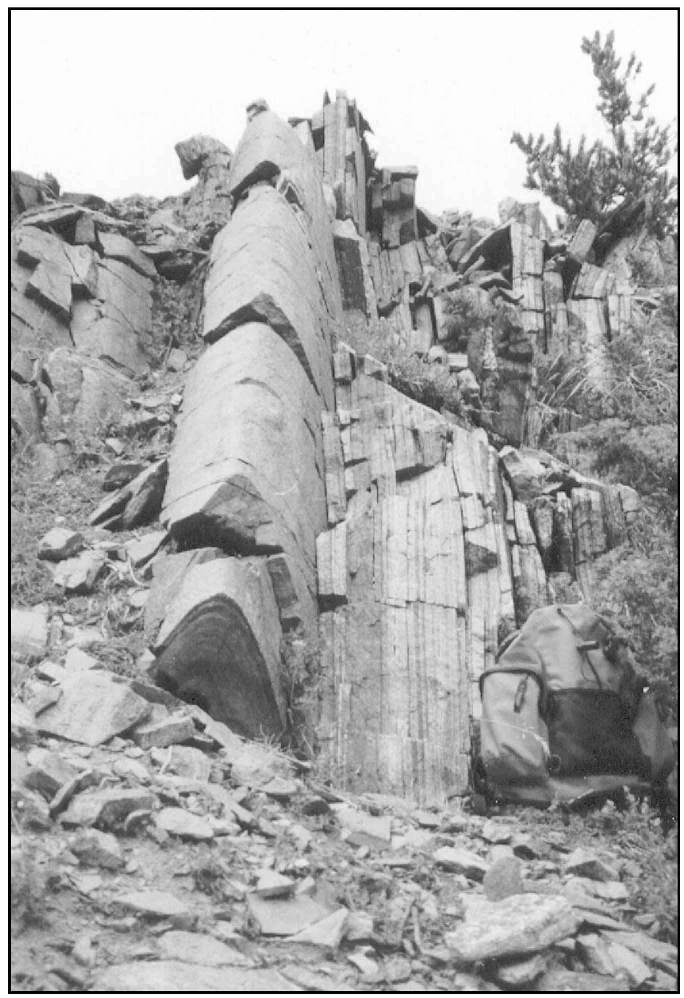


Figure 2. Sympathetic fold on the northwest limb of the major fold structure in the cliff exposure above Green Lake.

By Middle Proterozoic time, the regional deformation style was less ductile and produced major zones of cataclasis rather than large-scale folding. Several major Precambrian faults cut across the Georgetown quadrangle. Two major faults trend north-northeast: the Leavenworth Fault (named herein), which may connect to a similarly oriented fault near Empire Pass, and a buried fault beneath South Clear Creek. History of movement on these two faults is unclear. However, near Paines Mountain, the mass of rock bounded by the Leavenworth Fault on the west, by the fault beneath South Clear Creek on the east, by an inferred, concealed east-west-trending fault to the north (along the southern edge of sec. 17, T. 4 S., R. 74 W.), and by a northwest-trending fault off the quadrangle to the south (Bryant and others, 1981), may represent an uplifted block of older, sheared and deformed quartz monzonite gneiss that may be genetically related to the granodiorite of the Mount Evans batholith (Lovering and Goddard, 1950). A shorter fault near Empire Pass is inferred on the basis of north-northeast and northwest oriented conjugate fractures in the Silver Plume Granite south of the pass.

Other major faults in the area generally trend northwest to east-west. The best exposed of these faults is the Silver Gulch Fault (Figure 3). An exploration pit on Democrat Mountain reveals a steeply dipping fault oriented N55°W with a dip of 75°SW. The fault is well defined by a zone of fault gouge ranging from several inches to about 2.5 ft wide. Silver Plume Granite is highly fractured throughout a zone at least 14 in. wide on the south side of the gouge. To the north, sillimanitic biotite gneiss is intensely deformed and intruded by pegmatite and granite. Evidence of possible renewed fault activity during the Cenozoic is present at the Sceptre Tunnel in Silver Gulch, where an Oligocene-Eocene dike (Ta) is intruded into the fault zone. Fragments of breccia including Silver Plume Granite, sillimanitic biotite gneiss, and Oligocene-Eocene alaskite porphyry are abundant in the mine waste pile, indicating either post-intrusion fault movement or cataclasis associated with intrusion of the dike. Similar breccia fragments are found in several of the mine dumps in the Silver Plume area.

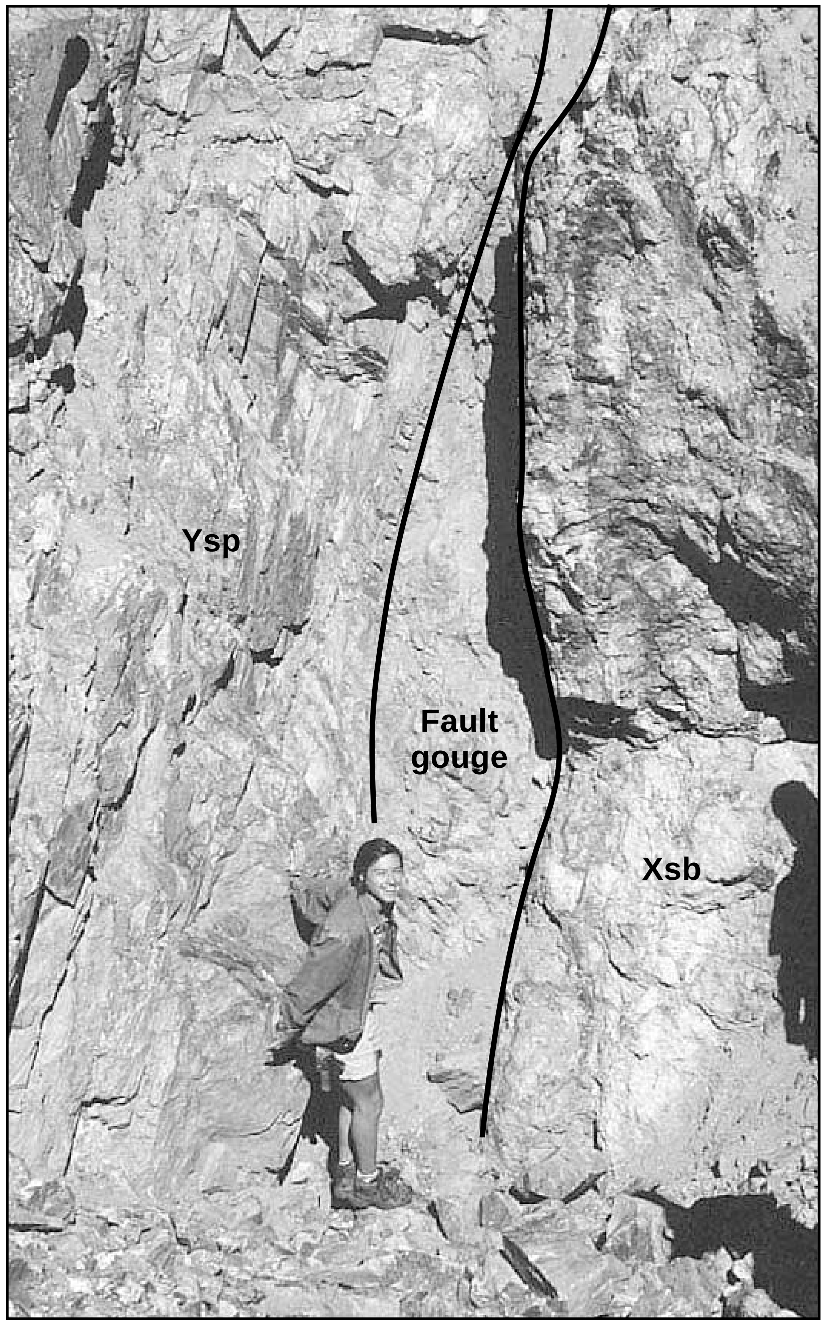


Figure 3. The Silver Gulch Fault on Democrat Mountain. Fractured Silver Plume Granite on the left side of the fault gouge, and intensely deformed sillimanitic biotite gneiss on the right side.

Evidence of Cenozoic movement on the Kennedy Gulch Fault Zone is debatable. Scott (1975) reported about 300 m of post-late Eocene displacement at the eastern end of the faults (more than 20 mi. east of the Georgetown quadrangle), on the basis of offset of Tertiary gravels. Harza Engineering Company (1985) evaluated the Tertiary gravels described by Scott (1975), and found no apparent displacement of those gravels. They also examined and logged four trenches, three roadcut exposures, and three boreholes as part of their investigation of the fault. Although multiple fractures in the Precambrian rock were observed in the exposures, they concluded that these features were the result of stressing and hydrothermal alteration associated with emplacement of large granitic plutons, such as the Pikes Peak batholith, rather than shearing associated with a major fault. In the Georgetown quadrangle there is no evidence of post- Precambrian movement on the fault.

Throughout the Colorado Mineral Belt numerous porphyry bodies intrude Proterozoic basement rocks. The Georgetown quadrangle lies between two centers of porphyry intrusion. The Upper Cretaceous Empire stock north of the Georgetown quadrangle was intruded between about 61 to 68 Ma (sphene and biotite fission-track ages; Cunningham and others, 1994). Many of the northeast-trending bostonite dikes within the Idaho Springs-Ralston Shear Zone (ISRSZ) in the Idaho Springs quadrangle east of Georgetown are associated with the Empire stock. Renewed igneous activity in the Empire district is evidenced by the Mad Creek explosion breccia that was intruded 40.5 ± 6.5 Ma (zircon fission-track age; Bookstrom and others, 1987) and the Red Mountain intrusive center, which was emplaced 29.9 ± 0.3 Ma (^{40}Ar/^{39}Ar age; Geissman and others, 1992).

The Montezuma stock, located several miles to the southwest of the Georgetown quadrangle, was emplaced 39.8 ± 4.2 Ma (zircon fission-track age; Bookstrom and others, 1987). This stock is bordered on the south by the northeast-trending Montezuma Shear Zone (MSZ), which is host to a swarm of dikes extending as far northeast as Silver Plume. These dikes are considered to have been emplaced ahead of and peripheral to the Montezuma stock (Bookstrom and others, 1987).

The vast majority of the porphyry dikes in the Georgetown–Silver Plume area are probably related to the Montezuma stock. Many of these porphyries occur within the MSZ and are texturally and mineralogically similar to rocks of the Montezuma stock. A porphyry dike near Silver Plume and another dike 3.2 mi. southwest of Silver Plume were determined to be 41.5 ± 4.8 Ma and 42.8 ± 4.2 Ma, respectively (zircon fission-track ages; Bookstrom and others, 1987). Both ages are consistent with the theory put forth by Bookstrom and others (1987) that these dikes and others within the MSZ were precursors to the 39.8 ± 4.2 Ma Montezuma stock.

A lengthy bostonite dike at the head of Ute and Cascade Creeks is texturally and mineralogically similar to rocks of the Empire district and other 61 to 68 Ma-old bostonite dikes within the ISRSZ. This dike is on strike with the ISRSZ and may represent the southwestern limit of the shear zone within the Georgetown quadrangle.

Two larger porphyry bodies outcrop at the south end of the quadrangle. The alaskite stock on the west flank of Paines Mountain was intruded 37.0 ± 4 Ma, and the granite porphyry stock northeast of Otter Mountain was intruded 36.6 ± 4.2 Ma (zircon fission-track ages; Bookstrom and others, 1987). No age data are available for the large porphyry stock at the north end of the quadrangle.

Porphyry dikes in the Georgetown quadrangle are oriented generally N70°W or N70°E, except for the dike at Silver Gulch, which trends east-west. Furthermore, the dikes tend to roughly parallel local fault systems since the deep-seated fractures provided conduits for pressurized magma sources at depth. Similarly, hydrothermal fluids followed these same channels, precipitating ore deposits in fracture openings as they ascended and cooled. The orientation of silver-bearing veins in Silver Plume and in the area north of Silver Gulch generally correspond to that of the Oligocene-Eocene intrusives. Later stage gold-bearing veins east of Georgetown are oriented about N50°E (Lovering and Goddard, 1950).

ORE DEPOSITS AND ALTERATION PRODUCTS

There are two significant vein systems in the Georgetown–Silver Plume mining district: silver-lead-zinc veins and gold veins. Veins of the silver-lead-zinc system are most commonly oriented N70°E or N70°W and predominate in the Silver Plume area and in the Republican Mountain belt north of Georgetown. Spurr and others (1908) theorized that the fissures of the N70°W-trending system were formed first, and the fissures of the N70°E-trending system developed syntectonically or shortly thereafter. Gold-bearing veins trend N50°E and are generally restricted to the Georgetown area between Leavenworth Mountain and Saxon Mountain. Silver and gold zones shown in Figure 4 are based on field observations and thin-section analysis and on descriptions of lodes by Spurr and others (1908) and Lovering and Goddard (1950). Only a few mines in the district contain both vein types (Griffith, Centennial, and Central Colorado), and at these locations gold-bearing veins cut silver-bearing veins, indicating the gold-bearing veins are younger.

More than 100 samples were collected in and across multiple vein systems in an attempt to fully characterize the mineral assemblages and alteration products of the Georgetown-Silver Plume district. All of the samples were examined macroscopically. Thin sections were made of more than 50 samples, and 12 samples were prepared for x-ray diffraction analysis (XRD). Two samples were chosen for $^{39}Ar/^{40}Ar$ age determinations. Mineralogy and alteration characteristics of several representative samples are presented in Table 1. For a more detailed discussion of all of these samples the reader is referred to Miersemann (in preparation). A preliminary overview of the data is presented below.

Ore minerals are found in quartz veins, hydrothermal breccias, and locally in the groundmass of Tertiary porphyry intrusions and, to a lesser extent, Precambrian granites and gneisses. Mineralized veins are typically characterized by elongate to sub-rounded quartz grains along vein margins. Sulfide minerals and, locally, carbonate minerals occur in the central part of the vein. Subsequent openings along quartz veins are filled with black quartz, which is microcrystalline quartz probably containing very fine-grained pyrite. Hydrothermal breccia consists primarily of angular host rock fragments cemented by sulfides and later-stage black quartz. Massive sulfide veins containing anhedral grains of sphalerite or pyrite are less commonly observed than quartz veins.

Silver-lead-zinc veins of the Georgetown–Silver Plume district are characterized by the presence of galena, yellow-green to dark-gray sphalerite with minor pyrite, chalcopyrite, and polybasite. Galena and, to a lesser extent, sphalerite are argentiferous (Spurr and others, 1908) and occur as separate grains within quartz veins or associated with chalcopyrite and tetrahedrite or tennantite. Minor polybasite, argentite, argentiferous tetrahedrite, pyrargyrite, proustite, and native silver may also be present (Spurr and others, 1908).

The gold veins of the district contain pyrite, chalcopyrite, and lesser amounts of galena. Gangue minerals are black quartz, carbonate (typically calcite, dolomite and siderite), and fluorite. Veins that have a high galena content usually contain the largest gold and silver concentrations. Gold occurs as free grains associated with pyrite (Lovering and Goddard, 1950).

Alteration products were determined petrographically, by XRD, and by carbonate staining. Many of the mineralized or hydrothermally altered rocks show an intense replacement of plagioclase, biotite, and a lesser replacement of microcline, hornblende, and muscovite. The replacing material is an intimate mixture of illite, muscovite, kaolinite, quartz, carbonate, pyrite, and dickite, listed in order of abundance. Spurr and others (1908), Lovering and Goddard (1950), Bonorino (1959), and Grybeck (1969), all noted a similar assemblage of alteration products within the district and throughout the Colorado Mineral Belt.

The paragenetic sequence of replacement in the Georgetown–Silver Plume area generally begins with muscovite and progresses to carbonate, illite, the kaolinite minerals (kaolinite, dickite, halloysite), and lastly, quartz, with each mineral having replaced any one of the preceding alter-

Table 1. Ore minerals and alteration products of several selected rock samples collected from the Georgetown–Silver Plume district. [Kaolinite group may include kaolinite, dickite, or halloysite. Carbonate alteration products may include Fe-dolomite, Fe-calcite, calcite, siderite, or magnesite. Abbreviations are as follows: alaskite porphyry (Ta), Silver Plume Granite (Ysp), biotite gneiss (Xb), chalcopyrite (cpy), galena (gn), hematite (hm), magnetite (mgt), pyrrhotite (po), pyrite (py), sphalerite (sph), tennantite/tetrahedrite (ten/tetr).]

Sample No.	Sample location	Rock type	Metalic minerals	Mineral association	Hydrothermal Alteration*	Microscopy	XRD	Carbonate staining
1	Silver Plume — SW of Zero tunnel	Ta	py, po, hm	occurs in matrix and as phenocryst replacement	Fe-dolomite, quartz, kaolinite	✔		✔
2	Silver Plume — SW of Zero tunnel	Ysp	gn, py, cpy, sph calcite,	quartz veins	kaolinite group, quartz, calcite, Fe-dolomite	✔		✔
3	Silver Plume — Pelican Mine	Ta	gn, sph, py, ten./tetr.,cpy	quartz veins quartz, illite, dickite, kaolinite, carbonate		✔	✔	✔
4	Silver Plume — Diamond tunnel	Ta	py, hm	occurs in matrix and quartz veins	carbonate, illite	✔		✔
5	Silver Plume — Diamond tunnel	Ysp	sph, gn, py, cpy, ten/tetr.		illite, muscovite, quartz	✔		
6	Silver Plume — Ashby tunnel	Ysp	sph, gn, cpy	sphalerite vein	carbonate, quartz, illite, muscovite, dickite	✔	✔	
7	Silver Plume — Ashby tunnel	Xb	py, gn,sph, cpy, ten/tetr	within black quartz and in quartz veins illite,	muscovite, carbonate, quartz	✔		
8	Roadcut along I-70 between Georgetown & Silver Plume	Ysp	py, cpy, tetr/tenn, hm, mgt	occurs in matrix and quartz veins	illite, quartz, kaolinite, dickite	✔	✔	
9	Georgetown — Griffith tunnel	Ysp	sph, gn, py, cpy, ten/tetr.	quartz veins	quartz, illite, muscovite, kaolinite	✔		
10	Woodchuck Peak	Ysp	sph, py, gn, ten/tetr, cpy	occurs in matrix and quartz veins	illite, quartz	✔		
11	Silver Gulch	Ta	py	occurs in matrix and as phenocryst replacement	quartz, illite, muscovite, dickite, kaolinite	✔		
12	Silver Gulch	Ta			quartz, illite, kaolinite group	✔		
13	Silver Gulch fault — Sceptre tunnel	Ta	sph, cpy, ten/tetr, gn, py	within black quartz and in quartz veins	quartz, illite	✔		
14	Silver Gulch fault — Democrat Mtn.	Ysp			quartz, illite, kaolinite, dickite, calcite, Fe-dolomite	✔	✔	
15	Silver Gulch fault — Democrat Mtn.	Xb	hm, po	matrix	muscovite, quartz, illite	✔		

*listed in order of abundance

ation products. Muscovite alteration of biotite tends to occur only in biotite-rich gneisses where abundant biotite is replaced by a mixture of fine-grained muscovite, magnetite, and iron oxides such as hematite. Carbonate alteration minerals include Fe-dolomite, Fe-calcite, calcite, and siderite. Illite appears in aggregates of tiny booklets and as elongated crystals arranged approximately parallel to plagioclase twinning. Locally, illite is replaced by hematite due to oxidation. Kaolinite often replaces illite, and where present, two generations can be distinguished. The first generation of kaolinite is a product of hydrothermal alteration (Bonorino, 1959). It appears as white, soft aggregates that have replaced plagioclase, and locally biotite, hornblende, and microcline. The second generation is a product of supergene processes (Bonorino, 1959). It is

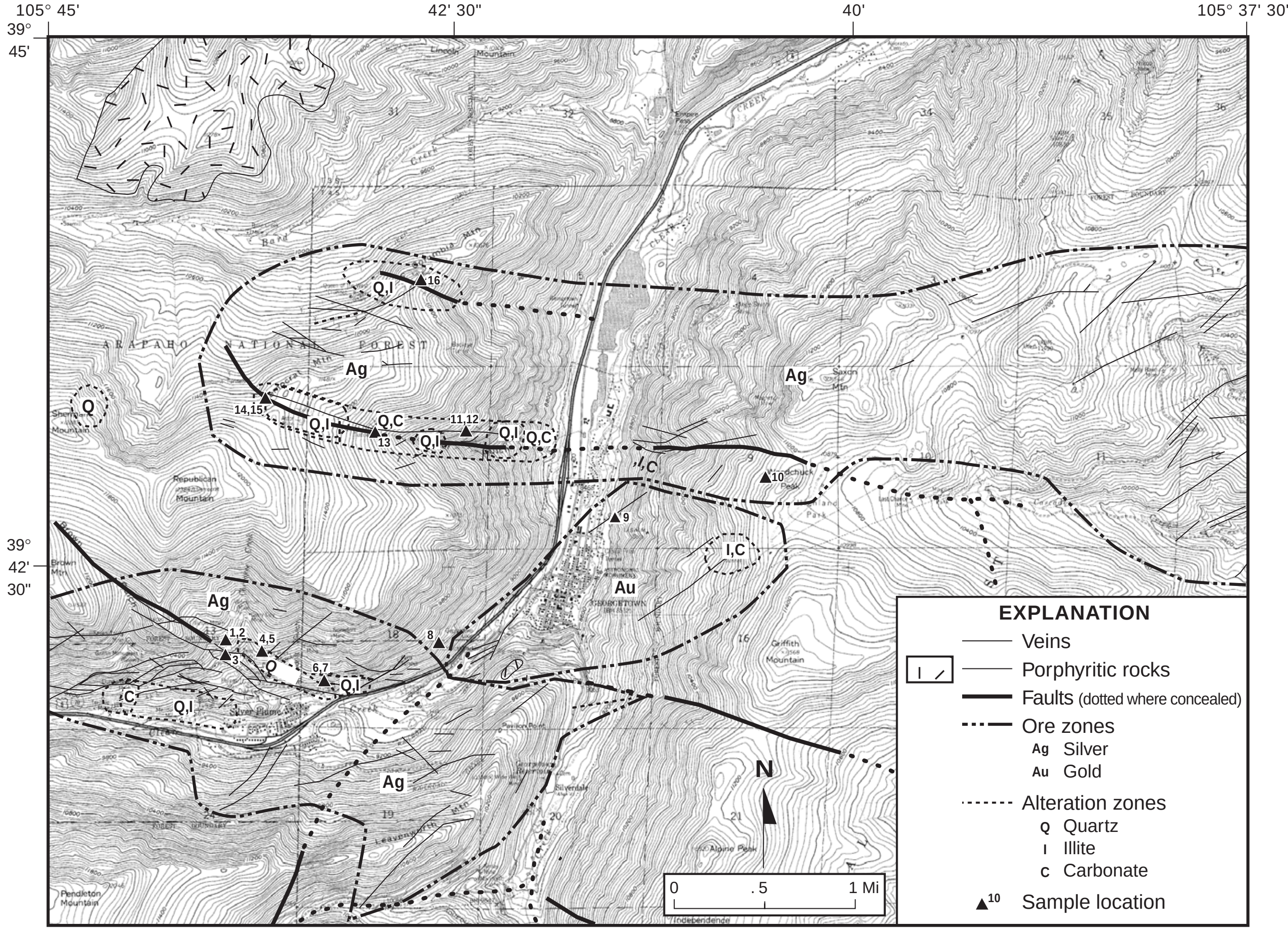


Figure 4. Location map of ore deposit features and selected rock samples collected from the Georgetown-Silver Plume district (see Table 1).

characterized by white, amorphous kaolinite, which was remobilized together with quartz and precipitated in younger fissures. Dickite is distinguishable only through XRD analysis since its appearance in thin section is similar to that of kaolinite. Quartz alteration is characterized by subeuhedral, fine-grained quartz. Secondary pyrite is an alteration product that occurs together with muscovite. Pyrrhotite, magnetite, and illmenite are all primary accessory minerals of the host rock.

Alteration in the Georgetown–Silver Plume district can be roughly outlined as areas of high quartz, illite, or carbonate alteration intensity (Figure 4). High quartz content and lesser amounts of illite, kaolinite, and/or dickite characterize quartz zones. Similarly, illite alteration is characterized by high concentrations of illite with subordinate quartz, kaolinite or dickite, and carbonate. Carbonate alteration is more often observed adjacent to Tertiary porphyries in the Silver Plume area, and may include Fe-dolomite, Fe-calcite, siderite, calcite, and quartz. Alteration is widespread throughout the mining district, but weak alteration haloes can be seen to extend a few inches either side of any given vein. In mineralized zones where multiple veins intersect and branch from one another, weak alteration haloes may extend 6 to 10 ft beyond the mineralized zone. Quartz, illite and muscovite tend to occur closest to the vein. Carbonate alteration minerals are widespread, but are generally more common closer to the vein. Kaolinite, illite, and quartz are typically more prevalent further from the vein.

Two samples of muscovite altered biotite gneiss were collected from the Georgetown–Silver Plume district and submitted to the U.S. Geological Survey for $^{39}Ar/^{40}Ar$ age determination of alteration. One sample was taken from near the Silver

Gulch fault on Democrat Mountain and the other is from a mine dump north of the Burleigh Tunnel in Silver Plume. Alteration of the sample from from Democrat Mountain occurred 68.75 ± 0.11 Ma (plateau age). The age of alteration for the Silver Plume sample ranged from 64.93 ± 0.26 to 65.42 ± 0.16 Ma (plateau ages). These two age determinations suggest alteration in the Georgetown–Silver Plume area occurred prior to the emplacement of the Tertiary porphyries and mineralization.

Only general statements can be made regarding the association between alteration and specific vein types or rock lithology. Illite and carbonate alteration were found associated with both silver and gold veins. Quartz alteration tended to be restricted to silver-bearing zones. Illite and quartz alteration are generally coincident throughout the district, except for Sherman Mountain where there is only silicification, and east of Georgetown where illite alteration coincides with carbonate alteration. Carbonate alteration products are found predominantly along the eastern end of the Brown Gulch Fault and locally along the Silver Gulch Fault. There does not appear to be any significant differentiation in alteration between granite and biotite gniess.

ECONOMIC GEOLOGY

The Georgetown–Silver Plume district has an aerial extent of about 25 sq. mi. and is known primarily for its silver production. Ore bodies in the district have been mined since their discovery in 1859, and have been well described by Lovering and Goddard (1950), Burbank (1947), and Spurr and others (1908). The principal ore metals are silver, lead, zinc, copper, and gold, listed in order of decreasing production (Vanderwilt, 1947). Early mining operations focused on production of gold, but by 1865 silver had also become an important mined commodity, and production quickly surpassed that of gold. The following figures are from Lovering and Goddard (1950).

The largest and most productive mine in the area was the Colorado Central, which had a total output value in excess of $8,000,000 and ore grades of 200 oz per ton for silver and 0.25 oz per ton for gold. Numerous high-grade silver veins comprise the Democrat Mountain group, which boasted silver ore grades on the order of several hundred oz per ton and a total production worth $2,000,000. Silver ore grades for the Dives-Dunkirk veins were as much as 300 oz per ton, and the Pelican-Bismark mine produced more than 200,000 oz of silver from veins averaging 150 oz per ton. Ore was mined from the Griffith tunnel at 40 oz of silver and 0.45 oz of gold per ton.

Mining in the Georgetown–Silver Plume district was most active from 1872 to 1894, but production figures for this period are not well documented. Production from 1907 to 1942 amounted to 3,203,448 oz of silver, 27,616 oz of gold, 324,592 lb of copper, 22,447,925 lb of lead, and 21,511,862 lb of zinc (Lovering and Goddard, 1950). During the period from 1946 to 1958 county-wide production amounted to 927,034 oz of silver, 34,586 oz of gold, 1,336,500 lb of copper, 10,731,100 lb of lead, and 4,451,600 lb of zinc (Del Rio, 1960).

Industrial mineral and construction material resources in the Georgetown quadrangle include sand and gravel, crushed aggregate, riprap, and building stone. Sand and gravel resources are in modern stream channels and Quaternary terrace and moraine deposits primarily along South Clear Creek, Clear Creek, Leavenworth Creek, and Bard Creek. Many of the Proterozoic rocks have potential as good quality crushed aggregate and riprap. The Silver Plume Granite was historically quarried for use as building stone because of its uniform strength and internal friction properties. The granite has an unconfined compressive strength of 22,000 to 33,000 lb per sq in. (psi), and a confined compressive strength of 65,000 psi determined on the basis of a confined pressure of 5,000 psi (Lee and Nichols, 1966).

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