OPEN-FILE REPORT 06-7

Geologic Map of the Fairplay West Quadrangle, Park County, Colorado

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by
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Description of Map Units, Structural Geology, Mineral and Water Resources, and Geologic Hazards

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Bill Ritter, Governor, State of Colorado
Vincent Matthews, State Geologist and Division Director, Colorado Geological Survey
Denver, Colorado
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FOREWORD

The Colorado Geological Survey is pleased to present Open File Report 06-7, *Geologic Map of the Fairplay West Quadrangle, Park County, Colorado*. Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle. Field work for this project was conducted during the summer of 2005.

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. 05HQAG0064, 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.

Vince Matthews
State Geologist and Division Director

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INTRODUCTION

LOCATION AND GENERAL GEOLOGY

The Fairplay West 7.5-minute quadrangle is located in northwestern South Park in central Colorado. In the northern part of the map area, the town of Fairplay straddles the boundary between the Fairplay West quadrangle and the adjacent Fairplay East quadrangle (fig. 1). State Highway 9 traverses the northeastern corner of the Fairplay West quadrangle and U.S. Highway 285 is just east of the quadrangle boundary. Several creeks and tributary streams flow east to southeast across the quadrangle and are part of the South Platte drainage basin. Principal streams in the area include, from north to south, the Middle Fork of the South Platte River, Sacramento Creek, Fourmile Creek, Sheep Creek, Twelvemile Creek, and Cave Creek.

In the eastern part of the quadrangle, topography is fairly subdued and ranges in elevation from about 9,500 to 10,500 feet. The western part of the quadrangle is dominated by a series of peaks and north-northwest-trending ridges that rise abruptly, thus producing a much more rugged terrain. The highest peak in the quadrangle is Sheep Mountain, which is 12,818 feet in elevation. Roughly two-thirds of the Fairplay West quadrangle is within the Pike National Forest, which is administered by the U.S. Forest Service. However, there are numerous privately held lands and historic mining claims within the Forest Service boundary. With the exception of the town of Fairplay, most properties in the eastern third of the quadrangle are privately held ranch lands or are leased sections belonging to the Bureau of Land Management and Colorado State Land Board.

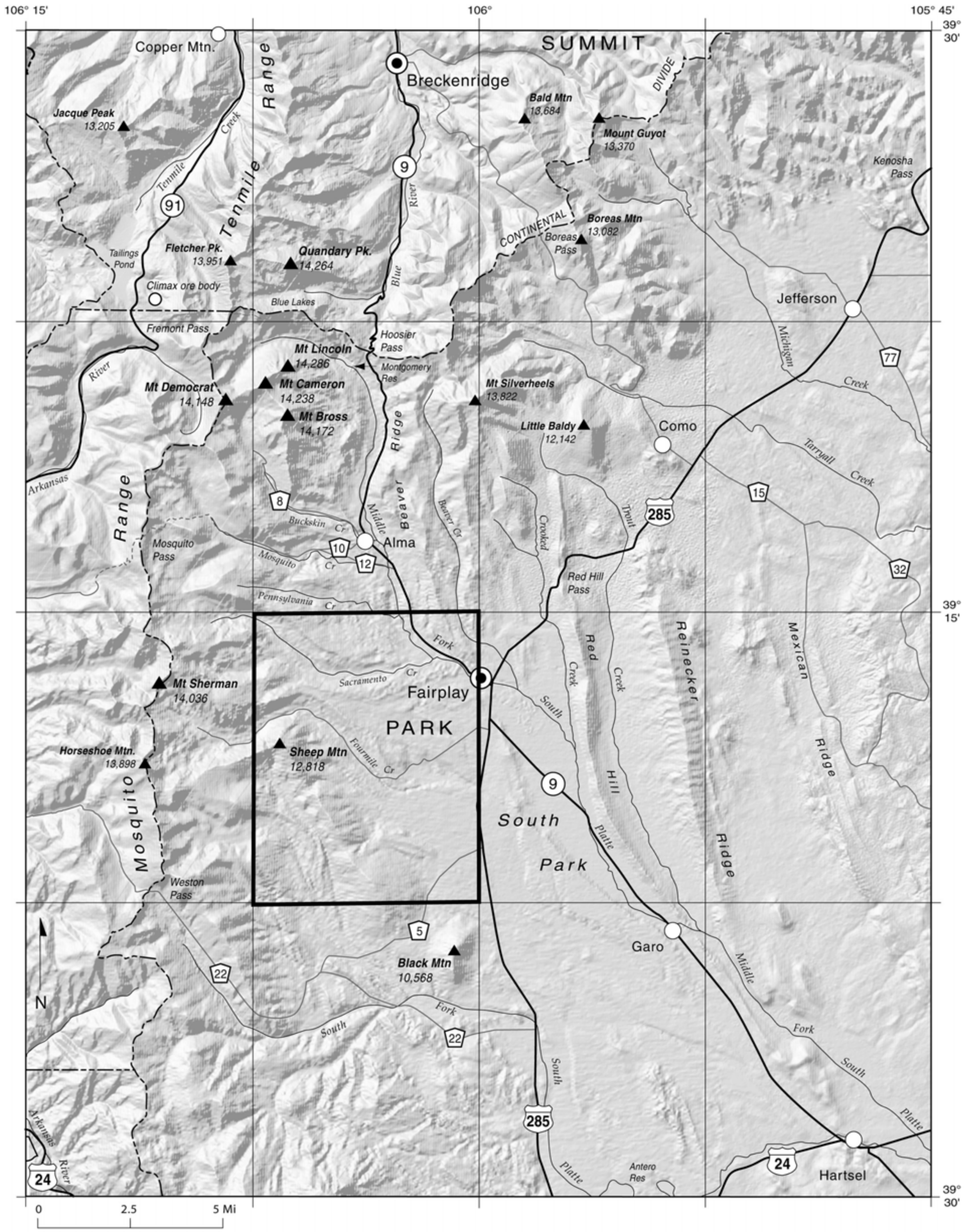

Figure 1. Shaded relief map of the Fairplay region showing outline of project area.

Geologic time divisions used in this report are shown in figure 2. The oldest rocks exposed in the Fairplay West quadrangle are Precambrian in age and consist primarily of biotite gneiss, migmatite and granite. These rocks form the core of the hills and peaks from Sheep Mountain to the northwestern corner of the quadrangle. The overlying series of lower Paleozoic rocks is well exposed in the same area and includes, from oldest to youngest, the Cambrian Sawatch Quartzite and Dotsero Formation, the Cambian-Ordovician Manitou Formation, the Devonian Parting Formation and Dyer Dolomite (both part of the Chaffee Group), the Mississippian Leadville Limestone, and a newly mapped quartzite unit, also presumably Mississippian in age, herein informally referred to as the quartzite of Sheep Mountain. The Pennsylvanian Belden Formation overlies the Leadville Limestone in the southwest corner of the quadrangle. Elsewhere, quartzose sandstones of the Coffman Member of the Pennsylvanian Minturn Formation rest unconformably on the Leadville Limestone or quartzite of Sheep Mountain surfaces.

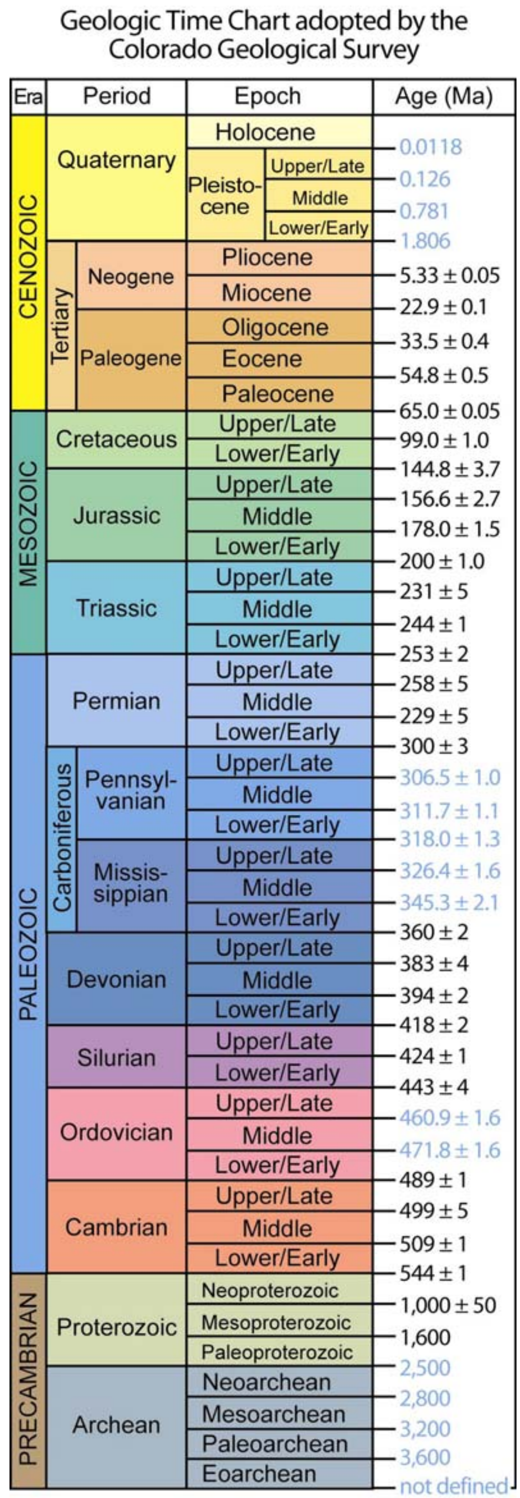

Figure 2. Geologic time chart used for CGS reports. Numerical ages shown in black are from the Geological Survey of Canada (Okulitch, 2002); ages shown in blue are from the International Commission on Stratigraphy (2005).

The Minturn Formation underlies much of the low-relief topography in the eastern part of the quadrangle, but it is typically obscured by surficial deposits. Paleogene igneous rocks are intruded primarily as sills into the Paleozoic rocks in the northwestern quarter of the quadrangle. Quaternary surficial deposits are widespread throughout the quadrangle. Till deposited during the last two major ice ages, and the associated outwash deposited by melt water, blanket much of the quadrangle. Alluvial fan sediments, modern stream alluvium, and mass-wasting deposits, including colluvium, talus deposits, and landslide debris, also are present. Felsenmeer is prevalent on Sheep and Lamb Mountains and in the vicinity of the historic Sacramento mining area to the north, but the felsenmeer is not mapped because it is a type of residuum resulting from in-situ freeze-thaw processes rather than surficial depositional processes.

The dominant structure in the Fairplay West quadrangle is the London fault, a north- to northwest-trending, high-angle reverse fault that cuts the rocks in the western part of the quadrangle. Down-to-the-west displacement across this structure amounts to more than 3,000 feet (Singewald and Butler, 1941). A breached anticline-syncline pair is associated with the London fault. In the footwall on the west side of the fault, rocks of the Coffman Member of the Minturn Formation are folded into a tight syncline. An anticline, which coincides with Sheep Ridge, Sheep Mountain, and the Sacramento mining area, formed in the hanging wall (east side) of the fault. An inferred, post-Oligocene, down-to-the-east normal fault is extended into the east-central part of the Fairplay West quadrangle on the basis of the juxtaposition of west-dipping Tertiary sediments and east-dipping Pennsylvanian rocks in the Fairplay East quadrangle (Kirkham and others, 2006).

SCOPE OF WORK

The present study focuses on geologic mapping of the Fairplay West 7.5-minute quadrangle. Field work for the Fairplay West quadrangle was undertaken during the summer and fall of 2005. The adjacent Fairplay East quadrangle was mapped concurrently (Kirkham and others, 2006). Geology was mapped on U.S. Forest Service color aerial photographs (1:24,000-scale) taken in September 1997. Bedrock mapping was completed by B. Widmann and field assistant N. Lindsay. Quaternary deposits were mapped by R. Kirkham. K. Houck contributed discussions on the Minturn and Maroon Formations. Map unit contacts were transferred from photogrammetric models of annotated aerial photographs to the topographic map of the Fairplay West quadrangle using the ERDAS (Earth Resource Data Analysis System) stereographic program. Bedrock units and surficial deposits that have a maximum thickness of 3 to 5 feet or dimensions of less than about 50 feet were generally not mapped. Some thin bedrock units, such as limestone beds, are represented on the map as single lines because they add to the stratigraphic and structural understanding of the geology in the area. The cultural features of the topographic base map were revised in 1994. Thus, roads, reservoirs, and buildings constructed after 1994 are not on the map base, nor are human-made deposits that postdate the 1997 aerial photography.

PREVIOUS STUDIES

The South Park region was part of the central Colorado trough during Pennsylvanian-Permian time. The region has been discussed in various papers focusing on the geology of the trough (e.g. Brill, 1952; DeVoto, 1965, 1980; Hoy and Ridgway, 2002). The geology and origin of South Park was outlined by Stark and others (1949) and DeVoto (1961, 1971, 1972). The area was studied in the 1960s and 1970s for oil and gas exploration, the chronicles of which are outlined by Clement and Dolton (1970). Bryant and others (1981) focused primarily on the Tertiary intrusive rocks and obtained numerous potassium-argon and fission-track ages that helped constrain the timing of events in the South Park-Breckenridge areas. Students from the Colorado School of Mines also conducted numerous geophysical and geological studies of the basin (Beggs, 1977; Durrani, 1980; Fatti, 1974; Shoffner, 1974). A recent book by McGookey (2002) provides a good overview of the geology in South Park, complete with road logs. Raynolds (2003) examined sediments of the Tertiary South Park Formation in a study that correlated these deposits with time-equivalent deposits in the Denver basin. The London fault has been studied in detail by Singewald and Butler (1941).

Several geologic maps of the area surrounding the Fairplay West quadrangle have been published by the Colorado Geological Survey or U.S. Geological Survey (fig. 3). The Fairplay West quadrangle is on the eastern edge of the Leadville 1° x 2° geologic map, which was mapped by Tweto and others (1978). The Mount Lincoln 15-minute quadrangle, just north of the Fairplay West quadrangle, was mapped by Tweto (1974a). In the same year, Tweto also produced a similarly scaled reconnaissance map of the area to the south (Tweto, 1974b); the Fairplay West quadrangle is in the northeast corner of this map area. Numerous 7.5-minute quadrangles that have been mapped in the area are shown in figure 3.

The Fairplay region encompasses several historic mining districts that have been the focus of intense study, particularly in the early 1900s. The Alma-Horseshoe mining district, also known in part as the London mining district, extends 10 to 15 miles northward from Sheep Mountain. The geology and mineralization characteristics of this district were described by Patton and others (1912), Singewald and Butler (1941), Johansing and others (1985), Berry (1990), and Barbá (2004). Emmons and others (1927) and Behre (1953) provided detailed accounts of the geology and mineralization in the Mosquito Range and in the neighboring Leadville mining district.

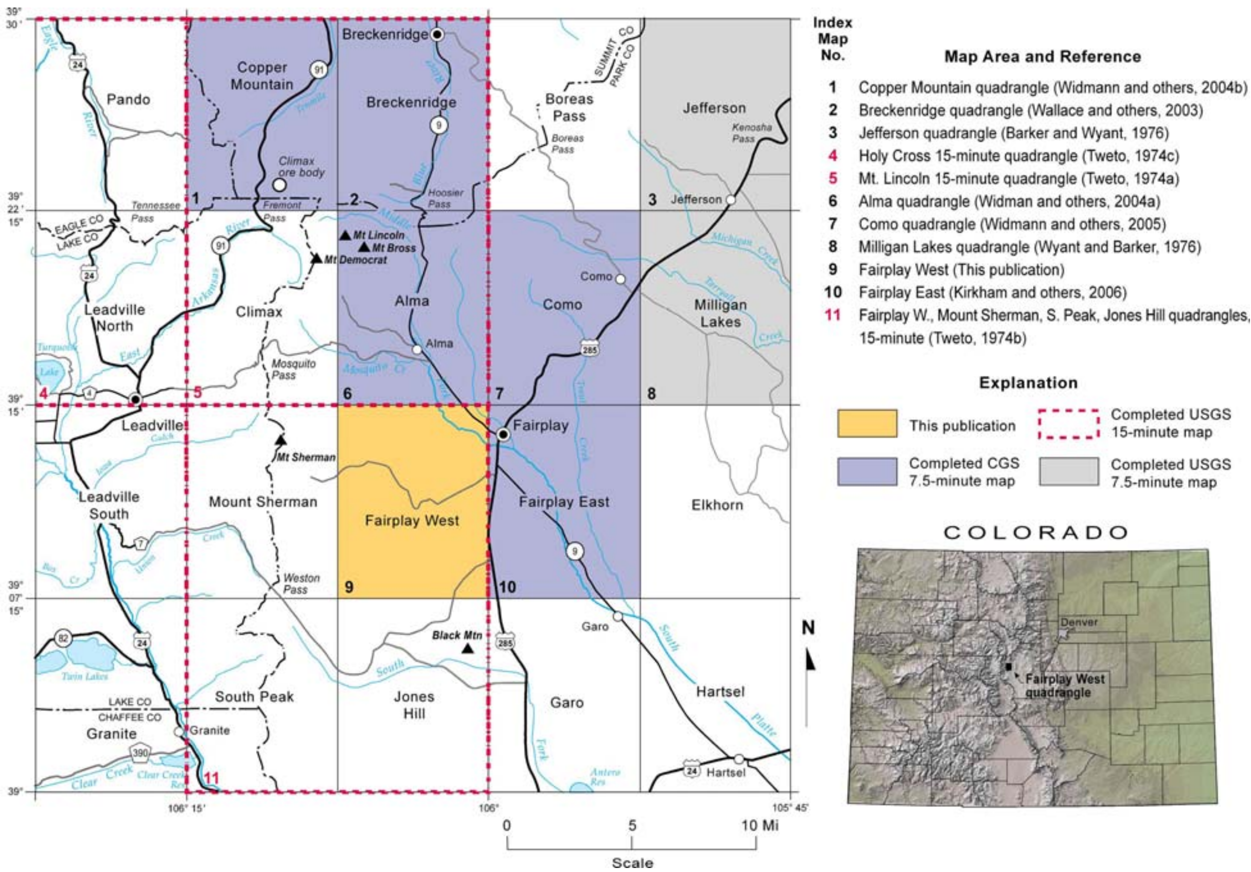

Figure 3. Location map and index of selected published geologic maps in the vicinity of the Fairplay West quadrangle.

ACKNOWLEDGMENTS

Warm thanks are extended to Rick and Michelle Carroll who opened their Fairplay home to our mapping team during the summer of 2005. Additionally, Sage Greising and Mary Ratliff (Timber Wolf Realty) are thanked for helping us obtain access to several communities and land owners in the area. Paul Myrow (Colorado College) contributed immensely to our understanding of the lower Paleozoic stratigraphic section in central Colorado. Special thanks are extended to Rich Madole (USGS, Emeritus) and Chuck Kluth (Colorado School of Mines) who provided thorough reviews of the report. Jane Ciener was our technical editor. Final GIS cartography and graphics were completed by Karen Morgan and Larry Scott (CGS).

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial geologic deposits of the Fairplay West quadrangle are divided into map units, first on the basis of either genesis or landform, then on relative age. Most of the surficial deposits in the mapped area are not well exposed. The best exposures result from human activities and are found in features such as active and abandoned mines, road cuts, foundation excavations, and utility trenches. These types of exposures sometimes are available for examination only for very short time periods because they may be promptly backfilled. Natural exposures of the surficial deposits, for example those in the eroded banks of streams, are relatively sparse. Because of the limited exposures, the physical attributes of the surficial deposits, such as thickness, texture, stratification, and composition, are based on observations made at only a few locations, and their origin is often deduced using only geomorphic characteristics.

Surficial units shown on the map generally are more than 3 to 5 feet thick. Deposits associated with distinct landforms locally may be thinner than 3 feet. Surficial deposits with a width of about 50 feet or less usually were not mapped because they are too small to show on the 1:24,000-scale map. Surficial deposits formed by in-place weathering of bedrock, such as residuum and felsenmeer, also are not mapped. Contacts for many surficial units were located using geomorphic characteristics. The contacts of some surficial deposits are gradational and are only approximately located.

Grain-size terminology used for sedimentary deposits follows the modified Wentworth scale (Ingram, 1989). This classification system describes pebbles, cobbles, and boulders as differing sizes of gravel, and it does not imply a genetic origin for the clasts. The general term "gravel" also is commonly used by many geologists for rounded clasts deposited in fluvial or beach environments. We herein use the terms gravel, pebbles, cobbles, and boulders to describe the size of the clasts, not the genetic origin. Terms used for sorting are those defined by Folk and Ward (1957). The term clasts as used here refers to rock and mineral fragments larger than 2 mm in diameter, whereas matrix refers to surrounding material that is 2 mm or less in diameter (sand, silt, and clay). In clast-supported deposits, the majority of the material consists of clasts that are in point-to-point contact. Matrix-supported deposits are composed predominantly of material smaller than 2 mm, and most clasts are separated by or embedded in matrix. Soil-horizon names used here are those of the Soil Survey Staff (1975) and Guthrie and Witty (1982), and the stages of secondary carbonate morphology are from Gile and others (1966), with the modifications of Machette (1985).

Deposits of glacial till and some alluvial deposits are correlated with oxygen isotope stages. Oxygen occurs in two common stable isotopes, ^{16}O and ^{18}O. The ratio of these two isotopes in water is temperature dependent. During cold glacial periods the $^{18}O/^{16}O$ ratio is high, and during warmer interglacial periods the ratio is low. By studying oxygen isotope ratios in thick ice caps and in fossils buried on the sea floor, changes in temperature over time can be evaluated (Martinson and others, 1987). An oxygen isotope stage consists of a lengthy time interval during which the temperature was generally either cold or warm. The modern warm interglacial period is assigned to oxygen isotope stage one, the last major glacial period (Pinedale glaciation) is oxygen isotope stage 2, and preceding interglacial and glacial periods are consecutively numbered. The Bull Lake glaciation is usually correlated with isotope stage 6.

HUMAN-MADE DEPOSITS

Earth materials placed by humans

lf **Landfill (Historic)—**Consists of refuse placed in a landfill south of Fairplay. The site is currently used as a trash transfer station. Maximum thickness estimated at 25 feet.

af **Artificial fill (Historic)—**Earth materials used as fill, mostly in road and dam construction. Artificial fill consists chiefly of sand, silt, rock debris, and clay with a maximum thickness of about 40 feet.

mw **Mine waste (Historic)—**Includes materials that resulted from mining and milling operations. Most mine waste in the quadrangle consists of rounded cobbles, pebbles, and boulders with minor sand and silt that resulted from gold placer operations. Both hydraulic mining and dredge mining were used within the quadrangle. Mine waste from placer mining is found in the valleys of Beaver Creek and the Middle Fork of the South

Platte River, on the ridge between Beaver Creek and the Middle Fork of the South Platte River, and on the north side of Fourmile Creek near the eastern margin of the quadrangle. A small deposit of angular rock fragments on the north side of Sacramento Creek upstream of the Duquesne smelter site is from milling operations. Several small waste-rock piles are associated with small mines and prospects in the mountainous western part of the quadrangle; only a few of these were large enough to show on the map. Deposits of mine waste locally include non-earthen materials such as scrap metal or timber. Maximum thickness of mine waste is 30 to 40 feet.

ALLUVIAL DEPOSITS

Gravel, sand, silt, and clay transported and deposited by flowing water. This sediment was deposited in channels and flood plains or on glacial outwash fans and plains.

Qa_1 **Alluvial unit one (Holocene)—**Mainly poorly sorted, clast-supported, unconsolidated, sandy gravel of all sizes, gravelly sand, silty sand, and sandy silt in modern channels, flood plains, and adjacent low-lying terraces that are approximately 5 feet or less above modern channels. Deposits of alluvial unit one typically are stratified, may have cut-and-fill channels, and locally contain beds of organic-rich material. These deposits may be overlain by or interbedded with very poorly sorted, matrix-supported gravelly silt and sand that probably were deposited by debris flows from tributary drainages. Most clasts are fresh and sound, and they typically are subround to subangular, although a few are round or angular. Only weakly developed pedogenic soil horizons have formed on deposits of alluvial unit one, which was deposited during oxygen isotope stage 1, perhaps during episodes of Holocene neoglaciation or flooding. The base of the unit is not exposed; thickness probably ranges from 3 to 20 feet.

Qa_2 **Alluvial unit two (upper Pleistocene)—**Alluvial unit two consists of stratified, poorly sorted, clast-supported, sandy cobble and pebble gravel, gravelly sand, silty sand, and sandy silt that locally are rich in organic material and peat. Most clasts are unweathered or very slightly weathered. Deposits of alluvial unit two are widespread in the valleys of the Middle Fork of the South Platte, Fourmile Creek, and High Creek. In these valleys, and also in the valley of Twelvemile Creek, alluvial unit two grades to the Pinedale terminal moraine or is adjacent to Pinedale lateral moraines upvalley from the terminal moraine. Deposits of alluvial unit two underlie glacial outwash fan and terrace surfaces downstream from the terminal moraines. The broad outwash fan between Fourmile and High Creeks is especially prominent.

Numerous topographic depressions are locally present in alluvial unit two immediately below the terminal moraine in Fourmile Creek; a single depression was noted near the Middle Fork of the South Platte. These closed topographic depressions are interpreted as kettles, which resulted from the melting of blocks of ice that detached from the glacier and were deposited with the outwash. Isolated areas of hummocky ground that are mapped as Qa_2 and lack exposures may be matrix-supported ground moraine. Locally the strata are deformed (fig. 4), probably by processes related to glaciation, not tectonism. Streams typically are incised only 3 to 20 feet into surfaces underlain by alluvial unit two, although the depth of incision is slightly greater along the Middle Fork of the South Platte River at the eastern edge of the quadrangle. Pedogenic soils formed in alluvial unit two have weakly to moderately well developed Bw horizons, very weak and thin argillic Bt horizons, and thin calcareous Cca horizons with stage 1 to weak stage 2 carbonate morphology. Stratigraphic relationships between alluvial unit two and the late Pleistocene tills of unit Qti_1, along with the degree of soil development and clast weathering, indicate the unit is Pinedale in age (oxygen isotope stage 2) and probably was deposited between about 35 and 13 ka. Singewald (1950) reported a maximum gravel thickness of 112 feet in alluvial unit two near the north edge of the quadrangle. Thickness rapidly decreases upstream.

Figure 4. Deformed glaciofluvial deposits (unit Qg) in a pit at the Golden Cross sand and gravel operation in the center of the N ½ N ½ of section 32, T. 9 S., R. 77 W. The apparent dip of the sediments, which is denoted by the arrows, steepens to the left. The dip direction is subparallel to the flow direction of the stream that deposited the sediments. Cause of deformation is uncertain.

Qao **Alluvium and organic-rich sediment (Holocene and upper Pleistocene)—**This unit consists of variable amounts of gravelly alluvium, organic-rich clayey silt, and peat. The silty beds may include windblown sediment. The unit accumulated in closed topographic depressions and other poorly drained areas, and it also underlies subtle ephemeral channels. Estimated maximum thickness is 25 feet.

Qa_3 **Alluvial unit three (upper middle Pleistocene)—**Similar to alluvial unit two (Qa_2), but it is older and usually, but not always, higher in the landscape than unit two. Alluvial unit three underlies glacial outwash fan and terrace surfaces. It is widespread in the east-central part of the quadrangle in an area north of Fourmile Creek. Alluvial unit three also caps a mesa on the south side of Fourmile Creek, and it underlies a topographically low area west of and adjacent to the deposit of alluvial unit two on the southwest side of High Creek. Small islands of alluvial unit three along the eastern margin of the quadrangle are elevated slightly higher than the encompassing younger units. Typically, original depositional surfaces associated with alluvial unit three are only 3 to 20 feet above adjacent streams, but along Fourmile Creek the Qa_3 surface is as much as 100 feet above the creek. These surfaces, however, converge with the valley floor downstream. Most gravel clasts contained within this unit are slightly or moderately weathered. Pedogenic soils commonly have moderately well-developed argillic Bt horizons with blocky or sometimes very weak prismatic structure and stage 1 carbonate morphology, and Cca horizons that have stage 2 to very weak stage 3 carbonate morphology. Alluvial unit three locally grades to terminal moraines formed by till unit two (Qti_2), most of which are interpreted as Bull Lake-equivalent deposits that are of late middle Pleistocene age (oxygen isotope stage 6). Some deposits of alluvial unit three may have been deposited during oxygen isotope stage 4. Alluvial unit three ranges from 3 to 25 feet thick and may be thicker locally.

MASS-WASTING DEPOSITS

Mass-wasting deposits, on hillslopes and adjacent valley floors, are transported downslope primarily by gravity, and not transported within, on, or under another medium such as flowing water or wind (Jackson, 1997). Water can be an important element in mass wasting, and it commonly triggers the movement. However, water is merely a part of the moving mass not the transporting agent. Colluvium, landslide deposits, and talus are the principal types of mass-wasting deposits in the quadrangle. The classification system of Cruden and Varnes (1996) is used to describe the type of slope movement.

Qc **Colluvium (Holocene and upper Pleistocene)—**Deposits of poorly sorted, sandy or silty, fine to coarse gravel and gravelly sand and silt that are on or at the foot of hillslopes. Colluvium can be rich in boulders where near cliffs and steep slopes with rocky outcrops. As used here, colluvium generally follows the definition of Hilgard (1892) in that it (1) is derived locally and transported only short distances, (2) is not distributed by channelized water flow, (3) contains clasts of varying size, (4) has little or no sedimentary structures or stratification, features which are typically caused by channelized flow of water, and (5) may include minor amounts of sheetwash and debris-flow deposits. Unit Qc also locally includes landslide deposits and talus that either are too small to differentiate at the map scale or which are difficult to clearly discern on aerial photographs.

The lithology of clasts within colluvial deposits depends on the source area. Clasts in colluvium typically are angular to subangular, except in areas where the source bedrock or surficial deposits contain rounded clasts. Maximum thickness of colluvium is estimated at about 30 feet.

Qta **Talus (Holocene and upper Pleistocene)—**Chiefly angular rock debris deposited below the base of cliffs that are held up by well-indurated bedrock. The debris came from the cliffs as rockfalls, rock slides, rock topples, and snow avalanches. Most talus is of cobble, small boulder, and pebble sizes, but boulders as large as 8 to 10 feet in diameter locally are present. Talus typically lacks matrix material, at least at shallow depths. Relatively large deposits of talus are present on the south sides of the glaciated valleys of Fourmile Creek, Little Sacramento Gulch, and Sacramento Creek. Maximum estimated thickness of talus is about 40 feet.

Qls **Landslide deposits (Holocene and upper Pleistocene)—**Landslide deposits consist of heterogeneous, mostly unsorted and unstratified debris that commonly is characterized by hummocky topography and lobate form. Most landslide deposits in the quadrangle occur in glaciated valleys, and they resulted from slope failures on bedrock dip slopes, in areas of strongly fractured bedrock, or in glacial till (fig. 5). Most landslide deposits appear to post-date the Pinedale glaciation. Many of the landslides probably failed after the last major glacial period. As a glacier advances down a valley, the valley walls are steepened by erosion along the margin of the ice. When the ice melts, the mass that supported the toe of the steepened slope is removed, allowing unstable or quasi-stable ground, especially material with high pore-water pressure, to fail. A relatively large slump block of fairly intact but dislocated bedrock was identified on the south side of Sheep Mountain. Landslide deposits typically are 5 to 40 feet thick, but the bedrock slump block on the south side of Sheep Mountain is much thicker.

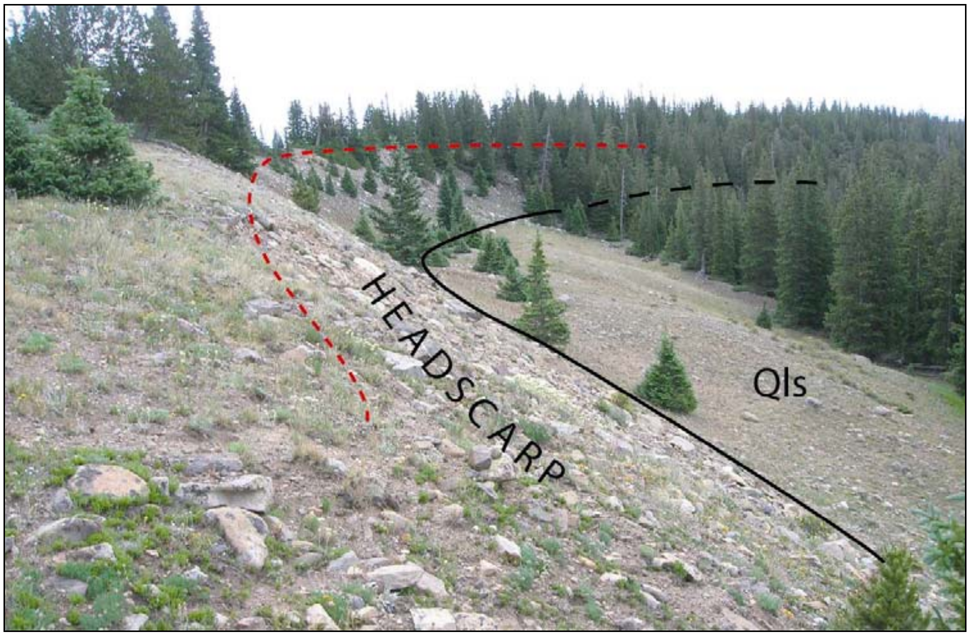

Figure 5. Photograph of the upper part of a landslide on the north side of Sacramento Creek near the northwest corner of the quadrangle. The steep slope that starts in the foreground and continues into the distance where it is concealed by trees is the headscarp of the landslide. The somewhat hummocky ground below the headscarp marks the upper end of the landslide deposit (Qls), which continues downslope and disrupts late Pleistocene till adjacent to the valley floor.

<u>ALLUVIAL AND MASS-WASTING DEPOSITS</u>

These deposits include alluvial and colluvial material that are mapped as a single unit because they are juxtaposed and are too small to show individually, or they have contacts that are not clearly defined. Fan deposits and piedmont deposits are included in this category because, in addition to alluvium, they also include significant volumes of debris-flow sediment, which are generally considered to be a form of mass wasting (Cruden and Varnes, 1996; Hungr and others, 2001).

Qf **Fan deposits (Holocene and upper Pleistocene)—**Includes sediment in small, geomorphically distinct fans at the mouths of tributary valleys. Fan deposits are chiefly poorly sorted, clast-supported sandy gravel and gravelly sand deposited as alluvium, but locally they include debris-flow deposits that are composed of matrix-supported, poorly sorted silty or sandy gravel. Clasts contained in younger fan deposits are mainly subangular to subrounded. Maximum thickness of the younger fan deposits is estimated at 25 feet.

Qac **Alluvium and colluvium (Holocene and upper Pleistocene)—**Unit Qac consists of sediment deposited in (1) channels, flood plains, and low terraces in tributary drainages, and (2) colluvium and sheetwash along valley margins and sidehills. The alluvial component of the unit is extremely poorly sorted to moderately well sorted and ranges from sandy pebble, cobble, and boulder gravel to stratified fine sand and silt. Clasts in the alluvial component are angular to subround. The colluvial component consists of very poorly sorted, unstratified or poorly stratified, gravelly to silty sand, sandy to silty gravel and gravelly sandy silt. Clasts in the colluvial component are chiefly angular to subangular. The unit also locally includes debris-flow deposits, which typically are matrix-supported gravelly silt. Paludal deposits may be included in unit Qac in tributaries that were dammed or partially dammed by moraines (e.g. Qac in SW¼ of section 11, T. 10 S., R. 78 W.), but no exposures of these sediments were found. Thickness of unit Qac is estimated to range from 3 to 25 feet thick.

<u>GLACIAL DEPOSITS</u>

Includes sediment deposited by or adjacent to glacial ice. These deposits are mapped as till, which is nonsorted and nonstratified sediment deposited directly by ice without reworking by glacial meltwater, but the unit locally includes stratified alluvial sediment, debris-flow deposits, and mass-wasting deposits.

Qti_1 **Till unit one (upper Pleistocene)—**Heterogeneous sediments deposited in lateral, terminal, end, recessional, and ground moraines in the valleys of the Middle Fork of the South Platte River, Sacramento Creek, Fourmile Creek, Sheep Creek, and Twelvemile Creek. These valleys also contain well-preserved recessional moraines that are progressively younger upvalley. Till unit one consists chiefly of nonsorted and nonstratified subangular to subround boulders, cobbles, and pebbles in a sandy or silty matrix (fig. 6). Sand-sized and smaller particles commonly comprise more than 50 percent of the deposit, although gravel-sized material locally is more abundant. Stratified, thinly bedded sand and fine gravel occur in places in the end and terminal moraines, and mass-wasting deposits of both landslide and colluvial origin may mantle the flanks of lateral, end, and terminal moraines. Debris-flow deposits also may be present locally. Most landforms composed of till unit one have sharp, well-preserved moraine crests and prominent knob-and-kettle landforms. Clasts contained within this unit are generally unweathered to slightly weathered and consist chiefly of Tertiary intrusive, Paleozoic sedimentary, and Proterozoic crystalline rocks. Pedogenic soils formed in deposits of till unit one typically have weakly to moderately developed Bw horizons or very weak and thin Bt horizons. Till unit one is tentatively correlated with deposits of the Pinedale glaciation, which formed during oxygen isotope stage 2 between about 35 and 12 ka. Singewald (1950) reported a maximum thickness of 157 feet for unit Qm_1 along the north side of the Middle Fork.

Figure 6. Exposure of matrix-supported till unit one (Qti_1) in the Rock and Pine pit in the NW ¼ NW ¼ of section 33, T. 9 S., R. 77 W. Note the thin Bw horizon immediately below the ground surface. Blue camera case at bottom of photograph is 6 x 9 inches.

Qti_2 Till unit two (middle Pleistocene)—Includes widespread deposits of till in the valleys of Beaver Creek, the Middle Fork of the South Platte River, Fourmile Creek, Twelvemile Creek, and Sheep Creek that are similar to unit Qti_1 but are older. Till unit two deposits are either down valley from or further from the valley center than till unit one. The moraine crests and hummocky knob-and-kettle landforms associated with till unit two are less distinct than those on till unit one, and the weathering rinds on clasts in till unit two are thicker than those on clasts in till unit one. Pedogenic soils formed in till unit two are thicker, more deeply oxidized, and contain more illuvial clay than those in till unit one (fig. 7). Most deposits of till unit two probably were deposited during the Bull Lake glaciation (oxygen isotope stage 6), which ended about 130 ka, but some may be older. Maximum thickness of till unit two is estimated at about 250 feet on the basis of the height of the moraine crest above and south of High Creek. In other areas the maximum thickness is about 100 feet and often is thinner.

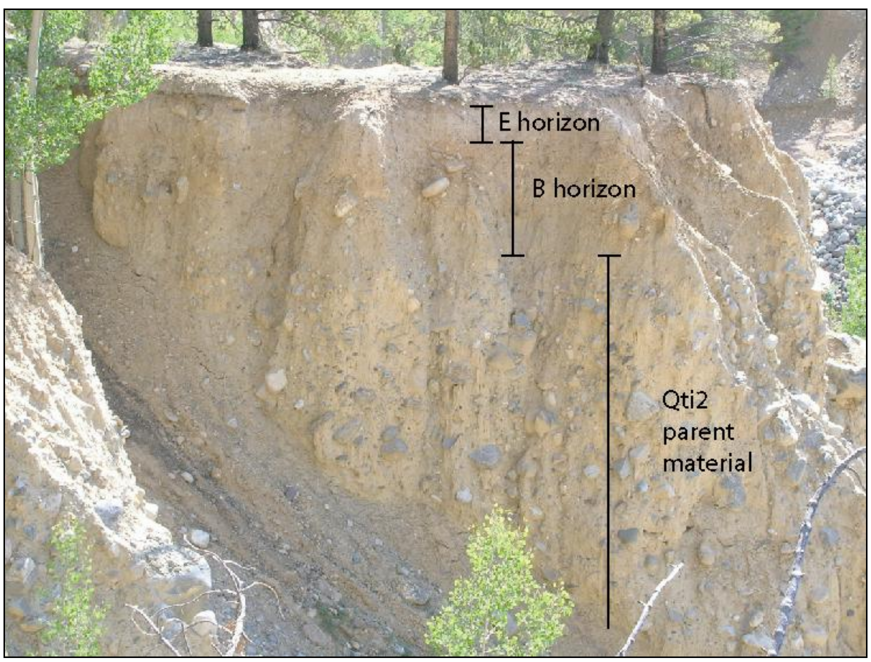

Figure 7. Exposure of matrix-supported till unit two (Qti_2) in the "China Bowl", which was created by a large placer mine in the NE ¼ of section 29, T. 9 S., R. 77 W. The tan, unweathered parent material is overlain by a thick reddish-brown B horizon, which in turn is overlain by a light-gray E horizon. A thin O horizon is present between the E horizon and the ground surface, but it too thin to be annotated in this photograph. The base of the tree immediately above the exposure is about 10 inches in diameter.

PERIGLACIAL DEPOSITS

Deposits formed in cold environments by freeze-thaw action, solifluction, and nivation.

Qptr **Protalus-rampart deposits (Holocene)—**Unsorted, unstratified, commonly matrix-free deposits of coarse-grained angular rock fragments that form arcuate or sinuous ridges at the downslope edge of existing or former snowfields. Protalus-rampart deposits form when rock fragments fall from a cliff or steep slope above a snowfield, and then roll or slide downslope across steep snowfield and accumulate at the distal end of the snowfield. Little or no fine-grained material reaches the lower edge of the snowfield. When the snowfield melts, the rampart or ridge stands some distance beyond any talus that may be present near the base of the cliff. Good examples of protalus ramparts are present on the south valley wall of Fourmile Creek below Sheep and Lamb Mountains. Maximum thickness of unit Qptr is about 30 feet.

Qs **Solifluction deposits (Holocene and upper Pleistocene)—**Angular to subrounded pebbles, cobbles, and large boulders in a chiefly sandy matrix. Solifluction deposits form in poorly drained parts of alpine and subalpine areas as a result of the slow, viscous, downslope flowage of water-saturated surficial deposits over frozen ground. Frost action, augmented by meltwater from alternate freezing and thawing of snow and ice, often initiates the movement. Areas with solifluction deposits are characterized by hummocky terrain, linear swales and ridges that mostly are cross-slope solifluction, and numerous seeps and springs. Mudsill Spring, located in a tributary to Little Sacramento Gulch, issues from the lower end of solifluction deposits that mantle the basin above the spring. Minor ground cracks and fissures also may be present in solifluction deposits. Lobes and terracettes with small ledges or benches that can be several feet high are common landforms associated with solifluction deposits. Solifluction deposits are estimated to range up to about 25 feet thick.

DIAMICTON

Flint and others (1960) proposed the nongenetic term "diamicton" for nonlithified, poorly sorted, terrigenous sediment containing a wide range of particle sizes. It is used herein for till-like deposits of uncertain origin on the north side of Sacramento Creek in the northwestern part of the quadrangle.

QTd Diamicton (middle to lower Pleistocene or Pliocene)—Subangular to subrounded cobbles, pebbles, and boulders with a sand or silty sand matrix. Matrix may comprise as much as 50 percent or more of the sediment. Most boulders are 1 to 3 feet in diameter, but some are as long as about 6 feet. These deposits are contiguous with deposits mapped as diamicton in the Alma quadrangle (Widmann and others, 2004a), which were assigned a lower Pleistocene? to upper Tertiary age. Their age assignment was chiefly based on the position of the deposits in the landscape; the diamicton was found at elevations higher than the level reached by late middle and late Pleistocene glaciers (Bull Lake and Pinedale equivalents) in adjacent valleys. In the Fairplay East quadrangle deposits of late middle and late Pleistocene till exist at elevations equal to or slightly less than diamicton. Clasts contained in the diamicton within the mapped area have weathering characteristics that are similar to the weathering of clasts in middle Pleistocene deposits elsewhere in the quadrangle, although the weathering profile may be younger than the deposit it formed in. The moraine-like landform associated with the diamicton suggests the sediment may attain a thickness in excess of 100 feet.

BEDROCK UNITS

TERTIARY INTRUSIVE ROCKS

Two distinctive porphyry units crop out in the western half of the Fairplay West quadrangle. In the northwest part of the quadrangle, the porphyry unit is a quartz monzonite intruded primarily as thin sills or small plugs into and at the base of the upper Paleozoic section. To the south, and particularly in the vicinity of Sheep Mountain, the second intrusive unit is an older granite porphyry with varying amounts of quartz that occurs as thick sills and plugs in the lower Paleozoic section. Descriptions of the rock units are primarily on the basis of hand sample petrography and limited thin section analysis. Names for intrusive rocks were assigned in accordance with the quartz-alkali feldspar-plagioclase (QAP) diagram of Streckeisen (1976).

Tqp **Quartz monzonite porphyry (Eocene)—**Grayish-tan- to orange-weathering porphyritic quartz monzonite comprised primarily of quartz, plagioclase, orthoclase, biotite, and hornblende phenocrysts set in a fine-grained matrix (fig. 8). Orthoclase phenocrysts comprise as much as 20 to 30 percent of the rock, are typically less than about 5 mm in maximum dimension, and are commonly altered to a chalky white color. Medium-gray, partially resorbed quartz phenocrysts are usually slightly larger than the feldspar crystals but make up only about 8 to 10 percent of the rock. Euhedral biotite forms 1 to 3 percent of the rock volume and is more abundant than the sparse hornblende, although locally, hornblende may predominate over biotite. When fresh, the rock is greenish in color due to biotite and hornblende content. Whole-rock geochemistry indicates a rock type that ranges from quartz monzonite to granodiorite. The porphyry commonly shows evidence of hydrothermal alteration in the form of sericite, chlorite, and carbonate. The porphyry may be contemporaneous with megacrystic varieties of quartz monzonite that crop out on the Copper Mountain quadrangle about 12 miles to the north-northwest and which yielded ages ranging from 36.7 ± 3.9 Ma (apatite) to 48.6 ± 6.6 Ma (zircon) (Mach, 1992). About 20 miles to the north, near the town of Frisco, similar megacrystic porphyry was dated at 44.1 ± 1.6 Ma by the K-Ar method (Marvin and others, 1989).

Figure 8. Quartz monzonite porphyry (Tqp) with characteristic orange-weathering surface (left) and medium-gray to greenish-gray fresh surface (central).

TKg Granite porphyry (Paleocene to late Cretaceous)—White to light-gray, very fine-grained porphyry with sparse small, clear, euhedral to subhedral quartz phenocrysts up to 3 mm in diameter set in an aphanitic matrix. Quartz phenocrysts comprise less than 2 percent up to about 10 percent of the rock. Sparse, highly altered, plagioclase and/or biotite phenocrysts may also be present locally. The matrix is composed essentially of orthoclase, plagioclase and quartz, with sericite and carbonate as common alteration products (Singewald and Butler, 1941). Behre (1953) classified this rock as a leucocratic granodiorite. Geochemistry of a similar transported clast collected from Reinecker Ridge, about 5.5 miles east of the quadrangle, indicates the rock may be closer in composition to granite (Widmann and others, 2005). In most outcrops, the rock has been intensely hydrothermally altered and is characterized by flat or platy weathering (fig. 9), pervasive limonite staining, and black manganese oxide dendrites. Some outcrops exhibit small (~2 mm) aggregations of bluish-gray quartz and elongate, locally flattened, vugs up to several millimeters in length filled with sericite and fine-grained quartz (fig.

10).

This porphyry unit is correlated with the “white” or “early white porphyry” of Emmons and others (1927), Singewald and Butler (1941), and Behre (1953), and with the Pando porphyry of Tweto (1953). K-Ar dating on biotite from this porphyry near Leadville yielded an age of about 70 Ma (Pearson and others, 1962). An $^{40}Ar/^{39}Ar$ age of 64.08 ± 0.11 Ma (Esser, 2005) was obtained for a clast of similar porphyry collected from a conglomerate on Reinecker Ridge (Widmann and others, 2005). Intense alteration of the porphyry on Sheep Mountain makes it difficult to obtain a reliable age at that locality.

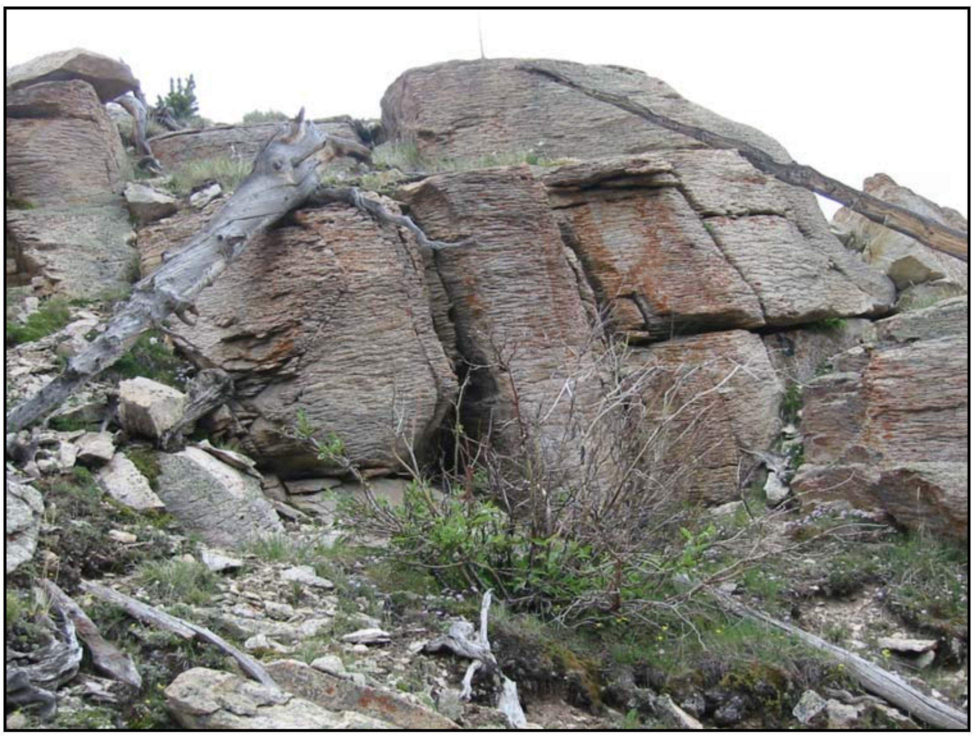

Figure 9. Outcrop of granite porphyry showing characteristic platy weathering that, from a distance, may easily be mistaken for bedding.

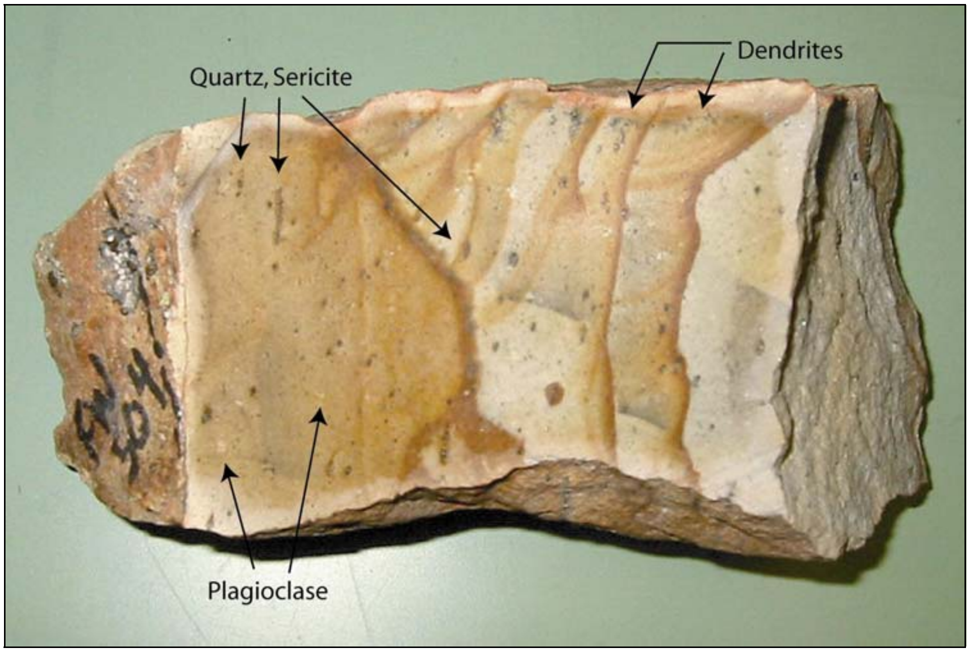

Figure 10. TKg hand sample from Sheep Mountain. Note light color, fine-grained texture, sparse plagioclase phenocrysts (buff), quartz-sericite aggregates (brownish-gray), and manganese dendrites (dark gray). Length of cut surface is 3.5 inches.

PALEOZOIC SEDIMENTARY ROCKS

The sequence of lower Paleozoic rocks in the Fairplay West quadrangle includes the Sawatch Quartzite and Dotsero Formation (Late Cambrian), Manitou Formation (Ordovician to Late Cambrian), Parting Formation and Dyer Dolomite of the Chaffee Group (Late Devonian), and Leadville Limestone (Mississippian). A newly mapped Mississippian (?) unit has been added to this sequence and is herein informally termed the quartzite of Sheep Mountain. In the southwestern corner of the quadrangle, the Leadville Limestone is overlain by the Pennsylvanian Belden Shale. Elsewhere, the Coffman Member of the Minturn Formation (Pennsylvanian) rests unconformably on the quartzite of Sheep Mountain. The youngest sedimentary rock unit in the quadrangle is the Minturn Formation (Pennsylvanian).

Carbonate-rich sandstone and shale beds overlying the Sawatch Quartzite were originally designated the Peerless Shale Member of the Sawatch Formation by Behre (1932) and were later upgraded to formation rank by Singewald (1947). This nomenclature was adopted for rocks of similar appearance in the Front Range by Berg and Ross (1959). However, detailed analysis of numerous measured sections of Lower Paleozoic rocks throughout Colorado by Myrow and others (1995, 1999, 2003) showed that the Peerless Formation, as mapped in the Front Range, does not correlate chronologically or stratigraphically with the Peerless Formation at its type section at Peerless Mountain. Instead, the Front Range strata are equivalent to glauconite-rich beds of the Middle Member of the Sawatch Quartzite. As a means of preventing future confusion, Myrow and others (2003) dropped the term Peerless Formation and reassigned the strata above the Sawatch Formation to the Dotsero Formation, thereby establishing a correlation to similar units mapped in the White River uplift by Bass and Northrop (1953). The "red cast beds" (Emmons, 1886), a local marker horizon formerly used to indicate the top of the Peerless Formation (Behre, 1953), is now considered to constitute the lowermost part (Taylor Pass Member) of the Manitou Formation (Myrow and others, 2003). Furthermore, the studies by Myrow and others (1995, 1999, 2003) also identified the stratigraphic location of the Cambrian-Ordovician boundary in the lower part of the Manitou Formation. The stratigraphic nomenclature put forth by Myrow and others (2003) is adopted herein.

Pennsylvanian-Permian strata are composed of a thick succession of varied rock types such as conglomerate, sandstone, siltstone, shale, and limestone, and show abrupt changes laterally and vertically. They were originally deposited as sediments on alluvial plains and in shallow tropical seas of the Central Colorado basin (Tillman, 1971; Walker, 1972; DeVoto, 1980). This basin was surrounded by the actively rising Ancestral Rocky Mountains, which were eroding to produce the arkosic sediment that was carried into the basin (Mallory, 1972). The Late Paleozoic Era was a time of frequent sea-level changes, and this also contributed to the variety of lithologies seen in rocks of this age in many parts of the world, including Colorado (Ross, 1985; Heckel, 1986). Throughout Colorado, it has proved challenging to divide this thick succession of strata into easily recognizable formations. Several different schemes have been used in the past (see Wallace and others, 2003 and Widmann and others, 2004a for review). They have generally fallen into two categories. Early workers such as Emmons (1889), Singewald (1942), and Koschmann and Wells (1946) realized that marine horizons with thin limestone beds were traceable over distances of several miles, and they used these to divide the section into intervals or formations. In particular, the Jacque Mountain Member of the Minturn Formation was used by Tweto (1949) as the boundary between the Minturn and Maroon Formations. Other workers (e.g., DeVoto, 1965; Taranik, 1974) used a color change from predominantly gray rocks to predominantly red ones as the contact between these formations. Though the color change has the advantage of being easy to see and map, it changes position in the section by hundreds or even thousands of feet on a regional scale (Schenk, 1989). The marine horizons are more difficult to find and trace in the field but have the advantage of maintaining the same position in the section.

In order to locate the Jacque Mountain Member in the Fairplay area, it was necessary to revisit the type locality at Jacque Mountain about 15 miles to the north-northwest and trace the Jacque Mountain Member and underlying marine horizons southward. This was done by measuring several sections and correlating beds from Jacque Mountain to Hoosier Pass to Fairplay (Houck and others, unpublished data). The Robinson, White Quail, and Jacque Mountain limestone members of the Minturn Formation were walked out where exposures permitted and were traced from their type areas at Jacque Mountain to the Fairplay area.

Near Fairplay, and just east of the Fairplay West quadrangle, an interval of interbedded limestone and siltstone approximately 150 feet thick was found at the correlated position of the Jacque Mountain Member, which is about 6,000 feet above the top of the Leadville Limestone. This interval was also identified in the Breckenridge, Alma, and Como quadrangles. At some localities the limestone beds in this interval exhibit the distinctive features of the Jacque Mountain Member, such as ooids and large cephalopods. At other localities the limestones change facies and show other features such as phylloid algae, algal laminations, and intraclasts. Though individual limestone beds do not continue for long distances, the interval was traced on the ground, with minimal interruption by surficial deposits, for a distance of at least 5 miles in the Fairplay East, Como, and Alma quadrangles. Igneous intrusions and erosional removal prevented continued tracing of the interval further north, but a zone of thin limestone beds bearing ooids and large cephalopods occurs at the same stratigraphic horizon in the Breckenridge quadrangle. The highest limestone bed in the Jacque Mountain Member interval, which is herein recognized as the contact between the Minturn and Maroon Formations, is tentatively located just east of the quadrangle.

The siliciclastic rocks of the Minturn and Maroon Formations in the area from Hoosier Pass to Fairplay are generally similar to those in the Minturn and Pando areas, but the proportions of various rock types are quite different. The Minturn and Maroon Formations at

Minturn and Pando are dominated by conglomerate and sandstone (Tweto, 1949; Tweto and Lovering, 1977), whereas these formations from Hoosier Pass to beyond Fairplay are dominated by siltstone. Conglomerate and sandstone are present but in lesser quantities that decrease to the south. Because siltstone is less resistant to erosion than conglomerate or sandstone, the presence of abundant siltstone in the Minturn and Maroon formations has contributed to the formation of the large valley between Red Hill and the Mosquito Range. The Coffman Member of the Minturn Formation is a light-gray to white arkosic quartz sandstone and conglomerate that occurs at the base of the Minturn Formation in some areas.

IPm **Minturn Formation (Middle and Early Pennsylvanian)—**Predominantly red to pinkish-gray, arkosic, micaceous siltstone, with lesser amounts of sandstone, and pebble- and cobble-conglomerate, interbedded with dark-gray limestone beds typically less than 15 feet thick. Quartz, feldspar, and granite clasts up to 5 inches in diameter are common in the conglomerate beds. Overall bedding varies from massive to planar, planar cross-bedded, and trough cross-bedded. Sandstone beds tend to be planar where fine grained and trough cross-stratified where coarser. Coarse-grained sandstone and small-pebble conglomerate in pervasive narrow (less than about 10 feet wide) channels quickly grade upward to medium- and fine-grained sandstone. Conglomerate in broad (up to about 100 feet wide) channels as much as 45 feet thick commonly contains cobble-size clasts and may exhibit both normal and reverse gradation. Strata in the main body of the Minturn Formation are differentiated from strata in the underlying Coffman Member of the Minturn Formation in that the former (1) contains a higher percentage of shale and siltstone, (2) sandstone units are commonly micaceous and have a greater abundance of feldspar, (3) and conglomerate beds contain larger clasts of more varied lithologies, including quartz, feldspar, granite, and black to dark-gray quartzite (fig. 11).

Limestone beds in the Minturn Formation are generally micritic and locally may contain intraclasts, stromatolites, bioturbation, calcareous algae, and/or fossil hash. The more prominent of these limestone beds have been formally named (Tweto, 1949) and those occurring within the quadrangle are described below. Exposure of the Minturn Formation within the quadrangle amounts to about 2,500 feet, but the top of the formation is not exposed in the quadrangle. Total thickness of the Minturn Formation in the region is as much as 7,000 feet (Widmann and others, 2004a).

Figure 11. Conglomerate bed in the Minturn Formation. Note larger clast size (particularly above hammer head) as compared to conglomerate in the Coffman Member (see fig. 12). Also, note clasts of pink to light-red granite, and dark-gray quartzite – clast lithologies that are rarely present in the Coffman Member.

Pmq **White Quail Limestone Member (Middle Pennsylvanian)—**Gray, micritic limestone and red siltstone with limestone nodules. The member is about 40 feet thick and includes about 10 to 15 feet of bedded limestone and 25 to 30 feet of siltstone with limestone nodules. Intraclasts, calcareous algae, fossil hash, and bioturbation were observed. In some places the limestones are recrystallized and have a reddish color.

Pml **Limestone beds, undifferentiated (Middle Pennsylvanian)—**Micritic limestone beds and nodule horizons about 1 to 5 feet thick occur sporadically throughout the Minturn Formation. Where fresh, the limestone is nearly everywhere dark to medium gray. However, individual beds have weathered or been altered to gray, black, dark reddish-gray, and tan. Limestone texture is either micritic or fine grained. Limestone horizons are typically separated by several tens to hundreds of feet of siliciclastic sediments. Fossil hash, algae, and intraclasts were observed in some of the limestone beds. The limestone is recrystallized at some localities.

₽co **Coffman Member (Middle and Early Pennsylvanian)—**Predominantly light-gray to white, fine-grained to conglomeratic, arkosic quartz sandstone. Clean, fine- to coarse-grained sandstone beds are poorly stratified and consist primarily of angular to subangular quartz and minor feldspar tightly cemented by silica. Conglomeratic units are poorly sorted and contain about 20 percent pebble and small cobble fragments in a coarse-grained matrix dominated by quartz (fig. 12). Most clasts are less than 1.5 inches in maximum dimension. Pebble and cobble clasts are chiefly composed of quartz, with lesser amounts of subrounded feldspar and salmon-colored granite. Precambrian granite and pegmatite are the likely sources of the clasts. Less commonly, black, green, and red chert or fine-grained quartzite of unknown origin may be found among the smallest of the pebbles (less than 0.25 inches). Although exposures are poor in the southwest corner of the quadrangle, the base of the Coffman Member appears to interfinger with shale of the Belden Formation. Grayish-brown, "dirty", micaceous sandstone is occasionally interbedded with the clean quartz sandstones and conglomerates; micaceous sandstones increase in frequency towards the top of the section where the Coffman Member grades into the Minturn Formation. The Coffman Member is best identified on the basis of abundant clean quartz sandstone and predominantly quartz pebble conglomerate, whereas the Minturn Formation has a greater abundance of dirty micaceous sandstone and coarser conglomerate (large cobbles are common) with a multitude of clast lithologies.

At the type locality in Coffman Park, roughly 25 miles south-southeast of the Fairplay West quadrangle, the Coffman Member is 615 feet thick (Gould, 1935), but the unit is said to pinch out northward and grade into the upper part of the Belden Formation and basal part of the Minturn Formation. In the Fairplay West quadrangle the Coffman Member thins and interfingers with the Belden and Minturn Formations to the south and east. In the western part of the quadrangle, the Coffman Member is about 1,100 feet thick; in the eastern part of the quadrangle it thins to zero thickness. Although nearly identical in characteristic, it is unlikely that the Coffman Member in the vicinity of Sheep Mountain was ever laterally continuous with the Coffman Member at Coffman Park. Rather, field relations suggest the Sheep Mountain and Coffman Park areas were distinct, near-source depositional areas, likely deltaic and stream channel environments (Gould, 1935), whereas the intervening area was occupied by a shallow sea in which the finer-grained sands and muds of the Belden Formation and lower Minturn Formation accumulated.

Figure 12. Pebble conglomerate in the Coffman Member of the Minturn Formation. Note light-gray color and predominance of quartz pebbles.

ℙb **Belden Formation (Middle and Early Pennsylvanian)—**Interbedded shale, sandstone, and limestone that crop out primarily in the southwestern corner of the quadrangle. Shale facies are dark gray to black, locally calcareous and/or carbonaceous, and may contain plant and marine fossils and silicified wood. Shale outcrops form saddles and topographic lows between the more resistant sandstone and limestone beds. Interbeds consist of fine-grained, micaceous and arkosic sandstone that is generally olive-drab to light gray in color. Sandstone beds are as thin as a few feet at the south end of the quadrangle but thicken and become coarser north of Cove Creek as they interfinger and grade into the Coffman Member of the Minturn Formation. Limestone beds are dark gray to black, may contain marine fossils and micro-laminations, and are about 5 to 10 feet thick. Estimated thickness of the Belden Formation in the southwest corner of the quadrangle is about 750 feet. However, the unit thins eastward to zero thickness and is not present on east flank of Sheep Mountain.

Due to the limited areal extent of the Belden Formation within the quadrangle, no attempt was made to break out lithologic subdivisions. However, within the greater Fairplay region, some previous workers have attempted to subdivide the Belden Formation. Johnson (1934) described in great detail three subdivisions within what he termed the Weber Formation, an historic term now replaced by the Belden and Minturn Formations. The lower two of Johnson's subdivisions include the shales, sandstones, and limestones of the Belden Formation. The lowest division consists almost entirely of black shale with only minor partings of fine-grained siltstone or shaley limestone. The middle division encompasses a wider variety of lithologies, including grit, sandstone, sandy shale, and limestone. The upper division consists of sandstone and conglomerate that appears to be equivalent to the Coffman Member. Gould (1935) also noted several lithologic subdivisions within the "Weber" Formation, including an informally termed "Newett" limestone member in the Salt Creek area of the Mosquito Range to the west. Less than 20 miles south of the Fairplay West quadrangle, the Belden Formation was divided into an upper and lower unit (Wallace and others, 2003). The lower unit consisted of black shale, calcareous siltstone, and fetid to argillaceous limestone, while the upper unit coarsened upwards into fine- and medium-grained micaceous sandstone. Additional field work south of the Fairplay West quadrangle is needed before the Belden Formation in this area can be subdivided.

Ms **Quartzite of Sheep Mountain (Mississippian ?)—**White to medium-gray, clean, fine-grained, well-sorted, silica-cemented orthoquartzite that commonly exhibits purple or reddish-purple staining on weathered surfaces. Due to its pervasiveness on the east flank of Sheep Ridge and Sheep Mountain, this unit is herein informally referred to as the quartzite of Sheep Mountain. This quartzite unit has not been mapped by previous workers in the area (e.g., Patton and others, 1912; Johnson, 1934; Singewald and Butler, 1941; Behre, 1953). Although the unit is relatively thin (50 feet or less), it is relatively widespread in the Fairplay West quadrangle and has been recognized (but not mapped) 20 miles to the south in the Castle Rock quadrangle (Wallace and Keller, 2003), where it is only about 20 feet thick. During recent mapping of the Alma quadrangle to the north (Widmann and others, 2004a), the Belden Formation was found to rest directly on the Leadville Limestone and no intervening quartzite was observed. Therefore, the quartzite of Sheep Mountain must thin northward to zero thickness or was eroded before deposition of the Belden Formation.

In the field, beds of fine-grained quartz sandstone within the Coffman Member are similar in appearance to the quartzite of Sheep Mountain. In thin section, however, there is virtually no feldspar in the quartzite of Sheep Mountain, whereas feldspar is readily observable in even the cleanest of the Coffman sands, thus establishing a difference in provenance between the two units. Stratigraphic relationships in the Fairplay West quadrangle and in the Castle Rock quadrangle to the south (Wallace and Keller, 2003) are not definitive, but they appear to suggest the quartzite of Sheep Mountain is conformable and interfingered with upper dolomite beds of the Leadville Limestone. In the field and in thin section, the quartzite of Sheep Mountain was found to be most similar in character to other lower Paleozoic quartzite units, and is therefore herein considered Mississippian in age.

Ml **Leadville Limestone (Mississippian)—**Bluish-gray to black, massive-bedded, fine-grained dolomite characterized by local patches of irregular, alternating 1 to 5 mm bands of dark-gray to black dolomite and white, coarse-grained, vuggy dolomite, known as “zebra rock”, and well-rounded to fragmented black chert pebbles and cobbles (fig. 13). The rock commonly has a mottled or brecciated appearance, with the breccia typically occurring within, and not across, beds. Lenticular beds of tan-weathering, medium-grained, white quartz sandstone and orthoquartzite (fig. 14) and localized beds containing abundant subangular rip up clasts of limestone (fig. 15), are found near the base of the formation. Within and adjacent to the London fault zone, the Leadville Limestone is highly silicified and intensely brecciated. Weathered dolomite typically has a highly pitted surface with a rough, or sharp, texture, and it often produces a distinctive reddish-brown soil. Thickness of the dolomite is highly variable, particularly where it is stretched and thinned over the axis of the anticline associated with the London fault. Overall average thickness of the formation is about 150 feet. For a more detailed description of the Leadville Limestone the reader is referred to Emmons and others (1927).

Figure 13. Leadville Limestone with characteristic black chert (upper left and lower right) and zebra stripes (upper right and beneath pencil).

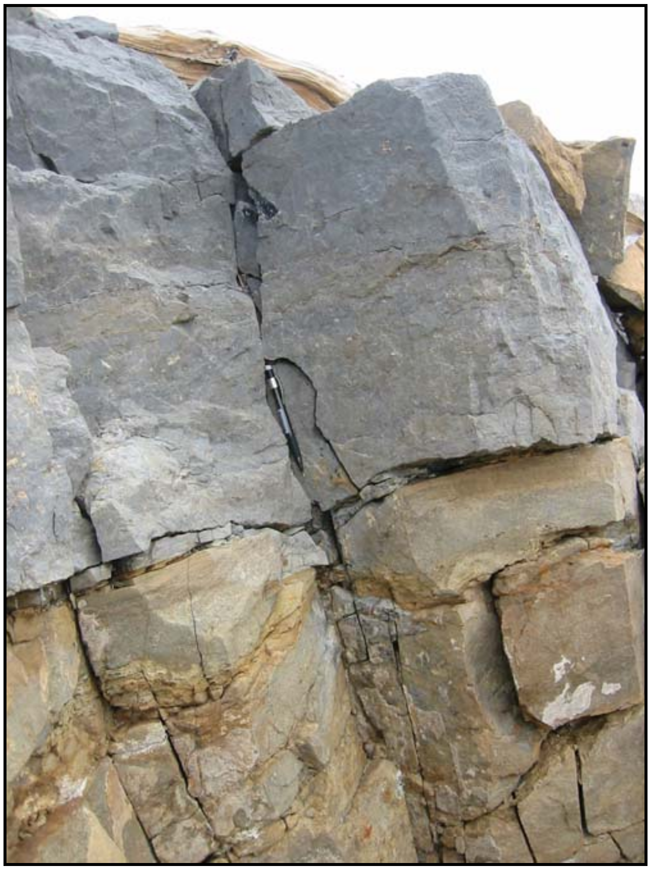

Figure 14. Interbedded nature of quartz sandstone (lower tan bed) and dolomite (upper gray bed) near the base of the Leadville Limestone.

Figure 15. Sandy dolomite bed with abundant limestone rip up clasts near the base of the Leadville

Limestone.

Dc **Chaffee Group, undivided (Late Devonian)—**Includes Dyer Dolomite and Parting Formation in areas where units are poorly exposed or too thin to be mapped separately.

Dd **Dyer Dolomite—**Thinly bedded to massive, finely crystalline and microcrystalline dolomite. The lower third of the unit is medium gray, whereas the upper part is slightly darker. Weathering produces a soft, smooth surface that is yellowish to brownish gray in outcrop. Thin (<2 inches) lenses of shale and/or chert occur locally. Average overall thickness of the formation is about 80 feet.

Dp **Parting Formation—**Predominantly bright-white to subdued-gray, fine- to medium-grained, well-sorted orthoquartzite and moderately well-sorted, quartz-rich sandstone with a few interbeds of tan dolomitic sandstone. Locally, this unit is coarse grained and contains quartz pebbles, particularly near its base. Orthoquartzite beds are typically massive, especially when fresh, but on weathered surfaces thin lenses of less well-cemented sandstone are revealed (fig. 16). Although similar in character, the Parting Formation is generally not as clean or white as the Sawatch Quartzite and quartzite of Sheep Mountain and is not as well sorted as the quartzite of Sheep Mountain. Finer-grained facies weather orangish brown, whereas coarser varieties tend to be light gray or purple. The average thickness of the Parting Formation within the quadrangle is about 30 feet.

Figure 16. Medium-grained orthoquartzite of the Parting Formation. Weathering helps accentuate centimeter-thick lenses of clean, well-sorted, white quartz sandstone.

O€m Manitou Formation (Ordovician to Late Cambrian)—Cliff-forming unit composed of light- to dark-gray, thin- to thick-bedded, fine- to medium-grained dolomite with rare interbeds of dark-gray limestone. The dolomite weathers medium to yellowish gray, and its surface texture is intermediate between the sharp, pitted texture of the Leadville Limestone and the smooth, rounded texture of the Dyer Dolomite. At Horseshoe Mountain, roughly three miles west of the Fairplay West quadrangle, Van Loon (1993) subdivided the Manitou Formation into six lithofacies, which included from top to bottom: (1) an oncolitic dolostone facies with abundant dark purplish-gray oncolites averaging 5 mm in diameter, (2) a massive-bedded, heavily bioturbated dolostone facies, (3) a coarse, bioclastic grainstone/packstone facies with crinoids, gastropods, echinoderms, and nautiloids, and black and white chert nodules (fig. 17), (4) a horizontally bedded, crystalline dolostone facies, (5) a finely crystalline, bioturbated dolostone facies with minor trilobite fragments and localized groove casts and other sole marks, and (6) a basal shale and flat-pebble conglomerate facies.

Below the flat-pebble conglomerate (subunit 6) is the distinctly purple Taylor Pass Member of the Manitou Formation, which consists of a basal, dark-red shale overlain by a cliff-forming, purple-tinged dolomite readily apparent above the similarly colored Dotsero Formation on the northern flank of Sheep Mountain. These beds, historically known as the "red-cast beds" (Emmons, 1886), were formerly considered the upper part of the Peerless Formation (Behre, 1953). Myrow and others (2003) placed these beds within the Taylor Pass Member (Cambrian) of the Manitou Formation. Although most of the aforementioned facies were observed at various locations throughout the Fairplay West quadrangle, no attempt was made to map these subdivisions given the scale of this mapping project. The upper and lower contacts of the Manitou Formation are fairly well marked by topographic breaks caused by shale and thinly bedded sandstone in the upper part of the underlying Dotsero Formation and thinly bedded, platy dolomite in the upper part of the Manitou Formation. Thickness of the Manitou Formation at Horseshoe Mountain three miles west of the quadrangle is approximately 200 feet (Myrow and others, 2003).

Figure 17. Stringers of white chert in the upper part of the Manitou Formation.

Ꞓd **Dotsero Formation (Late Cambrian)—**Fine- to medium-grained, cliff-forming quartzitic sandstone overlain by dolomite-cemented sandstone and thin, sandy to silty dolomite beds. The lower quartz sandstone is about 15 feet thick and has a distinctive reddish-purple color readily observed along the north flank of Sheep Mountain (fig. 18). This purple sandstone contrasts markedly with the uppermost clean, white quartzite bed of the underlying Sawatch Quartzite. The upper part of the Dotsero Formation contains glauconite, is less distinctively purple (tends towards tan), and forms a slight topographic break due to weathering of the less resistant, thinly bedded to shaley dolomitic sandstone. Overall thickness on Sheep Mountain is 45 to 50 feet.

Figure 18. Reddish-purple, fine-grained, quartzitic sandstone characteristic of the lower Dotsero Formation.

Ꞓs **Sawatch Quartzite (Late Cambrian)—**Bright-white, fine- to medium-grained, well-sorted orthoquartzite interbedded with reddish-purple, fine-grained, moderately well-sorted, quartzitic sandstone (fig. 19). White quartzite beds are composed almost entirely of well-rounded, well-cemented quartz grains with only minimal detrital feldspar. Feldspar content is somewhat higher in the reddish-purple quartzitic sandstones and glauconite may be present. Individual beds range from less than 2 feet to about 10 feet in thickness. The Sawatch Quartzite forms a distinctive, highly visible, white- and purple-banded cliff along the northern flank of Sheep Mountain. A basal quartz-pebble conglomerate less than one foot thick rests nonconformably on underlying Precambrian gneiss and granite. Thickness of the Sawatch Quartzite within the quadrangle is approximately 100 feet.

Figure 19. Typical white and reddish-purple beds of the Sawatch Quartzite. White beds are composed of clean, well-rounded, well-sorted quartz. Purple beds are similarly comprised but may be dolomitic (Patton and others, 1912) or may contain additional detrital feldspar or glauconite.

<u>PROTEROZOIC INTRUSIVE ROCKS</u>

Proterozoic intrusive rocks are exposed only in the northwestern corner of the Fairplay West quadrangle and are limited to relatively small, irregular bodies of quartz monzonite.

Yqm **Quartz monzonite (Mesoproterozoic)—**Pink to pinkish-gray, massive to moderately foliated, medium- to coarse-grained quartz monzonite consisting of roughly equal proportions of microcline, quartz, and plagioclase with lesser amounts of biotite and muscovite. The rock has a seriate porphyritic texture defined by alignment of tabular microcline phenocrysts (fig. 20), many of which exhibit Carlsbad twinning. Euhedral laths of microcline are typically less than 1 cm in length, but larger crystals up to 4 cm in length are not uncommon. Locally, the unit is pegmatitic. Quartz is present as anhedral grains and as aggregates of small sutured grains. Bergendahl (1963) noted apatite and rutile as accessory minerals. Weathered surfaces have a somewhat rusty coloration.

The seriate porphyritic texture and the monzonitic composition of this unit suggests it is part of the Berthoud plutonic suite dated in a variety of places at about 1.4 Ga (e.g., Graubard and Mattison, 1990).

Figure 20. Quartz monzonite granite (Yqm), exhibiting moderate alignment of tabular microcline phenocrysts up to 4 cm in length.

PROTEROZOIC METAMORPHIC ROCKS

Proterozoic metamorphic rocks, predominantly migmatite, crop out in the northwestern corner of the quadrangle. These rocks are part of the Proterozoic gneiss complex defined by Tweto (1987). Regional studies in the Front Range indicate peak metamorphism and deformation likely coincided with syntectonic plutonism during the Early Proterozoic (Selverstone and others, 1997). A similar time frame for metamorphism is assumed for the Precambrian rocks within the quadrangle and in the nearby Mosquito Range.

Xm **Migmatite (Paleoproterozoic)—**Medium- to dark-gray, medium-grained gneiss characterized by the intimate layering of locally schistose, dark-colored laminae containing biotite, hornblende, plagioclase, and quartz and light-gray to pinkish-gray, medium-grained to pegmatitic material composed primarily of quartz, plagioclase, and microcline. Accessory minerals include sillimanite, garnet, muscovite, apatite, epidote, and sericite (Bergendahl, 1963). Migmatitic rocks are well foliated and exhibit numerous ptygmatic folds, boudinage, and sigmoidal structures. Some layers contain abundant large, white, flattened pods of sillimanite and muscovite averaging about 1 inch in length and ranging up to 4.5 inches long and 2 inches wide (fig. 21).

Figure 21. Zone of sillimanite gneiss within an overall package of migmatite. The white pods are aggregates of sillimanite and muscovite rimmed by darker biotite.

STRUCTURAL GEOLOGY

The Fairplay West quadrangle straddles an important structural transition between the northern part of the South Park basin to the east and the Mosquito Range to the west (see fig. 1). South Park is a generally north-south elongated, intermontane topographic and structural basin that formed during the Laramide Orogeny and was later modified by late Cenozoic normal faulting. The basin is bound on the west by the Mosquito Range and on the east by the Front Range and Elkhorn thrust fault. The basin floor plunges to the south beneath the Thirtynine Mile volcanic field. Several north-south-trending intra-basinal ridges interrupt the low valley floor.

Precambrian rocks are exposed along both the western and eastern margins of South Park, but in the central part of South Park Precambrian rocks are buried beneath several thousand feet or more of Phanerozoic sedimentary strata. Cambrian to Mississippian rocks are present on the western margin of South Park along the east flank of the Mosquito Range but are absent along the eastern margin of the basin. A thick sequence of Pennsylvanian-Permian rocks was shed into South Park from uplifted highlands to the west, north, and northeast. These rocks thin eastward and onlap Precambrian basement rocks beneath the cover of South Park (DeVoto, 1971). Jurassic to Cretaceous rocks crop out in the eastern half of the basin but are not exposed in the Fairplay West quadrangle. Thick deposits of synorogenic strata were shed into the South Park basin during Laramide orogenesis. Raynolds (2003) reported that more than 7,800 feet of volcanic flows, volcaniclastic debris, and erosional sediments were emplaced contemporaneously with Laramide uplift and associated subsidence of the South Park basin. Remnants of these Tertiary deposits crop out just east of the quadrangle. Widespread igneous activity was concurrent with Laramide orogenesis and resulted in the emplacement of numerous stocks, plugs, dikes, and sills that are generally calc-alkaline in composition.

Tectonism during the late Cenozoic continues to shape South Park. Several Miocene and younger faults are documented in the southeastern part of South Park, the youngest of which last moved 30 to 15 ka (Widmann and others, 2002). Kirkham and others (2006) identified an Oligocene or younger, north-northwest-trending fault on the adjacent Fairplay East quadrangle that projects into the eastern part of the Fairplay West quadrangle. This fault is required to explain the juxtaposition of southwest-dipping tuff and overlying sediments in an Oligocene (?)

paleovalley in the Fairplay East quadrangle and the east-dipping Paleozoic rocks in the Fairplay West quadrangle. The fault's precise location, however, is uncertain.

The Mosquito Range is a north-south-oriented, fault block. It is cored by Precambrian granite and gneiss that is overlain by Paleozoic sedimentary rocks dipping, on average, 25° to the east, except where disturbed by faulting and fault-related folding. Within the quadrangle, Sheep Mountain and Sheep Ridge are part of an uplifted, east-tilted block on the east side of the Mosquito Range. Uplift of this block occurred along the northwest-trending London fault, which defines the southwestern margin of the block. A breached anticline-syncline pair is associated with this fault. The London fault and fold system was described in detail by Singewald and Butler (1941) and Berry (1990). Characteristics of the system are summarized below along with additional field observations made during the course of this investigation.

LONDON FAULT and FOLD SYSTEM

The London fault is a major Laramide, north-northwest-trending, high-angle reverse fault best exposed in the mine workings at London Mountain about 2 to 3 miles northwest of the quadrangle. About three miles northwest of London Mountain, the fault terminates against the Mosquito fault, a prominent high-angle, range-front fault on the west side of the Mosquito Range with a strike length of at least 33 miles (Behre, 1953) and with approximately 9,000 feet of normal displacement and 1,500 feet of left-lateral, strike-slip motion in post-Oligocene time (Wallace and others, 1968). At London Mountain, the London fault is characterized by a generally northwest-trending zone of fracturing, breccia, and gouge ranging up to 70 feet in width (Berry, 1990). Average dip of the structure is about 70° northeast (Singewald and Butler, 1941). Vertical throw is estimated at 3,300 feet at Pennsylvania Mountain immediately northwest of quadrangle (Berry, 1990). Singewald and Butler (1941) reported a total of 3,000 feet of displacement; they attributed 1,400 feet of offset to folding and 1,600 feet of offset to faulting. The West London fault is a high-angle, east-dipping subsidiary structure that roughly coincides with the trough of the syncline just west of the main London fault. Berry (1990) calculated 100 to 700 feet of reverse movement on the West London fault.

The London fault system enters the northwest corner of the Fairplay West quadrangle in section 28. Here, and continuing south through the saddle between Sheep and Lamb Mountains, the fault system strikes generally north-south and dips 51° to 90° east. Within the quadrangle, the main London fault and West London fault merge and splay and are no longer identifiable as distinct structures. Within this fault zone, strata are highly silicified and dip steeply to the west. The quartzite of Sheep Mountain and numerous intrusive porphyry sills (TKg and Tqp) are the principal units occurring within the fault zone. A few thin beds, or fault slivers, of Leadville Limestone are also present. On the flank of Sheep Mountain, the Leadville Limestone and quartzite of Sheep Mountain dip about 30° west and both are intensely brecciated and silicified within the fault zone.

South of Sheep Mountain, the structure is poorly exposed, but stratigraphic offset of lower Paleozoic rocks against the Coffman Member of the Minturn Formation indicates the fault curves to the southeast and is parallel to Sheep Ridge. Southeast of Sheep Ridge the structure cannot be traced with certainty, as a thick mantle of colluvium and residuum on Round Hill conceals the bedrock and any possible structure at that location. However, Stark and others (1949) showed the fault as continuing as far south-southeast as Antero Reservoir 11 miles southeast of the quadrangle.

The anticline and syncline pair associated with the London fault are relatively tight, asymmetric structures parallel to and occurring within 500 to 1,000 feet of the main fault (Berry, 1990). Within the quadrangle, Pennsylvanian rocks of the Coffman Member and late Cretaceous and Tertiary intrusive sills and plugs are exposed in the syncline; lower Paleozoic rocks and other late Cretaceous and Tertiary sills are exposed in the anticline. The syncline is best exposed on the north flank of Sheep and Lamb Mountains (fig. 20). The west limb of the syncline dips east 20 to 25° degrees and is intruded by a large plug and associated sill (TKg) near the synclinal axis. The east limb of the syncline dips steeply west to vertical where truncated by the London fault and is reportedly overturned at some locations north of the quadrangle (Berry, 1990). Strata in the east limb are stretched and thinned, and numerous bed-parallel faults and fractures are likely attributable to flexural-slip.

The anticline is well exposed on the north flank of Sheep Mountain (fig. 22). Here, a cross sectional view can be seen as east-dipping lower Paleozoic rocks are folded into a tight, overturned anticline. The west limb is stretched and thinned, broken by numerous accommodation faults, and is breached just west of the anticlinal axis. The east limb of the anticline dips about 20° to the east, mimicking regional eastward dips along the eastern flank of the Mosquito Range.

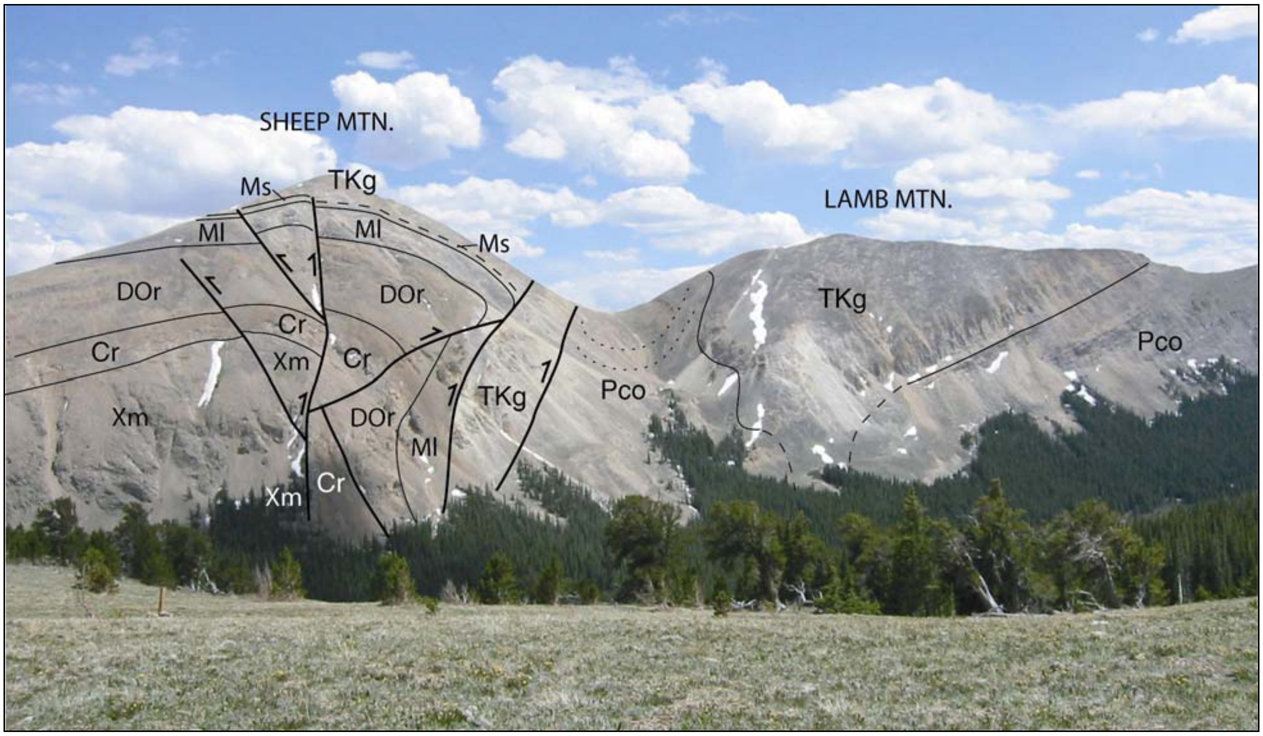

Figure 22. View looking south at the London fault and fold system at Sheep Mountain. Xm–Precambrian migmatite; Cr–Cambrian rocks (Sawatch Quartzite and Dotsero Formation); DOr–Devonian to Ordovician rocks (Manitou Dolomite, Parting Formation and Dyer Dolomite); Ml–Mississippian Leadville Limestone; Ms–Mississippian (?) quartzite of Sheep Mountain; Pco–Coffman Member of the Minturn Formation; TKg–Paleocene to Upper Cretaceous granite porphyry. Dotted lines indicate bedding within the Coffman Member.

FOURMILE CREEK FAULT and FOLD SYSTEM

The fault and fold system at Fourmile Creek is similar to the London fault and fold system. The Fourmile Creek fault is a high-angle reverse fault that strikes north to north-northwest and dips 74° east. It is well exposed along the creek bottom in the SW¼ of section 18, T. 10 S., R. 77 W. (fig. 23). Strata in the western downthrown side are folded into an asymmetric syncline, the axis of which is about 2,500 feet west of the main fault. West of the synclinal axis, bedrock is obscured by thick glacial deposits but bedding is presumed to be consistent with east-dipping bedding orientations on the eastern flank of Sheep Ridge. East of the synclinal axis bedding dips west and gradually steepens to about 45° as the main fault is approached. A triangular wedge of bedrock is tilted as much as 76° to the west immediately adjacent to the fault.

East of the Fourmile Creek fault, the rocks are deformed into a series of tight folds. These tight folds are interpreted as teepee (or popup) structures and are attributed to “localized volume accommodation that is related to lateral displacements of large rock masses" in a fold hinge developed over a fault block (Weinberg, 1978, p. 76). The bulk of the deformation across the Fourmile Creek fault and fold system appears to be attributable to folding, while actual offset due to faulting does not appear to be great – probably less than a few hundred feet.

Figure 23. View looking north at the Fourmile Creek fault. Labels indicate dip and dip direction of bedding in the Minturn Formation. Arrows indicate relative motion on fault surfaces.

OTHER STRUCTURES

An inferred, down-to-the-east normal fault, informally termed the Fairplay fault extends into the east-central part of the Fairplay West quadrangle on the basis of the juxtaposition of west-dipping Tertiary sediments and east-dipping Pennsylvanian rocks in the Fairplay East quadrangle (Kirkham and others, 2006). Because there is no known surface expression of the fault, its precise location and orientation are uncertain. However, cross sections suggest a minimum post-Oligocene displacement of approximately 1,500 feet (Kirkham and others, 2006).

ECONOMIC GEOLOGY

METALLIC MINERALS

The Fairplay West quadrangle is located along the southeastern margin of the Colorado Mineral Belt and is peripheral to the Alma mining district (fig. 22), which is known for its (1) carbonate-hosted silver-lead-zinc sulfide deposits, silver-gold bearing mantos (strata-bound orebodies) in lower Paleozoic carbonates (Machado, 1967), (2) world famous rhodocrosite associated with silver-bearing, quartz-fluorite-tetrahedrite-fluorite veins in Precambrian granite (Moore and others, 1998), and (3) extensive gold placering operations. The history, mining, and mineralization of the Alma district are well outlined by Emmons (1886), Patton and others (1912), and Widmann and others (2004a).

LODE DEPOSITS

The London mining district is a sub-district within the greater Alma district (fig. 24). The main London mine workings are roughly three miles northwest of Fairplay West quadrangle, although the London district itself encompasses an area which extends southward into the northwest quarter of the quadrangle. Near London Mountain, minor mineralization occurs in the hanging wall of the London fault, but the principal mine workings in the district have been found in the footwall at depths of 0 to about 700 feet (Singewald and Butler, 1941). Within the Fairplay West quadrangle, however, historic mine workings are limited to the hanging wall, and the potential ore-bearing zone in the footwall is at a much greater depth (likely as much as 2,000 feet below the surface). Although not fully explored, Singewald and Butler (1941) suggested the possibility of marginal (i.e., distant to main mineralized area) lode deposits at depth in the Mudsill Spring and Sheep Mountain area.

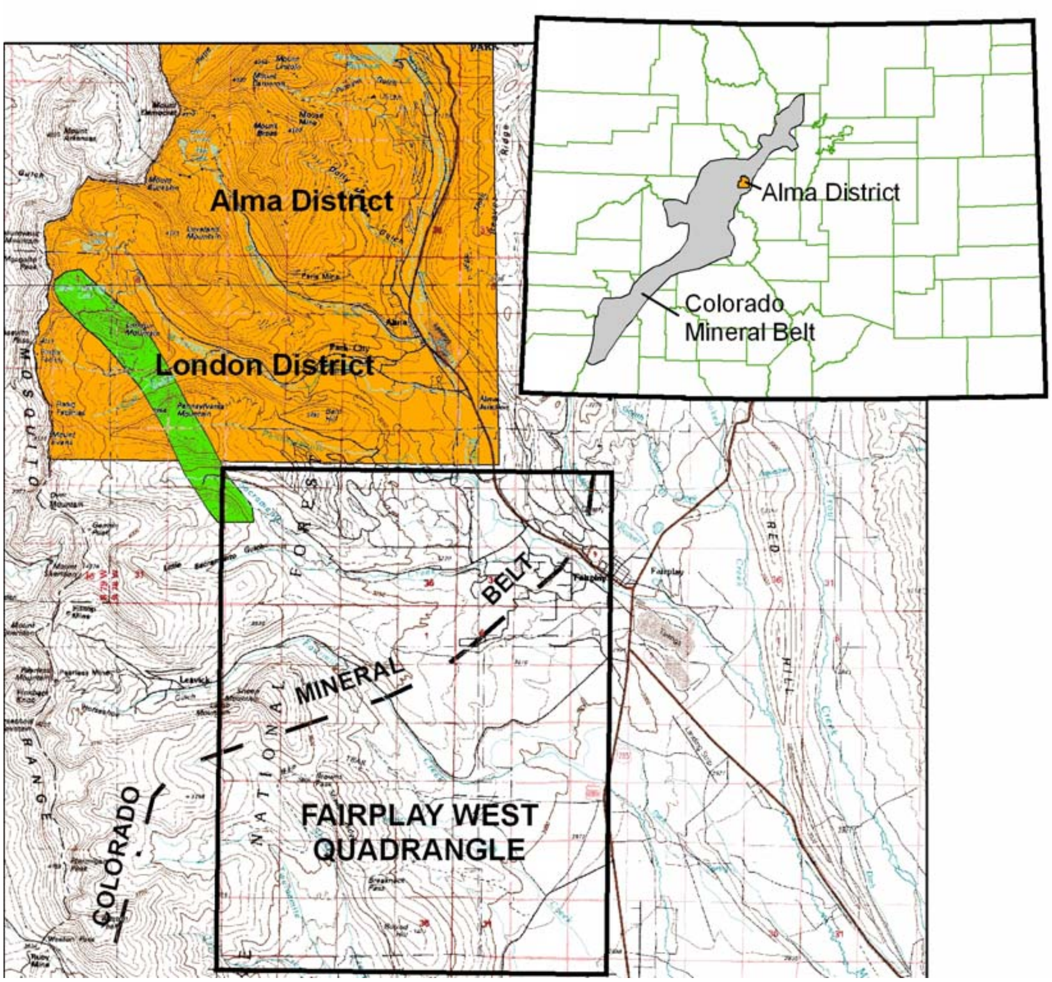

Figure 24. Overview of the London (green) and Alma (orange) districts relative to the Fairplay West quadrangle. Inset map of Colorado shows location of the Alma district within the Colorado Mineral Belt.

Mineralization

The London mining district is largely defined by the mineralized zones along the London fault. Three types of mineralization occur in the district; they are summarized below after Singewald and Butler (1941): (1) gold-bearing quartz veins along faults and fractures associated with the London fault, (2) silver-lead replacement deposits found to a lesser extent in Leadville Limestone that has been shattered due to movement on the London fault, and (3) gold ± silver mineralization, although rare, found in fractures in the Sawatch Quartzite. Most mineralization in the district occurs in the footwall of the London fault, although some mineralization has been observed both within the fault and in the hanging wall of the fault. Mineralization is also most prolific in the basal part of the Minturn Formation and upper Leadville Limestone, although mineralization is known to extend stratigraphically downward as far as the Sawatch Quartzite.

Gold-bearing veins are developed along two main fault types. The first, and most common, are flexural-slip faults. These faults, and associated veins, dip steeply to the west and flatten with depth in the footwall syncline of the London fault system. The veins occur primarily in the lower part of the Minturn Formation in a zone where porphyry sills are abundant. The second fault type is generally subparallel to the London fault. Veins associated with these faults tend to crosscut lower Paleozoic strata and typically dip eastward (Berry, 1990). Primary constituents of these ore deposits include quartz, pyrite, sphalerite, galena, and chalcopyrite, listed in order of typical abundance. Rarely, free gold may be found in particularly rich ore zones (Singewald and Butler, 1941).

Silver-lead deposits within the district are associated with karst and fault breccias in dolomitic rocks, particularly within the Leadville Limestone. The principal ore minerals include sphalerite, galena, tetrahedrite, and pyrite. Barite is locally abundant (Berry, 1990).

In the southern part of the London district, and within the Fairplay West quadrangle, mineralization is nowhere as extensive or rich as in the area of the main London mine workings. Mineralization in the quadrangle is generally limited to silver-lead replacement deposits in the Leadville Limestone. Unlike mineralization in the main part of the district, ore deposits in the southern part of the district are found in the hanging wall of the London fault. This is, in part, because the rocks exposed at the surface in the southern part of the district are higher in the stratigraphic section. There is also less clay gouge in the fault zone within the quadrangle, so mineralizing fluids were probably better able to migrate through the fault zone and into the hanging wall (Singewald and Butler, 1941). Detailed exploration studies are needed to determine the potential, if any, for footwall mineralization in the quadrangle.

Production

The London district has produced about 700,000 ounces of gold and an approximately equal amount of silver (Berry, 1990). Most production occurred in the late 1800s, however, renewed interest led to minor production in the late 1980s. A 1991 evaluation of waste piles and core drillings from the London mine indicated the need for higher gold prices to warrant continued production from the mine (Peterson and Cappa, 1991). The London mine remains shut down.

Historic production reported by Singewald and Butler (1941) from some of the London district mines within the Fairplay West quadrangle (fig. 25) are summarized below.

Sacramento Mine

The majority of the Sacramento mine area is in section 33 of the northwest part of the Fairplay West quadrangle. Ore was mined from an east-dipping replacement deposit in the Leadville Limestone. Gross output was $175,000 through 1882 (over $3.4 million in 2005 currency). Thereafter, production was minimal. Ore grade is listed at 10 percent lead, 0.75 ounces/ton gold, and $200/ton silver (historic prices).

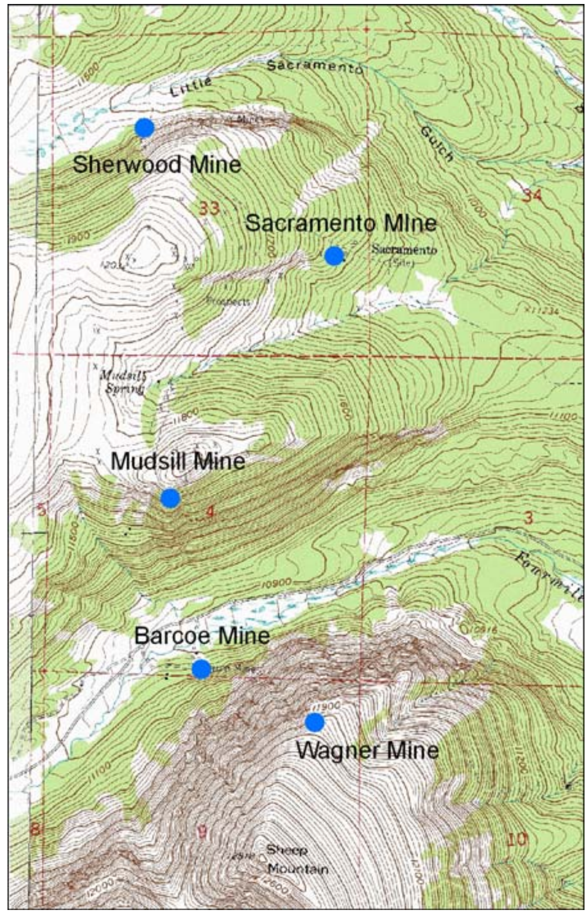

Figure 25. Map showing general location of mines in the Fairplay West quadrangle described in Singewald and Butler (1941).

Mudsill Mine

The Mudsill mine workings are in section 4 just south of the Sacramento mine area. Silver-lead replacement deposits were mined from the Dyer Dolomite. Gross production amounted to about $60,000 (over $1 million in 2005 currency).

Sherwood Mine

The Sherwood mine is located in the northwest quarter of section 33 on the south side of Little Sacramento Creek. Ore was derived from the Leadville Limestone, which dips steeply to the west adjacent to the London fault. Production from this mine was valued at approximately $50,000 (nearly $1 million in 2005 currency).

Other Mines

Other small mining operations, such as the Barcoe and Wagner mines, targeted silver-lead replacement deposits in the Leadville and Dyer Dolomites in the hanging wall of the London fault. The common ore minerals include galena, pyrite, sphalerite, limonite; gangue constituents include dolomite, barite, and jasperoid. Production from these mines was minimal.

PLACERS

Gold placering has been an important part of the mining history in Park County. Below follows a summary of a detailed report on placer operations in Colorado by Parker (1974).

The most productive placers in Park County are located along the South Platte River from Alma to about four miles south of Fairplay. Within the Fairplay West quadrangle, smaller placer deposits have also been worked along Beaver Creek, Sacramento Gulch, and Fourmile Creek. The placers occur in glacial outwash, moraines, and fluvial gravels that were derived from a multitude of mineralized areas throughout the Alma mining district. The first "large-scale" placering operation began in Alma around 1869-70 and was soon followed by placering in the Fairplay area in 1872 (Parker, 1974). During the first few years gold was recovered by hand methods, but by 1874 two flume and hydraulic operations were in place in Fairplay. The first hydraulic dredge was installed in 1922. Dredging continued in this area through the mid-1960s.

Prior to 1872, placer operations in the Fairplay area produced gold valuing roughly $1 million (over 20 million in 2005 dollars) (Raymond, 1873). From 1904 to 1938 Singewald (1950) reports production of 25,934 ounces of gold. The South Platte Dredging Company produced gold valued at over $3 million (over $24 million in 2005 currency) between 1941 and 1952 (Parker, 1974).

The long, sinuous piles of gravel, locally known as "the intestines", just southeast of Fairplay and east of the Fairplay West quadrangle are waste products left behind by the large dredge boats. The South Platte No. 1 dredge was the largest dredge in Colorado. It was a bucket-line dredge with a maximum processing capacity of 15,000 cubic yards of auriferous gravel per day and could dig to a maximum depth of 96 feet (Parker, 1992). The Snowstorm Dredge, currently residing in a pond at the Snowstorm sand and gravel pit northwest of Fairplay, is the last intact gold dredge in Colorado. Efforts are underway by the Park County Chamber of

Commerce to refurbish the dredge and relocate it to the nearby South Park City Museum in Fairplay.

Today, most mining activity in the Fairplay area involves extraction of sand and gravel. However, a few of the sand and gravel operations are utilizing gold recovery circuits to obtain gold as a secondary commodity. Small-scale recreational gold panning is still sometimes successful along the South Platte River and other local streams.

INDUSTRIAL MINERALS AND CONSTRUCTION MATERIALS

The Fairplay area is host to relatively abundant industrial mineral and construction material resources. There are four active permitted sand and gravel mining operations within the Fairplay West quadrangle (Guilinger and Keller, 2004). Although other potential industrial mineral resources exist, no other mining operations are currently permitted in the quadrangle.

SAND and GRAVEL

There are abundant and high-quality sand and gravel resources in the Fairplay West quadrangle that may be used for a variety of aggregate needs such as road base and ingredients in asphalt and concrete. Large deposits of glacial outwash and stream alluvium form numerous ridges and terraces along the Middle Fork of the South Platte River, Sacramento Creek, Fourmile Creek, High Creek, and Twelvemile Creek. Map units Qa, Qa_1, Qa_2, Qa_3, Qti_1, and mw are all potential sources of high-quality aggregate in the quadrangle. Unit Qti_2 is also a potential source for gravel, but moderate clast decomposition slightly reduces the quality of this particular resource. These deposits range in thickness from about 5 to as much as 300 feet and contain moderate- to well-rounded, hard, competent clasts of a wide variety of sizes and lithologies.

Sand and gravel deposits in the Fairplay region also have potential to yield significant amounts of placer gold in addition to construction aggregate. At least two of the aggregate operations in the area have implemented a secondary gold recovery system. Most historic gold placer production has come from units Qa_1, Qa_2, Qa_3, Qti_1, and Qti_2 (fig. 26), but only those deposits with a provenance of the Middle Fork of the South Platte or Beaver Creek seemed to have received much attention for placering.

Figure 26. China Bowl, located in the center of the NE¼ of section 29, T. 9 S., R. 77 W., is a deep pit resulting from hydraulic gold placer mining in middle Pleistocene till (Qti_2). The large piles of cobbles on the floor and right side of the pit were hand-stacked during mining.

<u>BUILDING STONE and CRUSHED ROCK</u>

Several of the rock types in the Fairplay West quadrangle may be suitable for building stone or crushed rock applications. Precambrian rocks throughout the state have long been quarried for building stone, crushed aggregate, riprap, and decorative stone. Small bodies of Precambrian granite (Yqp) are exposed along Fourmile Creek and Sacramento Creek in the western part of the quadrangle, and most of the peaks in this area are cored by Precambrian gneiss and migmatite (Xm). Additionally, several of the lower Paleozoic units (Ꞓs, Ꞓd, OꞒm, Dc, and Ml) in the area are extensive enough and potentially sound enough for a variety of construction or decorative uses. Tertiary intrusive rocks present in the quadrangle (Tqp, TKg) also are a potential source of crushed-rock aggregate. The flaggy weathering of both these units would likely prohibit either from being used as building stone or in applications where strength is of concern. Talus (Qta), protalus (Qpt), mw, and some glacial deposits (Qti_1, Qti_2) are potential sources of riprap and crushed stone. Units Qti_1, Qti_2, and mw are also locally mined for landscaping rock; the larger the boulder, the higher the price per ton.

CARBONATE ROCKS

Limestone and dolomite (₽m, Ml, Dd, and O€m) have a wide variety of applications such as dimension or crushed stone; ingredients in cement and concrete; coal mine dusting to prevent coal fires; soil conditioning; and metallurgical and chemical processes. Historically, the Leadville Limestone was used to make fluxing agents for local smelters. Thin limestone beds in the Minturn Formation may be of sufficient quality for some industrial uses, but their limited and discontinuous nature generally makes them economically undesirable.

PEAT

Several historic peat mines have operated in Park County, though none are currently active. Peat resources locally overlie Quaternary alluvial deposits and are found in low-lying, boggy or marshy areas mapped as Qao, particularly in the northern part of the quadrangle. Peat is primarily used in potting soil mixtures and as a soil conditioner.

OIL AND GAS

South Park basin, particularly the eastern portion, has been the target of sporadic oil and gas exploration since the early 1930s. No significant commercial production has so far been established and there have been no wells drilled within the quadrangle. The principal potential reservoir units in the basin are the Cretaceous Dakota Sandstone, Fox Hills Sandstone, and sandstone subunits within the Pierre Shale such as the Apache Creek Member (Clement and Dolton, 1970). The Permian Garo Sandstone is also a potential hydrocarbon reservoir. All of these units are stratigraphically higher in the geologic section than any of the rocks found in the Fairplay West quadrangle. Therefore, this quadrangle is not likely to be prospective for oil or gas.

COAL

The Fairplay West quadrangle is not highly prospective for coal resources. The majority of coal historically mined in Park County is from the Cretaceous Laramie Formation, which is higher in the stratigraphic section than any of the sedimentary rocks in the quadrangle. However, Brill (1942) reported thin seams of impure coal in the Belden Formation (ℙb) at some locations in the Gore Range to the north. The Belden Formation crops out in limited extent only in the southwest corner of the Fairplay West quadrangle. No coal seams were noted.

GEOLOGIC HAZARDS and ENGINEERING CONSTRAINTS

Geologic hazards and geotechnical constraints in the Fairplay West quadrangle include sediment-laden flooding, debris flows, rockfall, landsliding, solifluction, compaction, earthquakes, and perhaps subsidence. Areas underlain by alluvial unit one (Qa_1), alluvium and organic-rich sediment (Qao), alluvium and colluvium (Qac), and topographically low areas mapped as alluvial units one and two, undivided (Qa), are prone to flooding, including sediment-laden flood waters and possibly hyperconcentrated floods. Debris flows, mudflows, and sheet flooding may affect areas mapped as fan deposits (Qf) and alluvium and colluvium (Qac).

Rockfall, rock topples, and rock slides are a hazard on and beneath cliffs of hard rock, such as those found in the upper reaches of Fourmile Creek, Little Sacramento Gulch (fig. 27), and Sacramento Creek, and in the unnamed tributary to Sheep Creek south of the saddle between Lamb and Sheep Mountains. Areas mapped as talus (Qta) and some areas mapped as colluvium (Qc) are particularly prone to rockfall. Minor rockfall hazards may exist anywhere a cliff or rocky outcrop occurs on a steep slope.

Figure 27. Rock debris that falls from the cliffs on the south side of Little Sacramento Gulch forms an apron of talus beneath the cliffs. The rockfall hazard below the cliff is very high.

Several landslides are present in the quadrangle. They occur in a variety of geologic environments, but most are on bedrock dip slopes, in areas of strongly fractured bedrock, or in glacial till. The landslide on the north side of Sacramento Creek, which involved bedrock, diamicton, and till, has a prominent headscarp (fig. 3). No evidence of active or historical landslide activity was documented during this study. Most landslide deposits in the quadrangle post-date the Pinedale glaciation, but they appear to be stable or quasi-stable under present conditions. However, natural events such as intense rainfall, rapid snowmelt, ground shaking during earthquakes, and changes in ground-water levels can destabilize slopes and trigger landslides. Human activities, including excavations, emplacement of earth fills on slopes, and changes to the hydrologic environment from irrigation, septic systems, and water impoundments and diversions, also can contribute to slope failure. Areas mapped as landslide deposits (Qls) and also areas with geologic settings similar to the mapped landslide deposits may be prone to future slope failures. Some areas mapped as colluvium (Qc), especially the deposit of colluvium on the southwest side of Round Mountain, may be susceptible to future landsliding.

The area mapped as landfill is prone to compaction. Trash placed in a landfill usually compacts over time, causing the ground surface to lower. Landfills may also generate methane, an explosive gas that results from the decomposition of organic materials.

Although no active faults were identified within the quadrangle, earthquakes resulting from the surface rupture of nearby faults, like those at Spinney Mountain (Shaffer and Williamson, 1986) or in the upper Arkansas Valley (Ostenaa and others, 1981; Lettis and others, 1996), could cause moderately strong ground motion in the quadrangle. A random or “floating” earthquake along a fault that is deep in the crust and does not rupture the ground surface also could generate moderately strong ground motion in the quadrangle. Earthquakes can also trigger secondary effects, such as liquefaction, rockfall, and landslides, which potentially can cause great damage.

Several semi-circular topographic depressions of uncertain origin exist in the quadrangle and are denoted on the geologic map. A nearly linear string of depressions in the SE ¼ of section 32, T. 10 S., R. 77 W. occur in glacial outwash (Qa_2) that overlies the Minturn Formation. Several individual depressions lie within a larger, slight depression in the surface of the outwash fan. Shawe and others (1995) concluded that these features were sinkholes formed in surficial deposits that overlie the evaporite facies of the Minturn Formation and suggested they coincided with a north-trending fissure. Shawe and others (1995) also reported small areas of hummocky ground that may be associated with subsidence in section 5, T. 11 S., R. 77 W. along the southern edge of the Fairplay West quadrangle.

Dissolution of soluble evaporite minerals can create subsurface voids into which overlying materials collapse. Although the evaporite facies of the Minturn does not crop out within the quadrangle, it is present a short distance south (Shawe and others, 1995), and it could exist beneath the surficial sediments in the vicinity of the depressions. If the depressions are sinkholes associated with evaporite karst, then they may pose hazards that should be evaluated prior to construction activities. Adjacent areas in the southeastern part of the quadrangle also might be affected by subsidence if evaporite strata are present.

Other topographic depressions were observed in sections 6 and 18, T. 10 S., R. 77 W. These features are in surficial deposits adjacent to or within terminal moraines and are suspected of having a glacial origin. The depressions may be kettles, which form by melting of large blocks of ice that either were detached from a glacier and carried downstream by meltwater or left behind by a retreating glacier. If unrecognized evaporitic rocks exist beneath the surficial deposits at the depressions, then the depressions may be subsidence features.

WATER RESOURCES

SURFACE WATER

The Fairplay West quadrangle is located in the west-central part of the South Park drainage basin and is part of the South Platte watershed. The Middle Fork of the South Platte River flows across the northeast corner of the quadrangle. Other major drainages in the quadrangle include, from north to south, Sacramento Creek, Fourmile Creek, High Creek, Sheep Creek, Twelvemile Creek, and Cave Creek. Sacramento Creek is the only drainage that flows into the Middle Fork. All of the other drainages are tributaries to the South Fork of the Platte River several miles to the southeast. Sheep Creek, Twelvemile Creek, and Cave Creek all flow southward and are captured in Antero Reservoir, roughly 12 miles southeast of the quadrangle, before being released back into the South Fork.

There are currently no data available for annual stream flow rates or water quality of the surface waters emanating from the Fairplay West quadrangle. Surface waters are used primarily for irrigation, livestock, and recreational purposes. Stretches of Fourmile Creek and Twelvemile Creek are privately owned by local fishing clubs.

GROUND WATER

According to the Colorado Division of Water Resources there are about 475 water wells completed in the Fairplay West quadrangle (data from 2001). Nearly all wells are less than 600 feet deep with a mean depth of about 180 feet. Most well yields are less than 35 gpm with a mean yield of about 8 gpm. Vast alluvial and glacial sand and gravel deposits ranging from 5 to as much as 300 feet in thickness blanket the eastern half of the Fairplay West quadrangle. These types of deposits commonly constitute good ground water aquifers. Bedrock aquifers in the quadrangle are hosted in the porous conglomerate and sandstone beds of the Minturn Formation.

The USGS recently conducted an in-depth study of the groundwater quality of the aquifers in the Fairplay area (Ortiz, 2004). Water samples were collected from 53 domestic wells in both alluvial and bedrock aquifers. The USGS findings are briefly summarized in table 1. The reader is referred to the full USGS report for more detailed information.

Constituent	**Alluvial Aquifer (median value)**	**Bedrock Aquifer (median value)**	**General Relativity to EPA Standards**
pH (standard units)	7.6	7.7	n/a
Total dissolved solids (mg/L)	209	221	n/a
Dissolved organic carbon (mg/L)	0.5	0.4	n/a
Hardness (mg/L)	200	210	Considered “hard”
Alkalinity (mg/L as $CaCO_3$)	162	193	n/a
Chloride (mg/L)	1.1	1.2	Below
Fluoride (mg/L)	<0.17	0.2	Below
Sulfate (Mg/L)	21.0	21.2	Above
Nitrite (mg/L)	<0.008	<0.008	Below
Phosphorus (mg/L)	<0.004	<0.004	n/a
Aluminum (µg/L)	<15	<15	Below
Arsenic (µg/L)	<1.9	2.0	Below
Boron (µg/L)	<13	<13	Below
Cadmium (µg/L)	<8	<8	Below
Copper (µg/L)	<6	<6	Below
Iron (µg/L)	190	192	Above
Manganese (µg/L)	15	11	Above
Zinc (µg/L)	<24	<24	Below
Uranium (µg/L)	3.0	3.3	Below
Radon (pCi/L)	1,700	1,550	Above

Table 1. Measurements of groundwater quality in the Fairplay area as reported by the U.S. Geological Survey (Ortiz, 2004).

The groundwater characteristics of the many bedrock aquifers in South Park are described in the Colorado Geological Survey’s Ground Water Atlas of Colorado (Topper and others, 2003). However, within the Fairplay West quadrangle, the principal aquifer is the Minturn Formation, which is characterized by interbedded siltstone, sandstone, conglomerate, and limestone. Bedrock units underlying the Minturn Formation may also have aquifer potential, but depth to these units throughout much of the quadrangle is well beyond 1,000 feet.

According to Topper and others (2003), recharge to the South Park aquifers is almost entirely through direct infiltration of rainfall and snowmelt. Recharge also occurs where porous rock units underlie saturated alluvium or through individual septic disposal systems. Discharge occurs at natural springs, as base flow in adjacent stream courses, and by ground water withdrawal from wells. Ground water usage in South Park is primarily for domestic purposes and comprises only about 10 percent of total water consumption.

GEOTHERMAL SPRINGS

There are a few naturally-flowing springs and evidence for at least one dormant spring in the Fairplay West quadrangle. Only one of these springs, the Rhodes warm spring, has been sampled and described in the literature (Barrett and Pearl, 1976; 1978). The Rhodes spring is located in the SW¼ of section 13, T. 10 S., R. 78 W. Water emanating from this spring had a surface temperature of 25° C, contained about 190 mg/L total dissolved solids (TDS), and had a measured flow rate of 200 gallons per minute (October, 1975). The spring flows into a series of six privately held, trout-stocked pools in the gated community of Warm Springs. Several other small seeps and springs in the immediate vicinity also discharge into the community pools.

Another small spring is located in the NE¼ of section 18, T. 10 S., R. 77 W. Although this spring has not been sampled, the owner of the property (R. Carroll) indicated the spring flows throughout the year and does not freeze during the winter months. The spring discharges from alluvial deposits into a small, natural pool.

Tufa deposits and carbonate-cemented sand and gravel in the SW¼ of section 24, T. 10 S., R. 78 W suggest past seepage or spring activity, but evidence of recent flowage was not observed. Although Barrett and Pearl (1978) suggested the Rhodes Spring is fault controlled, our field investigations indicate that the springs in the Fairplay West quadrangle are more likely attributable to upward flow of groundwater along the interface between differing rock types such as between the Leadville Limestone and overlying quartzite of Sheep Mountain and Coffman Member of the Minturn Formation.

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