OPEN-FILE REPORT 01-01

Geologic Map of the Castle Rock Gulch Quadrangle, Chaffee and Park Counties, Colorado

By C. A. Wallace, and John W. Keller

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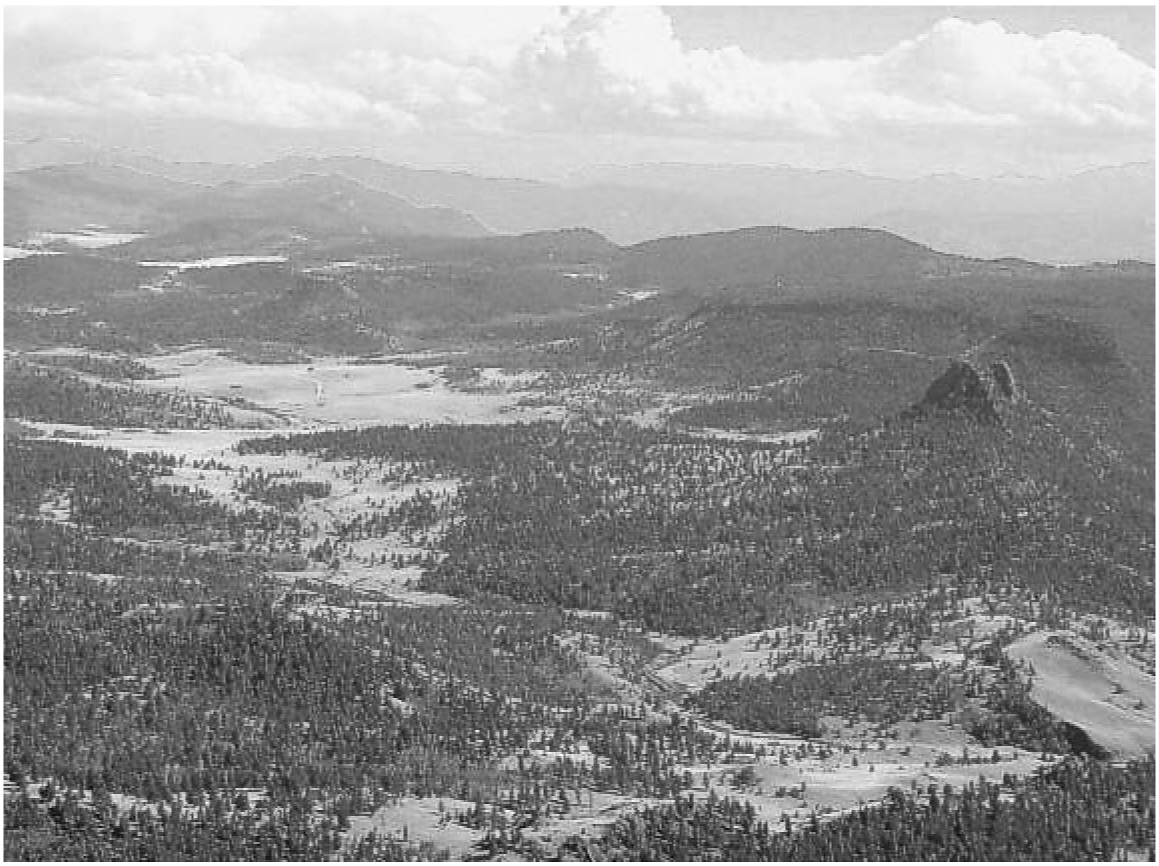

View from Kaufman Ridge looking to the southwest over the Castle Rock Gulch quadrangle

Colorado Geological Survey
Division of Minerals and Geology
Department of Natural Resources
Denver, Colorado / 2003

FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 01-1, *Geologic Map of the Castle Rock Gulch Quadrangle, Chaffee and Park Counties, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in the central Mosquito Range of central Colorado. Chester A. Wallace, consultant, and John W. Keller, staff geologist at the Colorado Geological Survey, completed the field work on this project in the summer of 2000.

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

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INTRODUCTION

The Castle Rock Gulch quadrangle is located in the east-central part of Chaffee County and the southwestern part of Park County in the central part of the Mosquito Range about 21 km north of Salida, Colorado and 10 km east of Buena Vista, Colorado. U.S. Highways 285 and 24 pass through the northwestern part of the quadrangle. The map area includes rugged terrain and steep canyons along the western border and northwestern part of the quadrangle and high rolling hills in the southern and central parts of the quadrangle. Kaufman Ridge and Bassam Ridge are prominent topographic features that trend southeast and northwest in the map area. Elevations range from about 8,600 to 10,800 ft.

The oldest rocks in the quadrangle are Proterozoic igneous and metamorphic rocks that are overlain unconformably by Paleozoic sedimentary rocks, Tertiary volcanic and sedimentary rocks, and Quaternary slope-wash, talus, landslide, and stream deposits. A large sill of probable Laramide age (Late Cretaceous or Paleocene) intruded Pennsylvanian sedimentary rocks in the northwestern part of the map area. Steep faults offset Proterozoic and Paleozoic rocks. Large- and medium-scale anticlines and synclines deform Paleozoic rocks. Mid-Tertiary volcanic rocks and associated tuffaceous sediment were deposited in a prominent paleovalley that trends from southwest to northeast across the quadrangle. Tertiary volcanic rocks in the map area are mainly intermediate and silicic welded tuff and air-fall tuff, and Tertiary sedimentary deposits are poorly consolidated, tuffaceous silt, sand, and gravel.

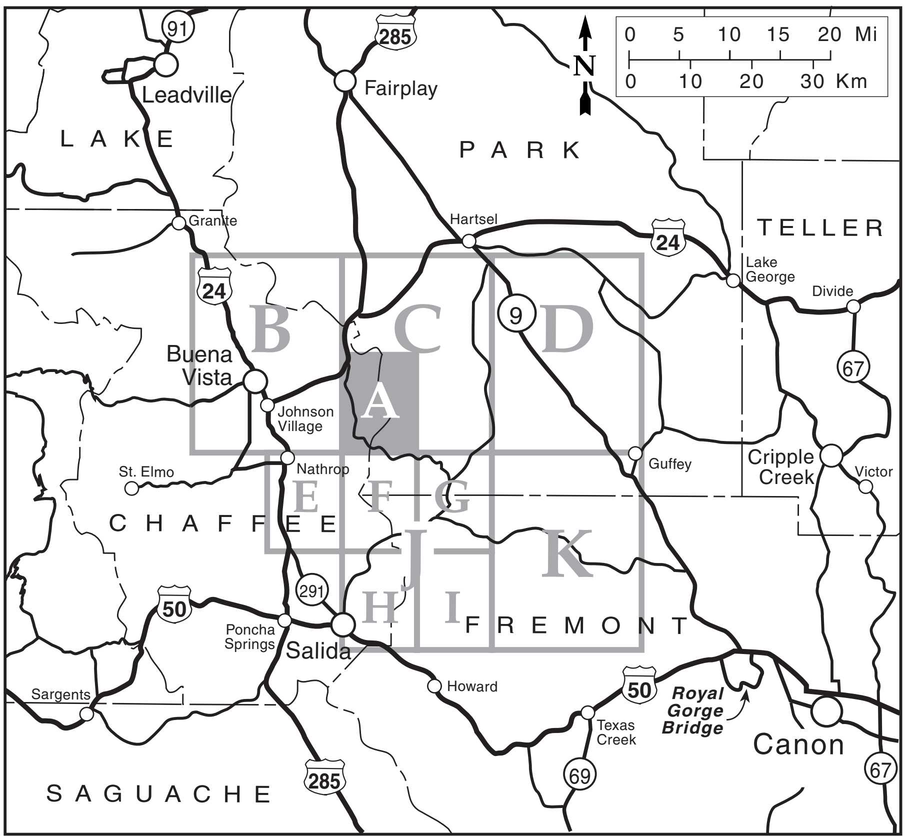
PREVIOUS STUDIES

Numerous geologic studies, most of which date from 1960 to 1980, established the regional geologic framework in the southern Mosquito Range. Reports on regional stratigraphy of lower and middle Paleozoic rocks by Campbell (1972), Conley (1972), Gerhard (1972), Nadeau (1972), and Ross and Tweto (1980) established the regional stratigraphic sequence and lithofacies relations. De Voto (1971, 1972, 1980a, 1980b), and De Voto and Peel (1972) established the stratigraphic framework for upper Paleozoic rocks in the southern Mosquito Range. Chapin and Lowell (1979), Epis and Chapin (1974), and McIntosh and Chapin (1994) developed regional correlations of ash-flow tuff deposits and determined isotopic ages for volcanic rock units.

A series of 15-minute geologic maps by the U.S. Geological Survey (Scott, 1975; Wrucke and Dings, 1979; Epis and others 1979a, 1979b) described geologic relations in the southern Mosquito Range (Fig. 1). De Voto (1971) published the Antero Reservoir quadrangle (scale 1:62,500), which includes this map area. The Colorado Geological survey published a series of geologic maps at 1:24,000 scale in the southern Mosquito Range (Wallace and others, 1997; Wallace and Lawson, 1998; Wallace and others, 1999, 2000), and this map area is the fifth map in that series. The geology of the Castle Rock Gulch quadrangle is shown in a generalized form in the western part of the Pueblo 1° x 2° quadrangle (Scott and others, 1978).

PRESENT STUDY

The present study focuses on geologic mapping of the Castle Rock Gulch quadrangle at a scale 1:24,000. Most geologic mapping was completed in the summer of 2000. Rock names in this report are field terms: sedimentary rocks are named according to the scheme proposed by Pettijohn (1957); metamorphic rocks names follow the system proposed by Best (1982); igneous intrusive rocks were named according to the I.U.G.S classifications proposed by Streckeisen (1973); and volcanic rocks were named based on chemical classifications proposed by LeBas and others (1986). Field data were plotted on U.S. Forest Service color aerial photographs taken in 1997 at a nominal scale of 1:24,000.



A. Castle Rock Gulch 1:24,000 geologic map (present study), CGS

B. Buena Vista 1:62,500 geologic map (Scott, 1975), USGS

C. Antero Reservoir 1:62,500 geologic map (De Voto, 1971), Colo. Sch. Mines

D. Guffey 1:62,500 geologic map (Epis and others, 1979b), USGS

E. Poncha Springs NE 1:24,000 geologic map (Van Alstine, 1969), USGS

F. Cameron Mountain 1:24,000 geologic map (Wallace and Lawson, 1998), CGS

G. Gribbles Park 1:24,000 geologic map (Wallace and others, 1999), CGS

H. Salida East 1:24,000 geologic map (Wallace and others, 1997), CGS

I. Jack Hall Mountain 1:24,000 geologic map (Wallace and others, 2000), CGS

J. Cameron Mountain 1:62,500 geologic map (Wrucke and Dings, 1979), USGS

K. Black Mountain 1:62,500 geologic map (Epis and others, 1979a), USGS

Figure 1. Location map of the Castle Rock Gulch quadrangle, showing previous geologic maps in the area.

The differences between the geologic features shown on the Castle Rock Gulch quadrangle and the Antero Reservoir quadrangle of De Voto (1971) result from differences of scale, not substance. De Voto's map of the Antero Reservoir quadrangle provided an accurate base from which to begin our work. We modified stratigraphic nomenclature of upper Paleozoic and volcanic rocks to reflect modern usage. We used a different stratigraphic name than De Voto (1971) for an upper Paleozoic unit in the southwestern corner of the map area on the basis of our new mapping.

STRATIGRAPHY

PROTEROZOIC ROCKS

Proterozoic rocks in the quadrangle are mainly igneous rocks and a lesser amount of metamorphosed igneous rocks. These include an Early Proterozoic granodiorite porphyry **(Xgd)** and younger stocks and dikes of granite **(YXgt)**. Pegmatites **(YXp)** locally intrude the both the granodiorite and the granite. A few xenolithic blocks of biotite gneiss occur within the granodiorite in the quadrangle. The Proterozoic rocks form the core of the Kaufman Ridge anticline and serve as the structural basement in the map area (Schmidt and others, 1993).

The oldest rocks on the quadrangle occur only as xenoliths within the large granodiorite pluton. Blocks of biotite gneiss **(Xb)** large enough to map separately were found at two places in the northern part of the quadrangle. One block of biotite gneiss is well exposed in a roadcut along U.S. Highways 285 and 24 and is dark gray to black, medium grained, and consists of biotite, quartz, plagioclase, and hornblende(?). The block is well foliated at the margins and poorly foliated in the center. Narrow dikes of granodiorite intrude the gneiss near the contact. Rarely, small pieces of the gneiss appear to “float” in granodiorite. A few pegmatitic dikes up to 1.5 m wide cut the gneiss. Foliation in the xenoliths is distorted by the dikes. Biotite gneiss is similar to metamorphosed sedimentary rocks found elsewhere in central and northern Colorado (Tweto, 1987). The sedimentary rocks from which the gneiss is derived were deposited sometime in the interval of 1.75 to 1.95 Ga (Hedge and others, 1986).

Early Proterozoic porphyritic granodiorite **(Xgd)** is the principal igneous rock in the map area. The granodiorite forms a large pluton that occupies the central part of the map area, and underlies Paleozoic rocks in the southwestern, eastern, and northern part of the Castle Rock Gulch quadrangle. The unit extends about 17 km (10 miles) south of the Castle Rock Gulch quadrangle into the northern border of the Salida East quadrangle (Boardman, 1971; Wrucke and Dings, 1979; Wallace and others, 1997). The granodiorite is gray, grayish-orange, and grayish-yellow, speckled, coarse- to very coarse-grained, slightly foliated to non-foliated granodiorite and, rarely, an augen gneiss. Nonweathered granodiorite from old mine workings is pinkish gray to greenish gray. Commonly this unit contains phenocrysts of quartz (~20 percent) and pink microcline feldspar 2 to 4 cm in length (~25 percent). Alignment of biotite, which makes up about 15 to 20 percent of the rock, defines the foliation. Subhedral plagioclase (~35 percent) is white and is partially altered to clay minerals and sericite. Locally biotite has been altered partly to chlorite, and at some places biotite is replaced by muscovite. Where foliation is developed, phenocrysts of microcline are sheared into augen that are as much as 6 cm in length. Because the percentage of quartz is variable this unit is a quartz monzonite locally. In the adjoining Cameron Mountain quadrangle, southernmost outcrops of the granodiorite are part of a strongly foliated border phase in a generally non-foliated pluton that extends for approximately 30 km north into the Castle Rock Gulch quadrangle (Wrucke and Dings, 1979). Granodiorite in the Castle Rock Gulch quadrangle appears to represent the interior and less foliated parts of the pluton. In the vicinity of the prominent north-northwest-striking fault in the northwest and west-central part of the quadrangle the granodiorite is very well foliated locally, and marked variations in degree of foliation occur over a few meters. This strong foliation near the fault zone was not observed to have any preferred orientation. To the southeast in the Jack Hall Mountain quadrangle, the granodiorite intrudes a metamorphosed sedimentary and volcanic unit that has an isotopic age of 1728 ± 6 Ma (Bickford and others, 1989). The granodiorite is of Boulder Creek age and has been dated at 1672 ± 5 Ma (Bickford and others, 1989) in the adjoining Cameron Mountain quadrangle.

Proterozoic granite **(YXgt)** occurs as relatively small stocks and a few dikes in the northwestern part of the Castle Rock Gulch quadrangle. These small masses intrude the older granodiorite unit **(Xgd)**. The granite is pale pinkish orange to light grayish pink, medium to coarse grained, hypidiomorphic granular. It is non-foliated to moderately foliated. De Voto (1971) described this unit as a leucogranite to leuco-quartz monzonite because of the lack of mafic minerals. One whole-rock geochemical analysis of a sample of the granite from the Castle Rock Gulch quadrangle shows the rock to consist of 78 percent SiO_2 (sample no. K0226, Table 1). This places the sample well into the range for granite on the I.U.G.S. classification scheme based on CIPW norms. The granite consists primarily of quartz, alkali feldspar (including perthite), plagioclase, and sparse muscovite and biotite. Some muscovite appears to be an alteration product of biotite. The plagioclase is weakly altered to sericite in places. The pegmatites in the vicinity of U.S. Highway 285 and 24 and in Mushroom Gulch appear to be spatially related to this granite intrusion. The granite stocks and dikes are interpreted to be the uppermost expression of a larger granite or quartz monzonite body at depth. Wrucke and Dings (1979) mapped similar intrusive bodies as quartz monzonite of both Early and Middle Proterozoic age in the Cameron Mountain 15-minute quadrangle to the south of Castle Rock Gulch. Van Alstine (1969) mapped similar granite intrusives in the Poncha Springs NE quadrangle, southwest of the Castle Rock Gulch quadrangle.

Pegmatites **(YXp)** intrude the granodiorite porphyry, and, to a lesser extent, the granitic stocks, in the northern part of the Castle Rock Gulch quadrangle. The pegmatite bodies are composed primarily of albite, microcline, and quartz. They form lensoid dikes and irregularly shaped bodies that may be zoned or unzoned and range in thickness from 0.1 m to 15 m. Pegmatite bodies contain accessory biotite and muscovite in different proportions. Several large pegmatites contain accessory garnet, euxenite, and allanite (Hanley and others, 1950). The pegmatites are spatially and probably genetically related to the intrusion of the granite bodies **(YXgt)**.

Table 1. Whole-rock analyses of samples from the Castle Rock Gulch 7.5-min. quadrangle, Chaffee and Park Counties, Colorado [analysis by Bondar-Clegg, Vancouver, B.C.; LOI, loss on ignition; NA, not analyzed; <, less than]

Rock Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Cr_2O_3	CO_2	Sample Total
Dacite tuff of Castle Rock Gulch (Tdc) (sample no. K0297)	63.89	0.58	15.63	4.12	0.07	1.19	3.29	3.23	3.89	0.24	3.06	99.20	0.01	NA	NA
Monzonite sill (margin) (KTm) (sample no. K0042a)	51.19	0.79	17.87	8.16	0.16	2.92	5.63	3.28	4.76	0.54	3.96	99.27	0.01	NA	NA
Monzonite sill (interior) (KTm) (sample no. K0042b)	46.57	0.86	14.69	12.01	0.19	5.26	7.79	2.46	3.04	0.52	6.00	99.43	0.04	NA	NA
Leadville Limestone Newett Quarries (sample no. K0053)	0.40	<0.01	0.14	0.09	<0.01	0.20	55.73	<0.01	0.03	0.03	43.36	99.98	<0.01	45.19	<0.02
Granite stock (YXgt) (sample no. K0226)	78.03	0.03	11.57	0.85	0.02	0.07	0.24	2.40	5.67	0.06	0.44	99.41	0.03	NA	NA

PALEOZOIC ROCKS

The Paleozoic sequence is about 1,190 m thick in the map area. At the base is the Sawatch Quartzite (Late Cambrian), which, in ascending order, is overlain by the Manitou Limestone (Early Ordovician), Harding Quartzite (Middle Ordovician), Fremont Dolomite (Late and Middle Ordovician), Chaffee Formation (Late Devonian), and Leadville Limestone (Early Mississippian). In the southwestern part of the map area the Kerber Formation (Lower Pennsylvanian) overlies the Leadville Limestone, and the Kerber is overlain by the Belden Shale (Middle Pennsylvanian), which is overlain by the Minturn Formation (Middle Pennsylvanian). In the northeastern part of the Castle Rock Gulch quadrangle the Kerber Formation is absent and the Belden Shale overlies the Leadville Limestone, and the Belden Shale is, in turn, overlain by the Coffman Formation (Middle Pennsylvanian) (De Voto, 1971). Most of the lower Paleozoic units are separated by disconformities that represent long periods of nondeposition or cycles of deposition and erosion (Ross and Tweto, 1980). Lower Paleozoic rocks were deposited in shallow marine environments, and Upper Paleozoic rocks were deposited in marine and continental environments.

Cambrian

The oldest Paleozoic unit in the Castle Rock Gulch quadrangle is the poorly exposed Sawatch Quartzite **(Ꞓs)**, of Late Cambrian age. The Sawatch Quartzite overlies Early Proterozoic granodiorite **(Xgd)** in the southwestern part of the quadrangle. In most of the map area the Sawatch Quartzite is absent, or is so thin that float doesn't occur in the soil. In the southwestern quadrant of the map area, on Bassam Ridge, the Sawatch Quartzite is nearly 3 m thick (De Voto, 1971). To the south of the Castle Rock Gulch quadrangle along the western side of the Cameron Mountain quadrangle, the Sawatch Quartzite thickens to about 8 m. The Sawatch Quartzite is a light-gray, moderate-gray, light-grayish-yellow, fine- to medium-grained, well-sorted, massive-weathering, silica-cemented orthoquartzite and pebbly orthoquartzite that contains planar crossbeds, ripple cross-lamination, and planar lamination at places where bedding is preserved. Pebbly quartzite contains subrounded and rounded vein-quartz clasts.

Ordovician

The Manitou Limestone **(Om)**, of Early Ordovician age, overlies the Sawatch Quartzite on a disconformable contact, or, where the Sawatch is absent, the Manitou Limestone overlies Proterozoic rocks. The Manitou Limestone is composed mostly of dolomite in the map area, rather than limestone. This unit is composed of dark-, moderate-, and light-gray, thin- to thick-bedded dolomite and cherty dolomite and rare beds of dark-gray limestone. The Manitou Limestone is about 60 m thick in most of the quadrangle, but in the east-central and southwestern parts of the map area the Manitou Limestone is 70 to 76 m thick. In the Mushroom Gulch area the Manitou Limestone is about 34 m thick. Dolomite and limestone are laminated and mottled, and beds range between 2 cm and 1 m in thickness. A distinctive characteristic of the Manitou Limestone is the occurrence of black and light-grayish-white chert nodules, lenses, and beds in the dolomite. The chert is internally laminated and parallel to bedding. In the northern and eastern part of the quadrangle along Kaufman Ridge, the bedded chert lenses and layers are most common in the lower one-third of the formation. The top of the formation commonly has no chert, or only rare white chert. At several locations proximal to high-angle faults, such as near Mushroom Gulch, the Manitou Limestone is composed of silicified beds that replaced dolomite, and of silicified breccia of pebble- and cobble-sized laminated chert in a matrix of chert that replaced dolomite. Secondary replacement silica is usually dark-red, reddish-brown, or brownish-orange. Silica may replace entire beds or may partially replace narrow haloes around fault-related fractures. In the Bassam Ridge area in the southwestern part of the quadrangle, chert occurs only as nodules and lenses in dolomite. In the southeastern part of the map area near faults south of Green Whiskers Windmill, the entire thickness of the Manitou Limestone is composed of chert breccia.

The Harding Quartzite **(Oh)** is of Middle Ordovician age, and it overlies the Manitou Limestone on a disconformable contact. The Harding Quartzite is a dark-reddish-gray, dark-grayish-orange, dark-grayish-red, light-gray, moderate-gray, and rusty-orange, fine- to medium-grained, well-sorted, silica-cemented, dense, mottled orthoquartzite. The orthoquartzite is completely cemented by silica, and it has the conchoidal fracture of a quartzite. This indurated, cliff-forming unit is about 30 to 37 m thick at most places in the quadrangle. Quartzite beds range from 2.5 cm thick to about 20 cm thick. They contain planar lamination and planar crossbeds, which commonly are obscured by pervasive replacement of diagenetic quartz. Rare phosphatic bony plates of primitive fish occur in this unit in the Cameron Mountain and Salida East quadrangles, but no fossils were found in the Castle Rock Gulch quadrangle. At a few places, the Harding Quartzite consists of angular breccia fragments of white quartzite in matrix of hematite-stained, maroon to dark-red quartzite. These breccias appear to be fault related. Stratabound breccias that were common in the Salida East quadrangle to the south are generally absent in the Castle Rock Gulch quadrangle. Pebbly sandstone and bioturbated sandstone occur in some beds of quartzite. Some exposures contain conglomeratic sandstone at the base. On the east side of Kaufman Ridge, the Harding Quartzite commonly breaks along fractures into large (0.3 to 1.5 m) talus blocks that may form elongated lobate talus flows or possibly slowly moving landslide deposits.

The Fremont Dolomite **(Of)**, which is of Late and Middle Ordovician age, overlies the Harding Quartzite on a disconformable contact. The Fremont Dolomite is about 34 m thick in the southern part of the quadrangle and about 40 m thick in the northern part of the map area. The Fremont Dolomite is a dark-, moderate-, light-gray, and brownish-gray, massive-weathering, crystalline, fetid dolomite that contains echinoid debris and dolomitized coral in a fine-grained dolomite matrix. Trilobite and brachiopod fragments occur on some bedding planes, and echinoid fragments are common in most of the unit. Solitary and colonial corals are preserved locally. The dolomite may be mottled light gray and dark gray, or it is laminated and microlaminated. Beds are generally 5 cm to 1 m thick and bedding is poorly preserved. This dolomite resists weathering and has a rough, uneven weathering surface that has sharp ridges.

Devonian

The Chaffee Formation **(Dc)** is of Late Devonian age and rests disconformably on the Fremont Dolomite. The Chaffee Formation is divided into the Parting Quartzite Member at the base and the Dyer Dolomite Member at the top (De Voto, 1971; Wrucke and Dings, 1979). Campbell (1972) applied group rank to the Chaffee and applied formation rank to the Parting Quartzite and Dyer Dolomite. He subdivided the Parting Quartzite and Dyer Dolomite into several members on the basis of measured sections. Members could not be mapped separately at a map scale of 1:24,000, so we retain the nomenclature hierarchy of Wrucke and Dings (1979). The Chaffee Formation is resistant to weathering, but the units are thinly bedded; therefore, they are less resistant to weathering than the massive-weathering Fremont Dolomite below and the massive-weathering Leadville Limestone above, so the Chaffee Formation forms slopes between the two carbonate units. Only in one small area in the northwestern part of the Castle Rock Gulch quadrangle was the Chaffee Formation mapped as a single undivided unit rather than as separate members.

The Parting Quartzite Member **(Dcp)** is a light-gray, pale-brownish-gray, light-grayish-red, and pinkish-gray, fine-grained, silica-cemented, dense, flinty, conchoidal-fracturing orthoquartzite. Rare thin interbeds of dolomite and green shale are 5 to 20 cm thick, and some pebbly and granular quartzite interbeds occur. Some thin beds of dolomite and dolomitic quartzite are interbedded with silica-cemented quartzite. Thinly bedded and massive-weathering quartzite beds are generally 5 to 25 cm thick. Planar lamination, ripple-cross-lamination, and rare planar crossbeds are the principal sedimentary structures. Breccias that were common in the Salida East quadrangle are rare in the Castle Rock Gulch quadrangle. The thickness of the Parting Quartzite Member varies considerably in the Castle Rock Gulch quadrangle. In the southwestern part of the map area the Parting Quartzite Member is a maximum of 12 m thick, and commonly this unit is 3 to 4 m thick. Along Kaufman Ridge a common thickness for this member is about 12 m. Southeast of Green Whiskers Windmill the Parting Quartzite Member is about 20 cm thick and it was not mapped as a separate unit.

The Dyer Dolomite Member **(Dcd)** is a yellowish-gray, light-gray, tan, and pale-yellowish-gray, prominently laminated and microlaminated, finely crystalline and microcrystalline dolomite that contains some lenticular interbeds of light-grayish-green and light-greenish-gray shale and laminated yellowish-gray chert. The dolomite is bioturbated and flaggy or massive-weathering. Rare chert layers are interbedded with dolomite and range from 1 to 5 cm thick. Near the top, the Dyer Dolomite Member commonly contains medium-gray, thin-bedded, or rarely massive-weathering, laminated limestone layers that have a greater resistance to weathering than the surrounding dolomitic rock. The Dyer Dolomite Member is about 32 m thick in the southeastern part of the map area, 34 m in the southwestern part of the map area, and about 36 m in the northeastern part of the quadrangle.

MISSISSIPPIAN

The Leadville Limestone **(Ml)** is of Early Mississippian age, and it overlies the Dyer Dolomite Member on a disconformable contact. The Leadville Limestone is a moderate-gray and dark-gray, massive-weathering, thinly bedded micritic limestone and finely crystalline dolomite. Beds range in thickness from 7 cm to 2 m. Two distinctive zones of flaggy-weathering, thinly bedded, laminated, grayish-pink and grayish-red micritic limestone and edgewise conglomerate occur in the lower third of the Leadville Limestone in the Salida East quadrangle (Wallace and others, 1997), but these zones are not present north of the Salida East quadrangle. Black laminated chert nodules and lenticular chert beds occur at some stratigraphic levels, and red chert locally occurs as irregular replacement masses. The Leadville Limestone is about 67 to 83 m thick in most areas of the quadrangle. The unit is as much as 135 m thick in the Bassam Park area (cross section B–B′). The Leadville Limestone is as much as 180 m thick in the northern part of the adjoining Cameron Mountain quadrangle, south of Bassam Park (Wallace and Lawson, 1998). Thickness variation may result from post-lithification solution of limestone and from volume reduction that resulted from solution and silicification of limestone.

The base of the Leadville Limestone is channeled into the underlying Dyer Dolomite Member, and the shallow channels are filled with medium-grained orthoquartzite cemented by calcite or silica. Sandy limestone, flat-pebble conglomerate, and limestone or dolomite breccia occur in the shallow channels at the base of unit. Clasts of grayish-yellow, laminated and microlaminated dolomite, presumably derived from the Dyer Dolomite Member, occur in the basal sandstone beds of the Leadville Limestone at some places. Above the basal sandstone several beds of calcareous sandstone are interbedded with moderate- and dark-gray micrite. These sandstone beds above the basal unit are 2.5 to 30 cm thick, and they decrease in thickness upward; about 3 m above the base the sandstone beds are absent.

Most of the Leadville Limestone is composed of interbedded zones of finely crystalline dolomite and micrite, with lenticular interbeds of biomicrite and oölitic limestone that occur sporadically through the sequence. Some limestone and dolomite beds are mottled light gray and moderate gray.

Silica-cemented orthoquartzite beds occur at the top of the Leadville Limestone east of Kaufman Ridge. These orthoquartzite beds were included with the Kerber Formation by De Voto (1971), but we include these beds with the Leadville Limestone in this report for the following reasons: (1) These orthoquartzite beds are similar in composition and texture to sandstone beds at the base of the Leadville Limestone, (2) Sandstone beds in the Kerber are always richly feldspathic, lithic, and micaceous, and are commonly conglomeratic, and (3) Along the eastern part of Kaufman Ridge, and in the northern part of the Gribbles Park quadrangle, limestone and dolomite beds of the Leadville Limestone are interbedded with fine- and medium-grained orthoquartzite, which suggests continuous deposition of clastic and carbonate beds at the top of the Leadville Limestone. The sandstone is mostly fine- and medium-grained, silica-cemented orthoquartzite; the degree of rounding cannot be determined because detrital grain boundaries are not preserved. Field relations suggest that in this area the sand was deposited in wide, shallow submarine channels, probably syndepositional with laterally equivalent limestone.

Alteration of the Leadville Limestone consists of an early diagenetic event of dolomitization (Conley, 1972), and post-lithification events of solution and silicification (De Voto, 1980). These events may have been sequential. Early diagenetic dolomite replaced zones of micrite; the result is interbeds of dolomite and limestone that are 60 cm to 3 m thick, but dolomitization was uneven laterally and vertically so that much of the Leadville Limestone is mostly micrite at some places or thick zones of dolomicrite at other places. A solution event after lithification of the Leadville formed prominent caves and solution breccias in the upper part of this unit. The solution breccias are composed of dolomitized clasts of limestone and red and deep yellowish-orange chert. This post-Mississippian solution event affected Mississippian limestones throughout much of the Cordillera and may have been related to a widespread event of silicification in the Leadville Limestone. The prominent zone of chert that was mapped in the Salida East quadrangle to the south was not mapped separately in the Castle Rock Gulch quadrangle.

PENNSYLVANIAN

During Pennsylvanian time, the Central Colorado Trough, an arm of the interior seaway, received a thick sequence of clastic and carbonate rocks (De Voto, 1972; De Voto and Peel, 1972). In the southern part of the Central Colorado Trough, repeated intervals of marine and clastic rocks formed four prominent cycles that continued from Pennsylvanian time into early Permian time (Wallace and others, 2000), but in the central part of the Central Colorado Trough, which includes this map area, cyclic repetitions of marine and continental deposits cannot be separated. In the Castle Rock Gulch quadrangle the Pennsylvanian sequence begins with marine deposits at the base and grades upward into a continental sequence, and tongues of continental deposits form wedges in marine strata (De Voto, 1971). Most of the Pennsylvanian units are conformable or have gradational contacts that intertongue.

An important regional change in lithofacies of late Paleozoic rock units occurs in the Castle Rock Gulch quadrangle in which coarse-grained Pennsylvanian rock units that are more typical of the southern part of the Central Colorado Trough give way to fine-grained units that characterize the central and northern part of the Trough. In the southwestern part of the Castle Rock Gulch quadrangle, the sequence consists of the Kerber Formation, Belden Shale, and Minturn Formation, in ascending order. In the northeastern part of the map area the sequence above the Leadville Limestone is the Belden Shale and Coffman Formation, in ascending order, with the Maroon Formation occurring at the top of the Pennsylvanian and Permian sequence north and east of the Castle Rock Gulch quadrangle. The Kerber and Minturn Formations thin and disappear to the north and east, and the Maroon Formation disappears to the south.

The Kerber Formation **(IPk)**, of Early Pennsylvanian age, disconformably overlies the Leadville Limestone in the southern part of the quadrangle. The Kerber Formation is estimated to be about 300 m thick in the southwestern part of map area, but an unfaulted sequence is not exposed in the map area. The Kerber Formation is absent in the eastern part of the map area. South of this map area in the Cameron Mountain quadrangle, the Kerber is estimated to be 320 m thick (Wallace and Lawson, 1998). This formation is composed of grayish-green, olive-drab, olive-gray, moderate-gray, and dark greenish-gray, coarse-grained arkose and conglomeratic arkose and subarkose interbedded with medium- and fine-grained sandstone, medium- and fine-grained feldspathic arenite, siltstone, and shale. Black, silty micaceous shale, black siltstone, moderate-gray biomicritic limestone, and rare dolomite occur as interbeds in the olive-drab and grayish-green rocks in the lower and upper parts of the unit.

Burbank (1932, p. 13) used the name “Kerber” for a sequence of carbonaceous black shale, siltstone, and brown sandstone that separate, red coarse-grained rocks (Sharpsdale Formation) from limestone of the Leadville Limestone at Kerber Creek, southwest of Salida, Colorado. De Voto and Peel (1972) described detailed lithofacies variations in the Kerber Formation from the Arkansas River Valley, described lateral stratigraphic relations with the Belden Shale, and discussed vertical stratigraphic relations with the Sharpsdale Formation. Wrucke and Dings (1979) and Taylor and others (1975) applied the name “Belden Formation” to this stratigraphic interval, but, as pointed out by De Voto and Peel (1972), the Belden Shale is primarily a fine-grained carbonaceous shale and siltstone, whereas the Kerber Formation is a coarse-grained arkose, conglomerate, and sandstone, and olive-drab shale and siltstone that contains lesser amounts of black shale and siltstone, so the term "Belden" is not properly applied to the latter rocks. De Voto (1971) assigned about 22 m of orthoquartzite to the Kerber Formation on Kaufman Ridge, which we have reassigned to the top of the Leadville Limestone. Where De Voto (1971) mapped Belden and Maroon Formations in the southwestern part of the Castle Rock Gulch quadrangle, we mapped a sequence of Kerber Formation, Belden Shale, and Minturn Formation. Coarse-grained, olive-drab arkose, interbedded with olive-drab fine-grained quartz sandstone, and lesser amounts of siltstone, shale, and limestone that De Voto (1971) included in the basal Belden Shale we assign to the lower Kerber Formation. De Voto (1971) restricted the Kerber Formation in the Antero Reservoir quadrangle to fine-grained, light-gray quartz sandstone that contained no shale, but we included olive-drab, gray, and dark-olive-gray arkose, siltstone, shale, and thin beds of gray limestone in the Kerber Formation where these rocks are below the black shale and siltstone of the Belden Shale in the southwestern part of the map area. The coarse-grained arkose and dark-colored shale included in the base of the Belden by De Voto (1971) was shifted to the upper Kerber Formation to maintain lithologic continuity with the Kerber Formation as mapped south and southeast of the Castle Rock Gulch quadrangle by Pierce (1969) and by Peel (1971), and as described by De Voto (1980b) and by Wallace and Lawson (1998). The effect of this change from De Voto's (1971) use of "Kerber" is to put fine-grained, dark-colored siltstone and shale directly above the Leadville Limestone in the Belden Shale, and to place rocks that contain coarse-and medium-grained arkose above the Leadville Limestone in the Kerber Formation. As the Kerber Formation changes in composition toward the north, olive drab and black shale increases in thickness and coarse-grained olive-drab arkose decreases in abundance, so rocks mapped as Kerber Formation in the southwestern part of the Castle Rock Gulch quadrangle contain only a few beds of coarse-grained arkose in more abundant medium- and fine-grained arkose, feldspathic siltstone, shale, and limestone. Defining rock units in the Central Colorado Trough solely on the basis of composition and grain size is a risky game because proximity to source areas or a local decrease in subsidence rate can result in introduction of coarse-grained debris in any unit. In the southern part of the Central Colorado Trough, however, De Voto's (1980b) original definitions result in regionally mappable units.

As the Kerber Formation is traced northward from the Salida East quadrangle the characteristic coarse- and medium-grained conglomeratic arkose is less common, and finer grained arkose, feldspathic silstone, and micaceous shale accounts for most of the sequence. Coarse-grained arkose beds are seldom more than 2 m thick. Coarse-grained zones are separated by zones of medium- and fine-grained arkose, feldspathic siltstone, or shale that commonly are 5 to 15 m thick. Coarse-grained rocks are most abundant near the base of the Kerber Formation, and finer grained rocks, mostly olive-drab shale and siltstone and black shale, become more common upward in the sequence. In the southwestern part of the map area, coarse-grained arkose is rare, and olive-drab and dark-gray, medium- and fine-grained arkose, feldspathic micaceous siltstone, and olive drab, dark-gray, and black shale dominate. Moderate-gray limestone interbeds occur near the top of the Kerber Formation, and the top of the Kerber is marked by an olive-drab, coarse-grained arkose that is 2 to 3 m thick. Zones of limestone beds are 1 to 2 m thick. Thin, mottled, bright grayish-green limestone beds that served as a marker near the top of the Kerber Formation in the Salida East, Cameron Mountain, and Gribbles Park quadrangles are absent in the Castle Rock Gulch quadrangle.

Primary sedimentary structures in the coarse-grained rocks are predominantly large-scale and medium-scale planar and trough crossbeds, channels, ripple cross-lamination, rib-and-furrow structures, cuspate and linguoid ripple marks, climbing ripples, and planar lamination that forms parting lineation. Shallow channels occur at the base of coarse-grained, conglomeratic sandstone beds. Primary sedimentary structures in the fine-grained rocks are ripple-cross-lamination, rib-and-furrow structures, climbing ripples, ripple marks, planar lamination, microlamination, and water-expulsion structures. Conglomeratic and sandy units have coarse-grained rocks at the base and become finer grained upward. Dark-gray and black limestone beds that occur in the upper and lower parts of the Kerber Formation are fine-grained, argillaceous, mottled or laminated, fetid micrite that are generally 12 cm to 2 m thick. Rare thin limestone beds near the top that form a brachiopod coquina in adjacent quadrangles are absent from the Castle Rock Gulch quadrangle.

The contact between the Kerber Formation and the overlying Belden Shale appears to be gradational. The top of the Kerber in the southwest part of the quadrangle is marked by a coarse-grained and pebbly, olive-drab, arkose bed, about 3 m thick, underlain by a light-gray weathering limestone bed that is about 2 m thick.

The Belden Shale **(IPb)**, of Middle Pennsylvanian age, is composed of black, laminated and nonlaminated shale, and black and dark-gray, argillaceous siltstone interbedded with moderate-gray, rusty-weathering siltstone and rare gray, fine-grained sandstone. Zones of black shale are as thick as 20 m, and are separated by beds of thin, micaceous, olive-drab siltstone, or fine-grained, olive-drab arkose. A fetid, black limestone occurs at the top in the southwestern part of the map area, but limestone beds are more common and as thick as 6 m in the northeastern part of the map area. Some limestone beds in the northeastern part of the map area contain microlamination that resembles stromatolites. Near the top of the Belden Shale is a fossiliferous limestone that contains large brachiopods, bryozoans, and trilobite(?) fragments. The dominance of black shale over olive-drab shale and siltstone differentiates the Belden Shale from the overlying Minturn Formation. The Belden Shale overlies the Kerber Formation in the southwestern part of the map area and the Leadville Limestone in the northeastern part of the quadrangle. The Belden Shale is overlain by the Minturn Formation in the southwestern part of the map area and by the Coffman Formation in the northeastern part of the Castle Rock Gulch quadrangle. The Belden Shale is estimated to be about 300 m thick in the southwestern part of the map area, which is similar to its thickness in the northwestern quadrant of the adjoining Cameron Mountain quadrangle (Wallace and Lawson, 1998) A minimum of about 180 m of Belden Shale is estimated in the northern part of the map area, but the top of the unit has been eroded. Faults, folds, and covered contacts make sections incomplete in the quadrangle.

In the northern part of the quadrangle, two informal members, each 90 m thick, were separated in the Belden Shale. The lower unit **(IPbl)**, which rests disconformably over the Leadville Limestone, consists of dark-gray, brownish-gray, and black shale and calcareous siltstone interbedded with medium- to dark-gray, dark-brownish-gray, and light-gray weathering, thin-bedded to locally flaggy-laminated, fetid limestone and argillaceous limestone. Some limestone beds are as thick as 5 m, but generally they are less than 3 m thick. Coquinoid limestone is present near the top of the lower part of the Belden Shale. Rare, discontinuous lenses of olive-drab to dark-reddish-green, fine- to medium- grained, micaceous arkose occur locally. Except for the limestone beds, this unit is very poorly exposed on the northern and eastern parts of the quadrangle because of the recessive nature of the shale and siltstone. The upper member of the Belden Shale **(IPbu)** represents a gradual upward coarsening of the formation and consists of interbedded and intertonguing layers of: (1) dark-grayish-brown and black shale, (2) olive-drab to dark-rusty-green, micaceous sandy siltstone, (3) fissile, micaceous, silty, fine- and medium-grained arkose, and (4) rare beds of dark-gray to dark-grayish-brown, fetid limestone that are 0.1 to 0.3 m thick. The contact between the upper and lower units of the Belden was placed at the base of a laterally continuous bed of medium- to coarse-grained, locally pebbly, reddish-brown to greenish-brown arkose that is prominently crossbedded. This bed is 2 to 3 m thick, and marks the transition between the dominantly shale-limestone sequence of the lower member of the Belden Shale, and the coarser shale-arkose sequence of the upper member. The upper unit of the Belden Shale is more resistant to erosion than the lower unit, and it is better exposed.

The Minturn Formation **(IPm)**, of Middle Pennsylvanian age, overlies the Belden Shale on an apparently conformable contact in the southwestern part of the map area; this formation is absent in the eastern part of the quadrangle. The Minturn Formation is generally poorly exposed. A minimum thickness for the Minturn is estimated at about 300 m, but the upper contact has been eroded in the map area. South of this map area in the northern part of the Cameron Mountain quadrangle, Wallace and Lawson (1998) estimated a thickness for the Minturn Formation of about 500 m. The Minturn Formation is composed mainly of dark-gray, gray, olive-drab, grayish-green, greenish-gray, and black, fine- and medium-grained feldspathic sandstone, argillaceous and micaceous siltstone, silty micaceous shale, and rare black fetid limestone and dolomite. Flaggy weathering, gray, grayish-green, and olive-drab sandstone beds are fine and medium grained and contain planar lamination, ripple cross-lamination, rib-and-furrow structures, low-amplitude hummocky crossbeds, and shallow channels. Coarse-grained, olive-drab and grayish-green arkose beds contain planar and trough crossbeds. Dark-gray and olive-drab siltstone and shale are planar laminated and microlaminated and contain ripple cross-lamination; sandstone and sandy siltstone are more common in the lower part of the unit, and siltstone and shale are more common in the upper part of the unit. Sedimentation units are fining-upward sequences that are capped by dark-colored shale. Limestone beds are thin, laminated and microlaminated, black and dark-gray, fetid micrite. Commonly limestone beds are 1 to 15 cm thick and are interbedded with black and dark-gray, silty shale; zones of interbedded limestone and shale form bedding units that are 1 to 3 m thick. An olive-drab, coarse-grained arkose marks the base of the Minturn Formation above black shale of the Belden Shale. The Minturn Formation weathers to a rusty color.

The Coffman Formation **(IPco)**, of Middle Pennsylvanian age, overlies the Belden Shale in the northeastern part of the Castle Rock Gulch quadrangle in the Kaufman Pasture area, east of Kaufman Ridge. De Voto (1971) indicated that the contact between the Belden Shale and Coffman Formation was conformable. As explained by De Voto (1971), the name "Coffman" was misspelled from Kaufman Ridge by Gould (1935) where he measured the type section at SE⁄, sec. 24, T. 13 S, R. 77 W. Gould (1935) defined the Coffman as the lowest member of the Maroon Formation rather than giving the Coffman formation status, but De Voto (1971) changed the rank of the Coffman from Gould's (1935) informal member to the formal use of formation, which we retain in this report. The Coffman Formation is chiefly composed of gray, light-brown, grayish-red to olive-drab and grayish-green, rusty-weathering, siliceous and micaceous, arkose conglomerate, medium- and coarse-grained arkose, and feldspathic siltstone, interbedded with dark-gray and black shale. Rare lenticular masses of algal limestone noted by Gould (1935) were not observed in the map area. The basal bed is a reddish-gray to light-gray, pebbly, coarse- and medium-grained arkose, that contains a few shale chips and abundant angular fragments of feldspar and quartz as large as 2 cm in diameter. The coarse debris was derived from the erosion of Proterozoic crystalline rocks. Arkose contains trough and planar crossbed sets that are as thick as 1 m. Channels and shale-chip conglomerates are common in the Coffman Formation. East of the map area, arkose beds of the Coffman Formation become thicker and coarser in grain size as the unit grades upward into the Maroon Formation. Only the lower part of the Coffman Formation is exposed in this quadrangle. Exposures of the Coffman Formation are incomplete, and only about 75 m of this unit are exposed along the northern boundary of the map area. Gould (1935) described drastic lateral thickness changes within the Coffman Formation from about 180 m near the type locality to about 300 m approximately 1.6 km east of the type locality. Concomitant with the change in thickness is an increase in the amount of coarse-grained arkose and conglomerate and a reduction in the amount of black shale and olive-drab siltstone (De Voto, 1971). Similar thickness and lithic changes were not recorded in the Castle Rock Gulch quadrangle because the areal extent of the Coffman Formation is small.

LATE CRETACEOUS OR EARLY TERTIARY ROCK UNITS

A large, northwest-trending, crescent-shaped monzonite sill **(TKm)** is exposed in Chubb Park in the northwest part of the Castle Rock Gulch quadrangle. The sill is equigranular, medium- to coarse-grained, and moderate to dark green, and gray to brown gray in color. The monzonite is the only Phanerozoic intrusive mapped in the quadrangle. Although the monzonite has not been isotopically dated, it is lithologically similar to a few of the intrusive bodies exposed to the north near Leadville that have been isotopically dated as late Cretaceous or early Tertiary (Pearson and others, 1962). Therefore, a Cretaceous or Tertiary age is tentatively assigned to this monzonite sill. The sill was injected between the Leadville Limestone and the Belden Shale, centered on the axis of a broad, gentle syncline. It measures over 1500 m (1 mi.) in length and is calculated to be about 180 m thick at its widest in the central part of the exposure. The sill dips northeast based on monzonite chips that occurred in drill cuttings from a water well collared in the Belden Shale about 100 m east of the monzonite contact. The upper and lower intrusive margins, for distances of 2 to 3 meters from the contacts, are finer-grained and slightly more silicic than the interior of the intrusive. The chilled margins are more resistant to erosion than the coarse-grained interior which is easily eroded and forms grüs at the surface. CIPW norms calculated from whole-rock geochemistry (samples K0042a and K0042b, Table 1) show the monzonite to be undersaturated with respect to silica and that it is possibly feldspathoid bearing. Thin section analysis of a sample of medium-grained, equigranular, dense, resistant material from near the upper contact of the sill shows the rock to be composed of approximately 20 to 30 percent euhedral, elongated, prismatic hornblende (1 to 3 mm), 60-70 percent altered subhedral feldspar, some with relics of albite twinning still visible, 3 to 4 percent magnetite, and traces of biotite and pyroxene. No feldspathoid minerals could be determined because of the pervasive clay alteration of most of feldspathic minerals. Chlorite is also present as an alteration product of the mafic minerals.

CENOZOIC ROCKS AND DEPOSITS

Tertiary Rocks and Deposits

Tertiary units are mainly volcanic rocks of intermediate and silicic composition and tuffaceous sedimentary deposits. The oldest volcanic unit is a dacite tuff, which is overlain in succession by the Wall Mountain Tuff, and the the Tallahassee Creek Conglomerate. The dacite tuff of Castle Rock Gulch (late Eocene) is an ash-flow deposit that filled a paleovalley (De Voto, 1971). The Wall Mountain Tuff (late Eocene) is an ash-flow deposit that filled drainages that dissected the older dacite tuff. The Tallahassee Creek Conglomerate (early Oligocene) occurs in isolated patches in Castle Rock Gulch, where the conglomerate also filled pre-existing drainages; the Tallahassee Creek Conglomerate has a highly tuffaceous matrix in this quadrangle. Tertiary sedimentary units are tuffaceous sequences of interbedded shale, siltstone, sandstone, conglomerate and limestone. The oldest of these units is the Antero Formation (Oligocene) which consists of lacustrine tuff, shale, fine-grained sandstone, and limestone. The Trump Formation (late Miocene) is a poorly consolidated conglomeratic and coarse-grained equivalent of the Wagontongue Formation (late Miocene) that was mapped to the south in the Gribbles Park quadrangle.

The dacite tuff of Castle Rock Gulch **(Tdc)** was first described as an andesitic tuff by De Voto (1971) from exposures in Castle Rock Gulch, and he suggested a late Eocene or early Oligocene age for this unit. A new argon 40/argon 39 age of 37.18 ± 0.11 Ma indicates that this tuff is late Eocene in age. This age was determined from biotite in sample K0447, obtained in section 22 in the west-central part of the map area. The biotite separate yielded a flat age spectrum with a plateau comprising nearly 100 percent of the $^{39}Ar_k$ released (Table 2). The tuff is light-gray, light-tan, light-reddish-gray, and light-orange-gray, moderately welded tuff, that contains abundant pumice fragments, angular volcanic rock fragments, abundant plagioclase and biotite crystals, and lesser hornblende crystals. The base of the tuff is densely welded and pumice fragments are glassy. Wispy, lensoid streaks of black glassy matrix material are conspicuous in the basal zone. Moderately welded tuff is locally foliated. The dacite tuff of Castle Rock Gulch was deposited in drainages that had been incised 250 to 300 m into the pre-existing granitic and sedimentary terrane (De Voto, 1971) in Mushroom Gulch, lower Castle Rock Gulch, and West Columbine Gulch.

Epis and Chapin (1974) and Scott (1975) included the exposures of the dacite of Castle Rock Gulch as part of the Badger Creek Tuff

Table 2. Argon 40/argon 39 summary table and analytical procedures, sample KO447, dacite tuff of Castle Rock Gulch. [analysis provided by Richard Esser, New Mexico Geochronology Research

Sample	L No.	Irrad	Material Dated	Age analysis	n	Percent ^{39}Ar	MSWD	K/Ca	Age	±2σ
K0447bi	51946	NM-133	9.07 mg biotite	plateau	8	98.2	1.6	10.1	37.18	0.11*
K0447hb	51947	NM-133	15.18 mg hornblende	plateau	4	94.1	3.3**	0.12	37.96	0.30*

** MSWD outside 95% confidence interval

* two-sigma errors

Notes:

Sample preparation and irradation:

Samples provided by John W. Keller of the Colorado Geological Survey.
The biotite and hornblende was separated using standard techniques (crushing, sieving, magnetics and hand-picking).
The biotite and hornblende were packaged and irradiated in machined Al discs for 7 hours in D-3 position, Texas A&M University Research Reactor.
Neutron flux monitor Fish Canyon Tuff sanidine (FC-1). Assigned age = 27.84 Ma (Deino and Potts, 1990) relative to Mmhb-1 at 520.4 Ma (Samson and Alexander, 1987).

Instrumentation:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.
All samples were step-heated in Mo double-vacuum resistance furnace. Heating duration 8 minutes.
Reactive gases removed during a 5-6 minute reaction with 2 SAES GP-50 getters, 1 operated at ~450°C and 1 at 20°C. Gas also exposed to a W filament operated at ~2000°C.

Analytical parameters:

Electron multiplier sensitivity averaged 3.05×10^{-16} moles/pA.
Total system blank and background for the step-heated samples averaged 2470, 4.3, 4.3, 5.5, 11.9 x 10^{-18} moles.
J-factors determined to a precision of ± 0.1% by CO_2 laser-fusion of 4 single crystals from each of 4 radial positions around the irradiation tray.
Correction factors for interfering nuclear reactions were determined using K-glass and CaF_2 and are as follows:
Texas A&M University: $(^{40}Ar/^{39}Ar)_K = 0.0002 \pm 0.0003$; $(^{36}Ar/^{37}Ar)_{Ca} = 0.00028 \pm 0.00001$; and $(^{39}Ar/^{37}Ar)_{Ca} = 0.00089 \pm 0.00003$;

Age calculations:

Weighted mean age calculated by weighting each age analysis by the inverse of the variance.
Weighted mean error calculated using the method of Taylor (1982).
Total gas ages and errors calculated by weighting individual steps by the fraction of ^{39}Ar released:
MSWD values are calculated for n-1 degrees of freedom for plateau and preferred ages.
Isochron ages, $^{40}Ar/^{36}Ar_i$ and MSWD values calculated from regression results obtained by the methods of York (1969).
Decay constants and isotopic abundances following Steiger and Jäger (1977).
All final errors reported at ± 2σ, unless otherwise noted.

(Oligocene) in the area of Trout Creek. Our more detailed mapping and $^{40}Ar/^{39}Ar$ analysis shows that the dacite underlies and predates the Wall Mountain Tuff. The Wall Mountain Tuff is older than the Badger Creek Tuff, which is not exposed in the quadrangle. Clasts of the dacite were found in the lower part of the Wall Mountain Tuff in this quadrangle. Van Alstine (1969) mapped a similar tuff (his "rhyodacite") 10 km southwest of the Castle Rock Gulch quadrangle in the Poncha Springs Northeast quadrangle. According to Van Alstine (1969, p. 11), the rhyodacite in the Poncha Springs Northeast quadrangle is overlain by a devitrified densely welded rhyolitic tuff with a black, glassy base. This rhyolite unit has since been identified as the Wall Mountain Tuff (Tweto and others, 1976), which overlies the dacite tuff in the Castle Rock Gulch quadrangle as well. Chemical data presented by Van Alstine (1969, p. 11) for the rhyodacite is very similar to that for a sample of dacite the authors collected in Castle Rock Gulch (sample K0297, Table 1). This is sufficient data to correlate the exposures in the two areas. Using calculated CIPW norms and a LeBas diagram (LeBas and others, 1986) for the classification of volcanic rocks, the chemical data show that the welded tuff we collected from Castle Rock Gulch is a dacite. The LeBas classification scheme does not use the term "rhyodacite".

The Wall Mountain Tuff **(Twm)** is late Eocene in age. This unit was originally named the Agate Creek tuff by De Voto (1971) for exposures in Agate Creek, about 10 km east of Kaufman Pasture in the northeast corner of the Castle Rock Gulch quadrangle. Epis and Chapin (1974) indicated that the Agate Creek tuff was correlative with ash flow units 1 and 2 of the Thirtynine Mile volcanic field east and southeast of the Castle Rock Gulch quadrangle, and these units were renamed the Wall Mountain Tuff. The Wall Mountain Tuff is a welded rhyolite ash-flow tuff exposed mainly in the northwestern and northeastern parts of this quadrangle. The tuff is mainly eutaxitic in texture and is moderately to densely welded. The basal 3 to 4 m of the tuff consists of black, perlitic glass that contains crystals of quartz and sanidine. The main body of the welded tuff is mostly light-gray, moderate-gray, light-brownish-gray, and grayish-red rhyolite that contains prominent sanidine and plagioclase phenocrysts (Epis and Chapin, 1974). De Voto (1971) assigned an age of early Oligocene to the Wall Mountain Tuff, and McIntosh and Chapin (1994) reported an argon 40/argon 39 age of 36.64 $\pm$ 0.06 Ma (late Eocene) for the Wall Mountain Tuff. Flow foliation in glassy welded tuff is prominent. Chapin and Lowell (1979) described primary and secondary deformation structures from the Wall Mountain Tuff in the Gribbles Run paleovalley where this glassy tuff formed a single cooling unit that slid and folded into the paleovalley as the plastic and mobile tuff degassed and compacted. Exposures of the Wall Mountain Tuff show similar plastic deformation features at Castle Rock in Castle Rock Gulch where prominent foliation dips at steep angles parallel to basal contacts that define pre-existing drainageways.

Whether the Wall Mountain Tuff is actually part of the Thirtynine Mile volcanic field is doubtful. Chapin and Lowell (1979) determined that the cauldron source for this ash-flow tuff was located about 20 mi. northwest of Salida, which is about forty miles west of the central part of the Thirtynine Mile volcanic field. The Wall Mountain Tuff should be considered a separate entity from the Thirtynine Mile volcanic field because the Wall Mountain Tuff is older than volcanic rocks of the volcanic field, the tuff extends over a much wider area than the volcanic field, and the cauldron from which the tuff erupted was located far to the west of the volcanic field.

The Tallahassee Creek Conglomerate **(Ttc)** is exposed as isolated remnants along Castle Rock Gulch and West Columbine Gulch, and more extensive exposures occur in the northeastern corner of the map area. Epis and Chapin (1974) formally named the Tallahassee Creek Conglomerate and noted its presence in the Castle Rock Gulch area. De Voto (1971) previously gave this unit the informal name "lower volcanic conglomerate". Stark and others (1949) had included this volcanic conglomerate unit as a lower member of the Antero Formation. The unique character of this unit was accurately described by De Voto (1971) as a polymict boulder conglomerate in a tuffaceous matrix, the boulders representing a residuum that remained after finer grained material had been deflated. Silicified fossil wood fragments (chalcedonic, opaline, and crystalline silica) are locally abundant in the Tallahassee Creek Conglomerate, which is a distinguishing feature that separates the Tallahassee Creek Conglomerate from the similar appearing Trump and Antero Formations, and from Quaternary terrace and pediment deposits. In the Castle Rock Gulch and West Columbine Gulch areas the Tallahassee Creek Conglomerate consists of subangular, subrounded, rounded, and well-rounded clasts of Middle Proterozoic granodiorite, Manitou Limestone, Harding Quartzite, Fremont Dolomite, andesite of Castle Rock Gulch, and Wall Mountain Tuff that occur in a matrix of light-gray water-laid and air fall tuff, grayish-white and yellowish-white slightly welded tuff, and tuffaceous sand and silt. Clasts of Paleozoic sedimentary rock are as much as 1.5 m in diameter, and, as noted by De Voto (1971), the Middle Proterozoic granodiorite boulders are rounded and as large as 10 m in diameter. The lithology of the clasts varies greatly over relatively short distances. At some locations, the boulders and cobbles are nearly all Wall Mountain Tuff, whereas a short distance away the clasts are dominantly granodiorite or Paleozoic rocks. At most localities where the Tallahassee Creek Conglomerate is preserved, boulders occur in silt and clay-rich soil that contains angular feldspar and quartz pebbles derived from Middle Proterozoic granodiorite. The soil developed on the Tallahassee Creek Conglomerate commonly is similar to grüs developed over granodiorite. In the southwestern part of the map area (SW⁄, sec. 2, T. 15 S., R. 77 W.) erosion exposed the upper 3 m of the conglomerate, and there granodiorite and schist clasts as large as 1 m are enclosed in a matrix of reworked tuffaceous sediment, which was deposited in channels cut into poorly stratified, slightly welded tuff. Tuff layers within the Tallahassee Creek Conglomerate are seldom exposed below the weathered and deflated boulder residuum. Where tuff is exposed in the southwestern part of the map area, it is a light-gray and light-yellowish gray, poorly stratified, slightly welded quartz latite. In the northeastern part of the quadrangle the tuffaceous matrix of the Tallahassee Creek Conglomerate is grayish to yellowish white and poorly welded. As in the southwestern part of the map area phenocrysts of feldspar are prominent in the tuffaceous matrix and biotite crystals are less common than feldspar. Abundant fragments of light-grayish-white and light-pink pumice occur in the slightly welded tuff, and dark-red and reddish-gray fragments of aphanitic volcanic rocks are a common lithic component. DeVoto (1971) assigned an early Oligocene age to the deposits now assigned to the Tallahassee Creek Conglomerate because the Antero Formation unconformably overlies this conglomerate and tuff. The total thickness of the Tallahassee Creek Conglomerate is difficult to determine because it was deposited on an uneven, eroded surface in a mid-Tertiary paleovalley and because it has been differentially eroded since its deposition. However, it is estimated to have a maximum thickness of between 20 and 30 m in the Castle Rock Gulch quadrangle.

The Tallahassee Creek Conglomerate must have been deposited in a very high-energy, wet environment to transport large boulders. The boulders suggest that the paleovalley (or paleocanyon) into which the formation was deposited had steep walls. At one location in section 11, T. 14 S., R. 77 W., a cohesive slide block **(Tsb)** about 300 m long is composed of Manitou Dolomite and Harding Quartzite, and this block lies upon chaotic landslide debris that includes boulders of Leadville Limestone and other lithologies. The landslide debris is included in the Tallahassee Creek Conglomerate. The strike and dip of the cohesive block suggests it slid from the northwest, over the present location of U.S. Highways 285 and 24. The slide block and underlying landslide debris appear stable and pose no landslide hazard. The slide block and landslide have probably not moved since deposition in Oligocene time.

The Antero Formation **(Ta)**, of early to middle Oligocene age, consists of tuffaceous sedimentary rocks and interlayered grayish-white to grayish-yellow tuff. This unit was described thoroughly by De Voto (1971), and we have used his definition as a mapping guide. The Antero Formation is exposed in the northeastern quadrant of the map area in the flat expanses of South Park. Although contact relations are obscure because of poor exposures, the Antero Formation appears to overlie the Tallahassee Creek Conglomerate unconformably. In places, the Antero Formation unconformably overlies the Pennsylvanian Maroon and Coffman Formations. The tuffaceous sedimentary deposits consist of beds of poorly consolidated grayish-white, light-gray, light-grayish-green, and black volcaniclastic and medium- and coarse-grained arkose, beds of light-gray to grayish-tan pebble conglomerate and beds of white, gray-green and brown siltstone and mudstone. The beds are lenticular and discontinuous. Biotite grains are commonly abundant. Crossbeds occur locally in coarse-grained beds. Pebbles in the conglomerate beds are mostly derived from the volcanic rocks of the Thirtynine Mile Volcanic Field. Dark-colored sandstone beds contain abundant magnetite and other mafic minerals. Discontinuous lenses of limestone occur locally, and these limestone beds show as white streaks on aerial photographs and have been mapped separately **(Tal)** because they show the strike of bedding in the Antero Formation. These limestones range from pale yellowish white, light yellowish gray, and medium brown, but usually limestone beds weather white and light gray. Some beds are porous and have been described as calcareous tufa deposited by algal colonies or reefs (Johnson, 1937a). Other limestone beds in the Antero Formation are dense and consist mainly of lime mud, and some limestone beds are oölitic and ostracod packstones and wackestones as described by De Voto (1971). Freshwater gastropods are also locally abundant in limestone beds of the Antero Formation (De Voto, 1971), although these were not identified in the Castle Rock Gulch quadrangle. Limestone beds were deposited in or along the shore of shallow, freshwater lakes (Johnson, 1937a) and these beds commonly have a tuffaceous component. Limestone beds range in thickness from a few centimeters to about 3 m. White, gray, and orange-brown chalcedony occurs locally as secondary alteration and replacement of the limestone. Terrestrial vertebrate fossils, such as the early horse, *Mesohippus*, have been found in sedimentary deposits of the Antero Formation (Johnson, 1937b), although not in the Castle Rock Gulch quadrangle. Silicified wood is locally abundant as well. In the Gribbles Park quadrangle the Antero Formation appears to grade laterally into the nonwelded member of the Badger Creek Tuff. An argon 40/argon 39 age on the Badger Creek welded tuff by McIntosh and Chapin (1994) of 34.35 ± .09 Ma places eruption of the tuff in early Oligocene time. The maximum thickness of the Antero Formation on the northeastern edge of the map area is estimated at 250 to 300 m.

The Trump Formation **(Tt)**, which is of late Miocene age, rests unconformably over the Antero Formation, the Belden Shale, and the Tallahassee Creek Conglomerate on the Castle Rock Gulch quadrangle. The Trump Formation is composed of moderate-gray to grayish-white, light-yellowish-gray, and medium-orange-brown, poorly consolidated and nonconsolidated, poorly to moderately sorted, interbedded tuffaceous, commonly calcareous, fine-grained to cobbly, silty, sandy gravel; pebbly, silty sand; and sandy silt. Some conglomerate beds consist almost entirely of pebbles and cobbles of light- to medium- gray vitric tuff (trachyte?). Gravel and sand beds have shallow channels at basal contacts and contain low-angle planar crossbeds. Beds of air-fall tuff are well indurated and contain small crystals of quartz, feldspar, and biotite in a lithified matrix of ash. Silicic tuff is locally opaline. Unusual beds of white, porous, highly calcareous, and well-indurated crystal-lithic tuff is present locally as 2 to 4 m-thick layers. In these beds, white crystalline calcite occurs as a matrix among softer ash lapilli, welded tuff lithic fragments, and quartz crystals. These beds are probably tuffs that were deposited in shallow lakes and ponds. Numerous terrestrial megafauna fossils have been found in the Trump Formation, including ruminid, camelid, and rodent bone fragments (De Voto, 1971). These fossils point to a late Miocene age for the formation. Pebble and cobble composition in the sedimentary beds varies greatly vertically and laterally. Fragments of Proterozoic igneous and metamorphic rocks (including quartz monzonite), Paleozoic quartzite, dolomite, limestone, and shale, a light-gray, vitric, trachytic(?) tuff, Wall Mountain Tuff, and rare basalt were found in the Trump. Outcrops of basalt, trachytic vitric tuff, or Proterozoic quartz monzonite are not present locally in the Mosquito Range to the west of the Trump outcrop area, or to the north, so the provenance of the Trump Formation was to south or east toward the Thirtynine Mile volcanic field, with secondary clastic input from the west. The angular and poorly sorted character of the sedimentary beds suggest rapid deposition in a dynamic depositional environment such as alluvial fans or aprons in an arid or semi-arid environment where severe rain events produced debris flows, mudflows, and local floods in alluvial channels. Stark (1949) described the Trump Formation as a fanglomerate. Large, resistant cobbles and rare boulders that occur in the Trump commonly mantle the surface as a residuum created by deflation of the easily eroded underlying finer sediment. This unit is poorly exposed at most places; the maximum thickness is estimated at about 150 m. De Voto (1961) showed that the Trump Formation grades vertically and laterally into the Wagontongue Formation to the south and east of the Castle Rock Gulch quadrangle. Previous mapping by the Colorado Geological Survey in the Gribbles Park quadrangle (Wallace and others, 1999) to the southeast show only the Wagontongue Formation. The two units grade into one another and were not differentiated due to poor exposure and only subtle grain-size differences. The contact between the Trump Formation and the underlying Antero Formation was determined based on grain-size differences which has resulted in subtle topographic contrasts which are visible on the aerial photographs. The Trump Formation contains significantly more cobble-rich gravel than does the Antero.

QUATERNARY DEPOSITS

Quaternary units include pediment, alluvial, colluvial, landslide, talus, eolian deposits. The oldest

Quaternary units occur as remnants of formerly extensive boulder gravel deposits on pediments. Eolian deposits are common in some drainages. Mass-flow deposits and rock-fall deposits are locally developed. Deposits of colluvium and alluvium formed in modern drainages during Holocene time. Mappable human-made deposits exist only near the Newett limestone quarries in the northwestern part of the quadrangle. Our nomenclature for Quaternary deposits in the Castle Rock Gulch quadrangle uses a relative time scale suggested by R. Kirkham (Colorado Geological Survey, written communication, 1997) that was used for the Cameron Mountain quadrangle (Wallace and Lawson, 1998).

Pediment deposits are probably Pleistocene in age, and are composed of poorly stratified sand and silt that contains dispersed boulders, cobbles, and pebbles. Deposits that we map as pediment deposits were deposited on pediment surfaces in drainages and these deposits are remnants of formerly extensive deposits that occur to the east of the map area and in the previously mapped Cameron Mountain and Gribbles Park quadrangles (Wallace and Lawson 1998; Wallace and others, 1999). Clasts in pediment deposits are composed of Harding Quartzite, cherty dolomite of the Manitou Formation, Proterozoic granodiorite, Wall Mountain Tuff, and vein or pegmatitic quartz . Gravel and boulder composition reflects a strong local provenance. The terminology used in the Castle Rock Gulch quadrangle is the same as that used in the adjacent Cameron Mountain and Gribbles Park quadrangles (Wallace and Lawson 1998; Wallace and others, 1999), but the terminology used in the Salida East quadrangle, the first map in this series, was different. Unit T_3 in the Salida East quadrangle was equivalent to unit Qsp of Wrucke and Dings (1979), but in the Castle Rock Gulch quadrangle two levels of pediment deposits were mapped as Qp_2 and Qp_3. Qp_2 is the older and higher level pediment deposit, and Qp_3 is the younger and lower level pediment deposit. These pediment deposits are alluvial in origin.

Pediment deposit three **(Qp_3)** is of Holocene and Pleistocene in age and is composed of poorly stratified sand and silt that contains boulders, cobbles, and pebbles. The gravel deposits are probably of alluvial origin. Boulders are subangular to angular and as large as 0.4 m in diameter. The upper surface is about 3 to 9 m above adjacent streams in Castle Rock and Mushroom Gulches. Pediment deposit two **(Qp_2)** is also of Pleistocene age, and it too consists of poorly stratified sand and silt that contains boulders, cobbles, and pebbles. Boulders are subangular to angular and as large as 0.4 m in diameter. The surface is about 12-14 m above adjacent streams in Castle Rock and Mushroom Gulches. Pediment deposit one **(Qp_1)** is of Pleistocene age. It occurs only as small erosional remnants in Chubb Park and capping a small hill in the northeastern map area. This pediment deposit consists of sub-rounded, well-rounded, and sub-angular cobbles, pebbles, and small boulders in a silty sand matrix. This deposit is locally clast-supported. The upper surface is about 25 m above the existing drainages of Trout Creek and Board Cabins Gulch.

Older alluvium **(Qao)** is likely of Pleistocene age. Older alluvial deposits occur in small alluvial fans scattered through the quadrangle, mostly in the drainage of Castle Rock Gulch and Mushroom Gulch. A larger eroded alluvial fan deposit occurs east of the water gap at the head of Mushroom Gulch in Kaufman Pasture. Nonconsolidated silty clay, clayey silt, silt, silty sand, sand, and pebble, cobble, and boulder gravel form prominent fan-shaped deposits where steep, ephemeral drainages meet Trout Creek, Castle Rock Gulch, and Mushroom Gulch. Boulders and cobbles are angular and sub-angular in a matrix of fine-grained sand and silt. Some of these deposits are probably the remnants of older debris fan deposits. Older alluvial deposits predate alluvium and colluvium.

Eolian sand and silt deposits **(Qes)** are of Holocene and possibly of Pleistocene age. Eolian deposits occur mainly in the southwestern part of the quadrangle. These light-tan, tan, and grayish-light-brown deposits are composed of a mixture of silt and very fine- to fine-grained sand. Rare angular pebbles occur as isolated clasts; most likely these pebbles were emplaced as sheet wash. A thin layer of eolian silt and sand overlies alluvium and colluvium at many places, but these thin alluvium and colluvium deposits are too thin and laterally discontinuous to show on the map.

Talus deposits **(Qta)** are composed of angular pebbles, cobbles, and boulders that accumulated at the base of cliffs. The largest talus deposit occurs on the southwest-facing slope of The Castle in Castle Rock Gulch, which formed below prominent cliffs of the Wall Mountain Tuff. Talus deposits may locally include some colluvial deposits.

Colluvium **(Qc)** is likely of Holocene and Pleistocene age, and it formed as slope-wash and sheet-wash materials accumulated on and near the base of steep to moderate slopes. Colluvium consists of nonstratified to poorly stratified, poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders, in varying proportions. These deposits may be clast or matrix supported. The matrix material is usually medium- to dark-brown or orange-brown clayey, sandy, silt. Colluvium commonly interfingers with alluvium at the base of slopes near modern drainages.

Debris fan deposits **(Qdf)** are of Quaternary age and consist of a nonsorted, nonstratified, chaotic mixture of silt, sand, pebbles, cobbles and boulders in varying proportions deposited near the base of steep drainages. Debris fan deposits are generally fan shaped or elongate lobe shaped. Clasts are sub-rounded to sub-angular and consist of different rock types, depending on the source area, although lower Paleozoic quartzite, dolomite, and limestone are the most common constituents of the debris fans mapped on this quadrangle. Several debris fan deposits underlie U.S. Highways 285 and 24 in this quadrangle.

Landslide deposits **(Qls)** of Pleistocene, Quaternary, and possibly Tertiary age are present in the north-central part of the quadrangle. In general, they consist of nonstratified and nonconsolidated heterogeneous debris consisting of boulders, gravel, sand, and silt, in different proportions. A large, older landslide deposit exists near the head of Mushroom Gulch on the west side of Kaufman Ridge. It consists mainly of subangular to angular cobble- and small boulder-sized clasts of lower Paleozoic dolomite and quartzite, with lesser amounts of sub-rounded clasts of Proterozoic granodiorite. This deposit is clast-supported, with a silty, sandy matrix. Soil is well-developed over the deposit, and the landslide has been truncated by Quaternary alluvium and older alluvium in Mushroom Gulch. This landslide originated on the crest of Kaufman Ridge in an area of low dips in Paleozoic strata where the rocks are cut by at least one east-northeast-striking fault. De Voto (1971) named this unit the Arkose of Mushroom Gulch, and placed its age as older than the Tertiary volcanic units such as the Wall Mountain Tuff. Our mapping shows, however, that landslide debris overlies the volcanic units. Volcanic units and granodiorite are exposed through landslide debris in erosional windows. This landslide appears to be stable as suggested by well developed soil and the presence of tall, straight older fir and spruce trees. Because of the advanced soil development over the deposit, this landslide is thought to be Pleistocene in age.

On the east flank of Kaufman Ridge, two landslides were mapped that consist mainly of boulders and cobbles of Harding Quartzite with lesser amounts of Manitou Dolomite and Fremont Dolomite in a matrix of silt, sand, and clay. These deposits originate in the upper or middle part of the Harding Quartzite near northeast-trending faults. Harding Quartzite clasts tend to be more rounded at the lower terminus of these long, lobate deposits and more angular near the source area, indicating that the landslides were probably very slow moving. They are covered almost entirely by aspen trees, indicating that they may still be active, because aspens prefer disturbed soil. These landslides may be partially composed of talus and colluvial material.

One small, lobate-cuspate landslide with a well-defined bench and toe was mapped below a cliff of Wall Mountain Tuff on the south side of the large exposure in the northeast map area, section 5, T. 14 S., R. 76 W. It is a single mass failure of the tuff on a large apron of colluvium and talus derived from the same slope.

Artificial fill **(af)** consists solely of one man-made deposit of quarry waste material and crushed limestone stockpiles located on private land in the drainage below the Newett Quarries in the northwest corner of the Castle Rock Gulch quadrangle. The material is composed of Leadville Limestone.

STRUCTURE

The Castle Rock Gulch quadrangle straddles a large, basement-cored anticlinal uplift, draped with faulted and folded Paleozoic strata. The most prominent single structure is the near-vertical, north-northwest trending Mosquito-Weston Fault which offsets Paleozoic strata by as much as 850 m in the Castle Rock Gulch quadrangle. Other structures in the map area are steeply dipping normal and reverse faults of small separation that trend northeast, east-northeast, and northwest, and folds in Paleozoic rocks. Cambrian to Mississippian sedimentary rocks are more intensely faulted than overlying Pennsylvanian and Permian sedimentary rocks, which are commonly folded above identified faults in the lower Paleozoic rocks, which suggests that the Pennsylvanian and Permian rocks were nonconsolidated at the time of at least some of the structural deformation. A series of northwest-trending anticlines and synclines occurs in Kaufman Pasture, Chubb Park, and Bassam Park. Proterozoic granodiorite, which serves as the structural basement, is generally weakly to moderately foliated. This weak to moderate regional metamorphism occurred during Proterozoic time. Numerous faults cut the granodiorite, but they are usually difficult to trace over long distances because the granodiorite is homogeneous.

The Castle Rock Gulch quadrangle is located in the late Paleozoic Central Colorado Trough of De Voto (1972), which is also known as the early Paleozoic "Colorado Sag" described by Ross and Tweto (1980). North to northwest trending faults parallel the trend of the central and southern part of the "Colorado Sag". The north to northwest orientation of the largest fault in the map area parallels the strike of principal faults in nearby Proterozoic terranes (Tweto, 1980). Many of these faults produced highlands adjacent to shallow basins (Tweto, 1980) and controlled erosion and sedimentation since Proterozoic time (Tweto, 1980; Ross and Tweto, 1980).

The main regional tectonic elements that influenced sedimentation during Late Paleozoic time (Figure 2) are: (1) the Sawatch Uplift of De Voto (1972), located west of the map area; (2) the

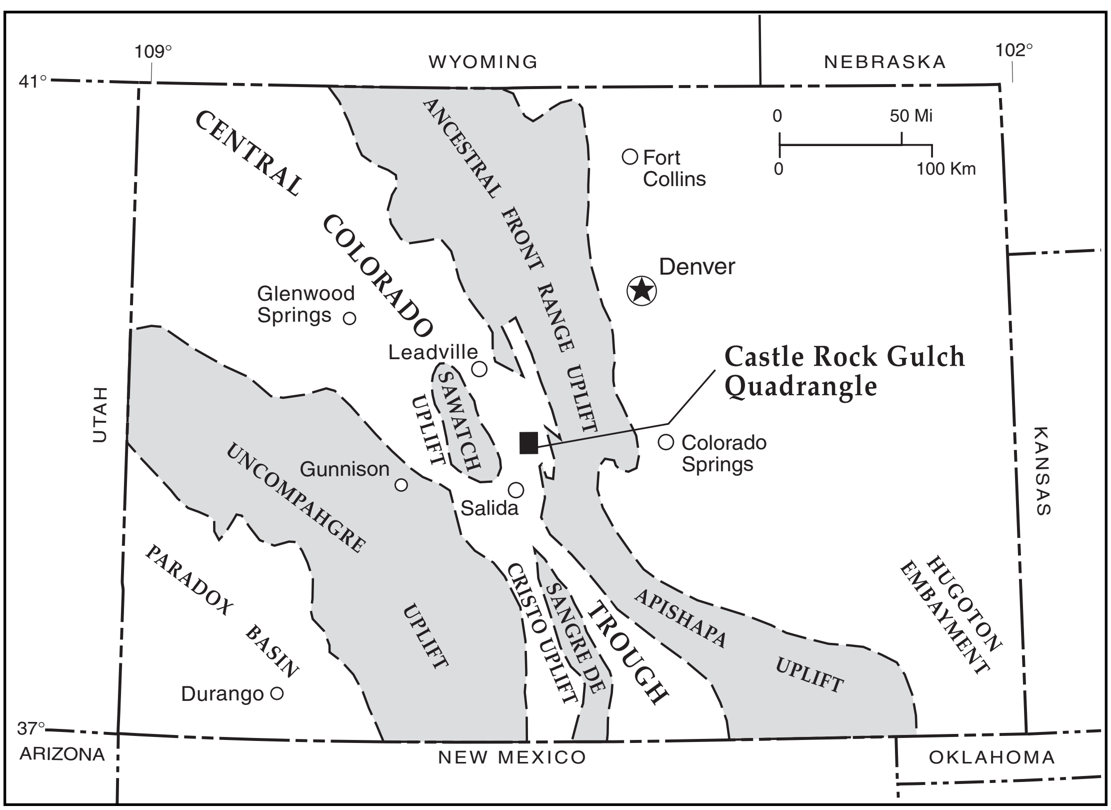


Figure 2. Sketch map showing tectonic uplifts (gray) in relation to the Central Colorado Trough of De Voto (1980) during Pennsylvanian time. Modified from De Voto, 1980b, Figure 3

ancestral Front Range Uplift and the Apishapa Uplift to the east (Ross and Tweto, 1980), which are equivalent to the Front Range and Wet Mountains uplifts of De Voto (1972); (3) the ancestral Uncompaghre uplift to the southwest (De Voto, 1972; Ross and Tweto, 1980); and (4) the Central Colorado Trough, which extended northwest between the ancestral Uncompaghre uplift to the southwest and the ancestral Front Range-Apishapa uplift to the northeast (De Voto, 1972). During the period 70 to 36 Ma (Maastrichtian to Rupelian age) sedimentary, metamorphic, and plutonic rocks in the map area were uplifted and the Central Colorado Trough, which received a large volume of sediment during Paleozoic time, became a source area for sediment during early Tertiary time.

FAULTS

A large, through-going, and reactivated fault was mapped across the Castle Rock Gulch quadrangle as the north-northwest trending Mosquito-Weston Valley Fault, and numerous faults of small separation trend northeast, west-northwest, and east-northeast occur scattered through the map area.

Mosquito-Weston Fault

De Voto (1971) mapped a prominent north-north-west-striking fault in the northern part of the Antero Reservoir quadrangle that he named the Mosquito-Weston Fault. Our detailed mapping has shown that the Mosquito-Weston Fault continues southward across the quadrangle where it connects with the East Bassam Fault of De Voto (1971). It is likely that the Mosquito-Weston Fault of De Voto (1971) connects to the Weston-Pleasant Valley Fault as mapped to the southeast by Wallace and others (1999, 2000), but the exact locations of connecting faults in the Gribbles Park quadrangle are not known because younger deposits cover critical segments of that fault system. Gould (1935) applied the name "Trout Creek Fault" to this fault in the northern part of the Castle Rock Gulch quadrangle, referencing the Geological Map of the United States by the U.S. Geological Survey (1935). Scott (1975) used the name "Trout Creek Fault" where the fault occurs in the Buena Vista 15-minute quadrangle northwest of our map area. In the Castle Rock Gulch quadrangle, the Mosquito-Weston Fault is a vertical to steeply east-dipping reverse fault, with the west block down-thrown in relation to the east block. The fault appears to anastomose into two or more splays at the north end of the quadrangle. Gould (1935) estimated a combined vertical separation along the fault zone of approximately 914 m about 1.5 km north of the Castle Rock Gulch map area where Proterozoic granodiorite is in fault contact with the Pennsylvanian Belden Shale. In the southern part of the quadrangle in sec. 7, T. 13 S., R. 77 W., the fault juxtaposes Proterozoic granodiorite against the top of the Leadville Limestone. We have estimated the fault to have minimum vertical separation of about 850 m at this location based on field relations.

Deformation in Early Proterozoic rocks along the fault is recorded by erratic orientations of foliation near the fault, and the local occurrence of quartz-veined, hematitic, silicified, fine-grained breccias. The latest slip on the Mosquito-Weston Fault postdates deposition and lithification of the Belden Shale in the northern part of the map area and postdates deposition and lithification of the Minturn Formation in the southern part of the map area. Stratigraphic relations in the Castle Rock Gulch quadrangle indicate that slip on the Mosquito-Weston fault predates deposition of the dacite tuff of Castle Rock Gulch at 37.18 ± 0.11 Ma, and that slip cannot be demonstrated since that time. De Voto (1971) suggests that the Mosquito-Weston Fault, and other north-northwest-trending faults in the region, underwent significant displacement during Late Pennsylvanian and Early Permian time, as evidenced by abrupt changes in lithofacies and thickness variations in Late Paleozoic strata. Wallace and others (2000) showed that the Weston-Pleasant Valley Fault and adjacent faults, located southeast of this map area, had a period of oblique slip that produced a negative flower structure between Middle Pennsylvanian and Late Cretaceous time, and slip on the Badger Greek Fault and growth of folds associated with that fault occurred during Virgilian and Wolfcampian time (latest Pennsylvanian and earliest Permian). Mapping in this region has not produced any data that suggests that slip occurred on the Mosquito-Weston Fault or the Weston-Pleasant Valley Fault during the Laramide orogeny.

Faults of Small Separation

Prominent bands of lower Paleozoic rocks on Kaufman Ridge and in the southwestern part of the map area are divided into numerous small fault blocks by a prominent set of northeast-striking faults of small separation, and many of these faults extend into adjacent Proterozoic rocks. Separation on these faults generally ranges between 5 and 30 m. They are difficult to trace across the homogeneous Proterozoic granodiorite.

Several east-northeast striking faults and a few west-northwest striking faults are present, especially on Kaufman Ridge and the southwestern area of the quadrangle. These faults offset lower Paleozoic rocks and appear to have greater offsets in Pennsylvanian rocks than do the north-northeast striking faults. Offsets range between 5 and 25 m. The east-northeast faults are generally perpendicular to the apparent tilting of Miocene tuffaceous sedimentary beds. Faults could not be traced through Tertiary tuffaceous sediment because of poor exposure and an absence of marker beds in homogeneous poorly consolidated clastic deposits.

In the Bassam Ridge area, De Voto (1971) showed the contact between Pennsylvanian and Mississippian rocks as a stratigraphic contact, but our more detailed mapping indicates that part of the contact is a fault. We mapped northwest-trending faults that cut obliquely across the contact of the Leadville Limestone and Kerber Formation so at the northwestern end of those faults, the Minturn dips toward and is in fault contact with the Leadville Limestone, but at the southeastern end of these faults the Kerber appears to overlie the Leadville Limestone on a normal contact.

Several low-angle normal faults occur in lower Paleozoic rocks along U.S. Highways 285 and 24 at Trout Creek. These faults have doubled the apparent thickness of the Manitou Dolomite.

Regionally Tilted Fault Blocks

Attitudes of bedding from rare exposures of the Trump Formation show a consistent north-northwest strike and southwest dip of 16° to 21°. Dips of this magnitude are not likely to occur in a depositional environment and may be the result of regional tectonic tilting to the southwest after late Miocene time, possibly a result of subsidence of the Rio Grande Rift to the west of the Mosquito Range in the Arkansas Valley. The observed attitudes in the Trump Formation correspond with the average structural tilt direction for Miocene sediment in the Upper Arkansas axial basin of the Rio Grande rift (Chapin and Cather, 1994). However, no direct observations proving fault movement in late Tertiary or Quaternary time have been made in this quadrangle.

FOLDS

Folds in the map area form a large-scale anticline-syncline pair, and numerous, discontinuous, medium-scale anticlines and synclines. The large-scale folds deform sequences of Cambrian to Mississippian rocks, and medium-scale folds deform Pennsylvanian rocks.

Large-Scale Folds

The large-scale basement-cored anticline plunges northwestward through the central part of the Castle Rock Gulch quadrangle, and the large-scale syncline plunges toward the southeast in the area of Bassam Park. The northwest-plunging anticline is formed from Cambrian to Mississippian rocks draped over an Early Proterozoic granodiorite core. The trace of the axial surface of the anticline is generally defined by the symmetry of folded Paleozoic rock units, and the axial surface is approximately located on the map. The trace of the anticlinal surface generally parallels the trace of the Mosquito-Weston fault, and if the fold formed in response to slip on that fault, the slip direction was likely oblique up on the east and toward the north on the east block. The large-scale, southeast-plunging syncline in the Bassam Park area is defined by the symmetry of folded Cambrian to Mississippian rock units, and the trace of the axial surface of the syncline is approximately located. The arcuate trace of the synclinal axis generally parallels the trace of the Mosquito-Weston fault in the southern part of the map area, and the synclinal trace also parallels a set of northwest-trending faults southwest of Bassam Ridge. The large-scale anticline and the large-scale syncline could represent a local response to compression that resulted from oblique, west-block-up-to-the-north crustal shortening during Late Pennsylvanian and Early Permian time.

The crystalline basement is not considered susceptible to folding in Colorado during Phanerozoic time. Maximum burial depths were insufficient to make the granodiorite ductile (Matthews, 1986). Although the large-scale folds shown on the map are defined by trends of Paleozoic rocks, the fold symmetry is likely the product of numerous faults of small separation that cut the Early Proterozoic granodiorite, faults that were not mapped because of poor exposures and because the granodiorite is homogeneous. Oblique shear along an arcuate fault should cause folding of sufficiently ductile rocks at restraining bends along the fault.

MEDIUM-SCALE FOLDS

Medium-scale anticlines and synclines occur mainly in Paleozoic rocks in the Kaufman Pasture and Chubb Park areas. In the Kaufman Pasture area De Voto (1971) showed a series of northwest- and north-south-trending anticlines and synclines, but only the southern ends of the axial traces of the folds mapped by De Voto (1971) occur in this map area. De Voto (1971) showed a large-scale syncline that trends generally north from Limestone Ridge in the northwestern part of the Castle Rock Gulch quadrangle through Chubb Park, and he named this fold the Pony Spring Syncline. Our more detailed mapping shows two separate synclinal structures rather than one syncline. On Limestone Ridge, a syncline that plunges gently toward the northeast deforms lower Paleozoic strata. In Chubb Park, a tight syncline in the Belden Shale trends and plunges north-northwest, and north of this map area this fold parallels the west side of the Mosquito-Weston Fault. In this map area, this tight fold is the southernmost part of De Voto's (1971) Pony Spring Syncline, which may have developed in response to slip on the Weston-Mosquito Fault. Lower Paleozoic beds are only very gently folded by this syncline; strain may have been relieved by faulting in these older and well-indurated rocks.

In the Bassam Park area several open folds occur in upper Pennsylvanian rock units. De Voto (1971) mapped the Pleasant Valley Syncline and an anticline-syncline pair that was not named in the Bassam Park area. We show several folds in approximately the same places as De Voto (1971), but our detailed mapping shows the folds as being isolated on separate fault blocks rather than continuous fold axes as did De Voto (1971). Folds do not appear to be continuous across the faults. In this area folds generally trend northeast and northwest, although one east-west trending anticline was mapped on one fault block.

MINERAL RESOURCES

Several mineral commodities have been produced from deposits on the Castle Rock Gulch quadrangle, and although no mining is currently taking place, resources of high-purity limestone, feldspar, and rare earth elements occur in the map area. In addition there is some potential for the occurrence of small deposits of silver, zinc, lead, and uranium in this map area.

INDUSTRIAL MINERALS

Limestone

The largest mining operation in the Castle Rock Gulch quadrangle was the Newett limestone quarry, which is located in the northwest part of the map area. This site consists of several individual open-cut quarries on a dip-slope of the lower part of the Leadville Limestone. The limestone is of metallurgical grade because of its low content of magnesium and other impurities (sample no. K0053, Table 1). Quarried limestone material was transported via the Colorado Midland Railroad to Leadville for use as a smelter flux during the early 1900s (Argall, 1949). When the railroad ceased operating in 1918, the quarry was abandoned. In the mid-1990s, a smaller quarry was operated to produce limestone for mine reclamation applications in Leadville (Mark Hanratty, personal communication, 2000). Limestone of similar quality is common on the eastern slope of Kaufman Ridge in the quadrangle, but this limestone has not been mined.

Pegmatite Minerals

Most pegmatite bodies occur in the northern part of the Castle Rock Gulch quadrangle in the eastern part of the Trout Creek Pass pegmatite region (Hanley and others, 1950). One mine, the Clora May, was operated prior to 1944 to produce feldspar. Located on the eastern edge of sec. 10, T. 14 S., R. 77 W., this mine consists of an open cut about 40 m long, 20 m wide, and 8 m deep. The pegmatite consists mainly of quartz, microcline, and plagioclase; accessory minerals include biotite, muscovite, garnet, fluorite, euxenite, allanite, and gadolinite. About 600 pounds of bismuth were reportedly produced from the Clora May mine in addition to feldspar (Hanley and others, 1950). Del Rio (1960) lists bismutite, a bismuth carbonate, as a minor accessory mineral. Euxenite and allanite contain rare-earth elements and these minerals may have been recovered as byproducts of feldspar mining. Baillie (1962) estimates feldspar reserves of more than 1000 tons at the Clora May Mine. Several other smaller pegmatite bodies were prospected in the area near the Clora May Mine, but none were developed. One small pegmatite body is east of Trout Creek and is clearly visible from U.S. Highway 285. The smaller pegmatite bodies that have not been mined commonly consist primarily of white quartz and feldspar, and have lower concentrations of accessory minerals than larger, productive pegmatites. All of the pegmatites are thought to be related to small stocks of granite **(YXgt)** that intruded the large mass of older granodiorite.

Several other quartz-feldspar pegmatite bodies were prospected and partially developed in the northern part of this quadrangle. The Lucky Jack Mine is located in the southern half of sec. 1, T. 14 S., R. 77 W., where small open-cuts expose several small pegmatite bodies similar to that at the Clora May Mine. The adit at the Lucky Jack pegmatites tend to be elongated lenses and pods that trend north-northeast. Biotite crystals up to 1 m in diameter are present locally. The enclosing rock is massive, poorly foliated Proterozoic granodiorite. The adit at the Lucky Jack Mine was an apparently unsuccessful attempt to drive a tunnel to access one or more of these pegmatites underground. Only unaltered granodiorite is present on the mine dump.

VEIN AND REPLACEMENT DEPOSITS

A few fault-related vein and replacement deposits occur in the quadrangle, none of which have been significant producers of metal. Quartz veins occur locally in Proterozoic granodiorite and in Paleozoic carbonate rocks. Several areas of secondary silicification are associated with faults that cut Paleozoic rocks.

The most significant fissure-vein system occurs in the northwest part of the map area along a major north-northwest fault in Proterozoic granodiorite in the SW/of sec. 35, T. 13 S., R. 77 W. The vein is more than 15 m wide at its widest point, and at least 150 m long. The vein strikes N. 30 W., dips steeply southwest, and consists contains mainly of quartz, and smaller amounts of calcite, fluorite, hematite, pyrite, and traces of malachite. The vein has been explored by a 15 to 20 m shaft and several smaller prospect pits. Geochemical sample K0063 (Table 2) of dump material from the shaft contained 2.4 ppm silver. The sample contained no significant gold or base metal content, although traces of copper carbonate minerals were noted.

Trout Creek No. 2 Mine, in the northwestern part of the Castle Rock Gulch quadrangle, consists of a decline adit (now caved) and several short adits and shallow shafts in the NW/sec. 2, T. 14 S., R. 77 W. This area is 300 to 500 m southwest of the fissure vein described in the paragraph above. Sheared, brecciated, altered dolomite (Dyer Member of the Chaffee Formation?) occurs along the north-northwest-trending, steeply dipping Mosquito-Weston fault and a related north-northeast trending high-angle fault. Iron and manganese oxide is abundant, but no vein quartz was observed at this site. Geochemical samples K0089 and K0095 (Table 3) are moderately anomalous in zinc and weakly anomalous in lead and silver. No references to this mine could be found in the geologic literature. The mineralization probably represents a small, Laramide-age hydrothermal system that developed during or shortly after the emplacement of the large monzonite sill exposed about 200 m west of the area of the workings.

Several shallow shafts and prospect pits are located in the northern parts of secs. 3 and 4, T. 14 S., R. 77 W. in Chubb Park. These small mines have been described as the “Mizpah Gold Mine” in the Mineral Resource Data System of the U.S. Geological Survey (Mason and Arndt, 1996). Pods and lenses of gossan mineralization occur at and near the contact between the monzonite sill and the underlying Leadville Limestone. The limestone has been dolomitized and commonly has narrow veinlets of carbonate. Sandstone lenses common at the top of the Leadville Limestone here are altered and oxide stained. Mineralized rock is poorly exposed. Geochemical samples of dump material (samples K0032 and K0035, Table 3) display anomalous concentrations of silver, zinc, and copper, but no gold. The monzonite is severely altered near these prospects. A sample of altered monzonite near the center of the thick, crescent-shaped sill was slightly anomalous in zinc (sample K0045, Table 3).

Fluid migration along high-angle faults on Kaufman Ridge produced lenses of strong secondary silicification of Paleozoic dolomite and limestone adjacent to faults. Bright-orange and deep-red silicified carbonate and local low-grade metal mineralization occurs as irregular shaped replacement bodies along several faults. Geochemical samples showed that these silicified zones commonly contain mildly anomalous concentrations of silver (samples K0060, K0127, K0174, K0183, K0219, K0253, K0372, Table 3). One sample also contained abundant hematite, barite, and highly anomalous lead and zinc concentrations (sample K0183, Table 3). Drusy quartz veins occur rarely in the Paleozoic rocks. Two narrow quartz vein-breccia zones associated with northeast-trending faults are present on the east side of Kaufman ridge. No anomalous concentrations of metals were detected in samples K0287 and K0290 (Table 3).

STRATABOUND MINERAL DEPOSITS

Regionally, occurrences of copper, silver, and uranium are most common in clastic rocks of Pennsylvanian and Permian age (Lindsay and Clark, 1995), but stratabound occurrences of this type have not been identified in the Castle Rock Gulch quadrangle. Stratabound mineral occurrences that were common in Pennsylvanian and Permian rock units in the Cameron Mountain, Gribbles Park, Jack Hall Mountain, and Salida East quadrangles (Wallace and others, 1997; Wallace and Lawson, 1998; Wallace and others, 1999, 2000) are absent from the Castle Rock Gulch quadrangle. Growth faults, which occur in the Futurity Gulch area south of this map area, provide avenues for movement of mineralizing fluids (Wallace and Lawson, 1998), but growth faults were not identified in the Castle Rock Gulch quadrangle. Because redbeds of the Sharpsdale and Sangre de Cristo Formations are absent in the map area, the stratabound mineral occurrences described by Lindsay and Clark (1995) and by

Wallace and others (1997, 1999) as typical of "red-bed" stratabound copper-silver deposits in this region do not occur in the Castle Rock Gulch quadrangle.

In the 1950s and 1960s, several companies actively explored for uranium in South Park. The Miocene-age Antero Formation and Trump Formation, and the Oligocene-age Tallahassee Creek Conglomerate were considered prospective rock units. Although uranium was never mined in the area, several sub-economic occurrences were discovered in the Antero Formation (De Voto, 1971). The Carson Mining and Development (Nina No. 7) uranium prospect is reportedly located about 2 mi. north of the map area (Nelson-Moore and others, 1978). Autunite occurs along fractures in what De Voto (1971) mapped as "lower volcanic conglomerate", or what we have mapped as the Tallahassee Creek Conglomerate. Because of the presence of the Antero Formation and the Tallahassee Creek Conglomerate, the northeastern part of the map area has potential to host small uranium deposits.

HYDROCARBON TESTS

An exploratory well was drilled by the Geary Oil Company in 1967 in sec. 11, T. 13 S., R. 77 W., 6.5 km north of the Castle Rock Gulch quadrangle boundary (Colorado Oil and Gas Conservation Commission data, written communication). In that area, a salt spring that emanates from the Belden Shale contains hydrocarbon gas (De Voto, 1971). The structural target was the Kaufman Ridge anticline. The well penetrated the Leadville Limestone at a depth of 235 m where it yielded gas and hot water. The total hole depth was 268 m. However, subsequent source-rock analysis of Belden Shale from the Trout Creek Pass area suggests that the thermal history of the area is not conducive to the preservation of oil in nearby reservoirs (De Voto, 1971).

TRACE ELEMENT GEOCHEMISTRY

Twenty samples were collected from the map area and analyzed for trace elements. These were collected from altered Paleozoic sedimentary rocks, quartz vein deposits, and altered Tertiary monzonite. The results are listed in Table 3.

Table 3. Trace-element geochemistry of samples taken in the Castle Rock Gulch quadrangle. [All analyses were performed by Bondar-Clegg (Intertek Testing Services, Inc.) of Vancouver, B.C. All concentrations are in parts per million (ppm) unless otherwise noted. Gold was analyzed by fire assay (30 g charge). All other elements were analyzed by inductively coupled plasma optical emission spectrometry (ICP) with acid digestion (HCl and HNO_3). <, less than; >, greater than; ppb, parts per billion]

Sample No.	Description	Au (ppb)	Ag	Cu	Pb	Zn	Mo	Ni
K0032	dump, alt ss w/ abund. oxides, top of Leadville	<5	<0.2	217	70	469	7	68
K0035	dump, alt. Leadville dolo., calc vlts, FeOx	<5	1.2	8	6	48	2	7
K0045	FeOx-stained alt. monzonite	<5	<0.2	6	9	64	<1	5
K0060	Silicified Leadville ls, red, local breccia	<5	1.0	13	16	30	1	4
K0063	dump — qz vein in Xgd	<5	2.4	5	3	8	<1	<1
K0074	Harding quartzite layer w/ blu-grn color	<5	0.5	6	4	7	<1	3
K0089	dump, oxidized, sheared dolo.	<5	1.2	11	87	150	<1	3
K0092	alt. Xgd on at fault exposure, blu-grn	<5	<0.2	5	7	20	3	7
K0095	Trout Creek Mine No. 2 — alt dolo.+qtzte	<5	1.3	13	94	398	<1	2
K0127	silicif. Manitou Dolo. at near fault, org-red	<5	0.2	8	22	22	2	8
K0174	silicif. Dyer Dolo., red + org, solution bx	<5	0.4	5	12	34	1	7
K0183	massive hematite zone in Manitou, fault, barite	<5	0.7	46	896	257	10	19
K0219	red chert (fault?), top of Leadville Ls	<5	0.4	5	15	81	6	14
K0253	silicif. fault zone in Leadville Ls, org + red	<5	0.4	17	22	51	2	6
K0285	Harding Quartzite (float), dissem. fine green mineral	<5	<0.2	4	14	15	2	5
K0287	vuggy qz vein along fault in Dyer Dolo.	<5	<0.2	4	5	9	3	6
K0290	vuggy qz vein along fault in Dyer Dolo. (prospect)	<5	0.3	24	5	9	2	5
K0296	silicif. fault zone in Xgd w/ qz stockwork veining	<5	<0.2	10	4	14	1	8
K0372	silicif. Manitou Dolo. w/ abund. blu-grn stain	<5	0.5	5	5	10	4	8
00314	alt. Xgd, fault zone	<5	<0.2	3	15	7	2	4

Sample No.	Description	Co	Cd	Bi	As	Sb	Hg	Fe%
K0032	dump, alt ss w/ abund. oxides, top of Leadville	19	2.1	<5	39	5	0.040	>10.0
K0035	dump, alt. Leadville dolo., calc vlts, FeOx	5	0.3	<5	8	<5	0.056	2.81
K0045	FeOx-stained alt. monzonite	7	<0.2	<5	<5	<5	<0.01	2.66
K0060	Silicified Leadville ls, red, local breccia	2	0.2	<5	15	<5	<0.01	0.82
K0063	dump — qz vein in Xgd	<1	<0.2	<5	<5	<5	0.027	0.05
K0074	Harding quartzite layer w/ blu-grn color	<1	<0.2	<5	<5	<5	0.020	0.29
K0089	dump, oxidized, sheared dolo.	<1	0.7	<5	13	<5	<0.01	0.91
K0092	alt. Xgd on at fault exposure, blu-grn	2	0.2	<5	18	<5	0.024	0.88
K0095	Trout Creek Mine No. 2 — alt dolo.+qtzte	<1	2.2	<5	11	<5	0.012	0.62
K0127	silicif. Manitou Dolo. at near fault, org-red	1	0.3	<5	24	<5	0.305	0.89
K0174	silicif. Dyer Dolo., red + org, solution bx	2	0.3	<5	13	<5	0.046	0.60
K0183	massive hematite zone in Manitou, fault, barite	8	7.3	<5	1574	270	0.165	>10.0
K0219	red chert (fault?), top of Leadville Ls	3	0.6	<5	107	6	<0.01	3.51
K0253	silicif. fault zone in Leadville Ls, org + red	2	0.5	<5	84	5	0.175	1.36
K0285	Harding Quartzite (float), dissem. fine green mineral	<1	0.3	<5	5	<5	0.024	0.44
K0287	vuggy qz vein along fault in Dyer Dolo.	<1	<0.2	<5	<5	<5	<0.01	0.38
K0290	vuggy qz vein along fault in Dyer Dolo. (prospect)	<1	<0.2	<5	<5	<5	0.013	0.38
K0296	silicif. fault zone in Xgd w/ qz stockwork veining	3	<0.2	<5	<5	<5	<0.01	1.12
K0372	silicif. Manitou Dolo. w/ abund. blu-grn stain	1	0.2	<5	18	<5	<0.01	0.60
00314	alt. Xgd, fault zone	1	<0.2	<5	8	<5	<0.01	1.18

Table 3. Continued.

Sample No.	Description	Mn	Te	Ba	S (%)	Cr	V	Sn
K0032	dump, alt ss w/ abund. oxides, top of Leadville	3991	<10	25	0.04	39	103	<20
K0035	dump, alt. Leadville dolo., calc vlts, FeOx	791	<10	16	0.14	12	10	<20
K0045	FeOx-stained alt. monzonite	790	<10	73	0.01	32	32	<20
K0060	Silicified Leadville ls, red, local breccia	408	<10	24	0.10	15	11	<20
K0063	dump — qz vein in Xgd	44	<10	29	0.26	2	1	<20
K0074	Harding quartzite layer w/ blu-grn color	19	<10	21	0.04	62	14	<20
K0089	dump, oxidized, sheared dolo.	1260	<10	6	0.15	2	3	<20
K0092	alt. Xgd on at fault exposure, blu-grn	615	<10	84	0.02	153	21	<20
K0095	Trout Creek Mine No. 2 — alt dolo.+qtzte	899	<10	4	0.14	4	5	<20
K0127	silicif. Manitou Dolo. at near fault, org-red	65	<10	83	0.02	218	10	<20
K0174	silicif. Dyer Dolo., red + org, solution bx	405	<10	71	0.04	80	8	<20
K0183	massive hematite zone in Manitou, fault, barite	2220	<10	>2000	0.20	6	81	<20
K0219	red chert (fault?), top of Leadville Ls	513	<10	93	0.03	94	40	<20
K0253	silicif. fault zone in Leadville Ls, org + red	193	<10	582	0.05	55	16	<20
K0285	Harding Quartzite (float), dissem. fine green mineral	158	<10	35	0.03	168	24	<20
K0287	vuggy qz vein along fault in Dyer Dolo.	109	<10	21	<0.01	211	3	<20
K0290	vuggy qz vein along fault in Dyer Dolo. (prospect)	41	<10	541	0.03	204	4	<20
K0296	silicif. fault zone in Xgd w/ qz stockwork veining	144	<10	62	<0.01	203	12	<20
K0372	silicif. Manitou Dolo. w/ abund. blu-grn stain	276	<10	79	0.02	248	6	<20
00314	alt. Xgd, fault zone	396	<10	57	<0.01	105	17	<208

Sample No.	Description	W	La	Ti	Mg (%)	Ca (%)	Na (%)	K (%)
K0032	dump, alt ss w/ abund. oxides, top of Leadville	<20	4	<0.01	0.19	1.29	<0.01	0.02
K0035	dump, alt. Leadville dolo., calc vlts, FeOx	<20	2	<0.01	9.25	>10	<0.02	0.17
K0045	FeOx-stained alt. monzonite	<20	12	0.078	0.67	1.64	0.05	0.25
K0060	Silicified Leadville ls, red, local breccia	<20	<1	<0.01	9.08	>10	0.01	0.02
K0063	dump — qz vein in Xgd	<20	<1	<0.01	0.14	>10	<0.01	0.02
K0074	Harding quartzite layer w/ blu-grn color	<20	2	<0.01	0.19	5.63	<0.01	0.26
K0089	dump, oxidized, sheared dolo.	<20	<1	<0.01	<10	<10	0.02	<0.01
K0092	alt. Xgd on at fault exposure, blu-grn	<20	7	<0.01	0.09	2.23	<0.01	0.23
K0095	Trout Creek Mine No. 2 — alt dolo.+qtzte	<20	<1	<0.01	<10	<10	0.02	<0.01
K0127	silicif. Manitou Dolo. at near fault, org-red	<20	5	<0.01	0.07	0.29	<0.01	0.15
K0174	silicif. Dyer Dolo., red + org, solution bx	<20	4	<0.01	2.59	5.04	<0.01	0.08
K0183	massive hematite zone in Manitou, fault, barite	93	6	<0.01	9.30	<10	0.02	0.03
K0219	red chert (fault?), top of Leadville Ls	<20	1	<0.01	1.88	3.63	<0.01	0.05
K0253	silicif. fault zone in Leadville Ls, org + red	<20	2	<0.01	2.82	5.01	<0.01	0.08
K0285	Harding Quartzite (float), dissem. fine green mineral	<20	65	<0.01	0.13	3.29	0.01	0.31
K0287	vuggy qz vein along fault in Dyer Dolo.	<20	2	<0.01	0.43	1.04	<0.01	0.05
K0290	vuggy qz vein along fault in Dyer Dolo. (prospect)	<20	1	<0.01	0.61	2.42	<0.01	0.04
K0296	silicif. fault zone in Xgd w/ qz stockwork veining	<20	5	<0.01	0.21	0.07	0.02	0.10
K0372	silicif. Manitou Dolo. w/ abund. blu-grn stain	<20	<1	<0.01	0.67	3.37	<0.01	0.07
00314	alt. Xgd, fault zone	<20	14	0.012	0.07	0.10	0.07	0.15

Table 3. Continued.

Sample No.	Description	Sr	Y	Ga	Li	Nb	Sc	Zr
K0032	dump, alt ss w/ abund. oxides, top of Leadville	213	26	<2	22	4	7	<1
K0035	dump, alt. Leadville dolo., calc vlts, FeOx	45	6	<2	8	<1	<5	<1
K0045	FeOx-stained alt. monzonite	109	11	5	18	2	<5	3
K0060	Silicified Leadville ls, red, local breccia	17	1	<2	2	<1	<5	1
K0063	dump — qz vein in Xgd	85	1	<2	1	<1	<5	<1
K0074	Harding quartzite layer w/ blu-grn color	14	6	<2	24	1	<5	8
K0089	dump, oxidized, sheared dolo.	26	<1	<2	1	<1	<5	<1
K0092	alt. Xgd on at fault exposure, blu-grn	8	9	<2	2	2	<5	6
K0095	Trout Creek Mine No. 2 — alt dolo.+qtzte	18	<1	<2	1	<1	<5	<1
K0127	silicif. Manitou Dolo. at near fault, org-red	7	3	<2	2	<1	<5	4
K0174	silicif. Dyer Dolo., red + org, solution bx	16	3	<2	4	<1	<5	2
K0183	massive hematite zone in Manitou, fault, barite	87	10	>2	3	4	<5	<1
K0219	red chert (fault?), top of Leadville Ls	10	3	<2	1	2	<5	<1
K0253	silicif. fault zone in Leadville Ls, org + red	18	2	<2	2	1	<5	2
K0285	Harding Quartzite (float), dissem. fine green mineral	40	136	<2	25	2	<5	7
K0287	vuggy qz vein along fault in Dyer Dolo.	19	1	<2	<1	<1	<5	2
K0290	vuggy qz vein along fault in Dyer Dolo. (prospect)	52	1	<2	4	<1	<5	2
K0296	silicif. fault zone in Xgd w/ qz stockwork veining	3	7	<2	6	<1	<5	2
K0372	silicif. Manitou Dolo. w/ abund. blu-grn stain	29	<1	<2	2	<1	<5	2
00314	alt. Xgd, fault zone	5	12	<2	9	1	<5	3

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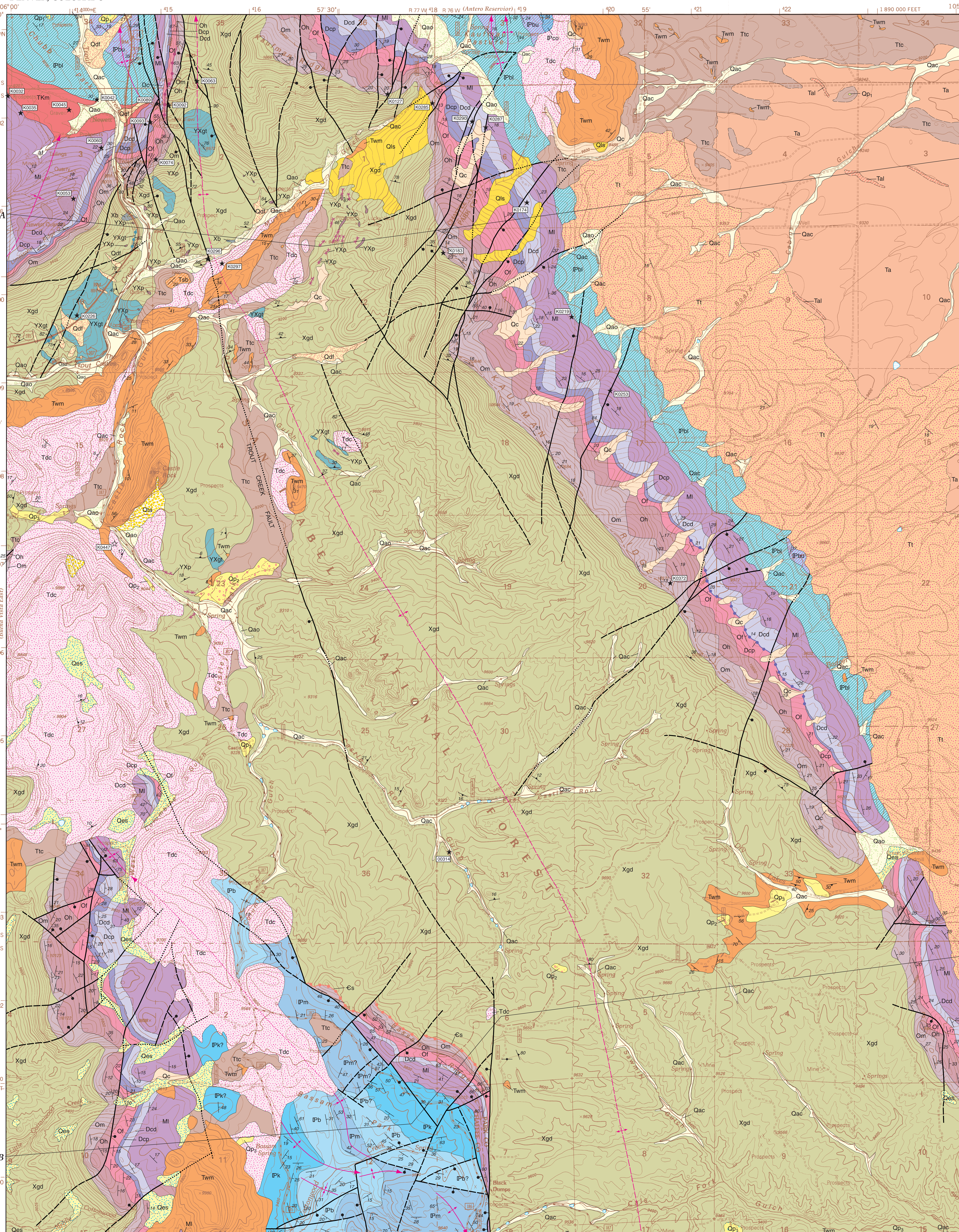
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO



Base from U.S. Geological Survey, 1991
10,000-foot grid based on Colorado coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 13

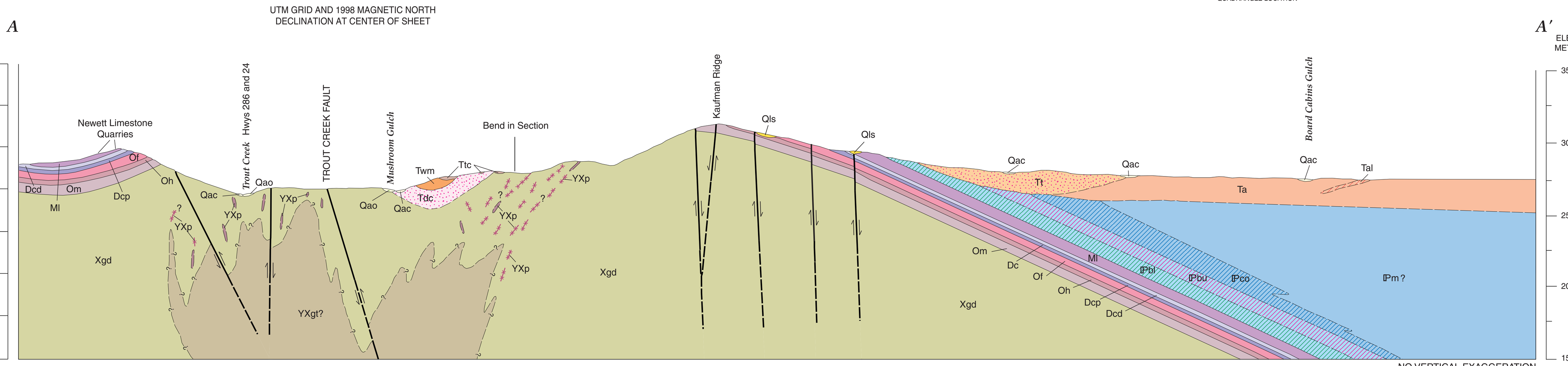
UTM GRID AND 1998 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

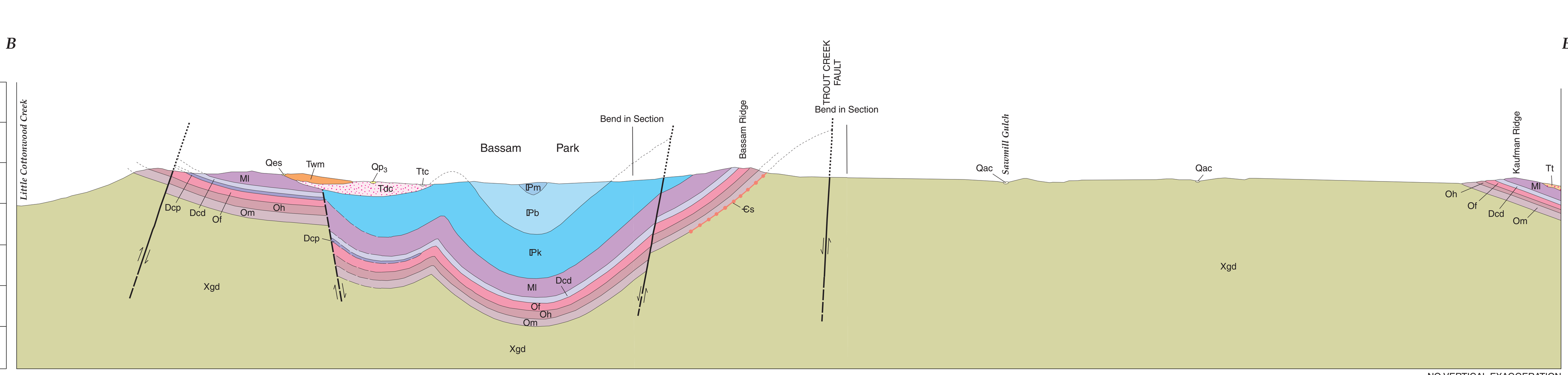
SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

Geology mapped in 2000
Digital cartography by Cheryl Brchan and Jason Wilson





CONDENSED DESCRIPTION OF MAP UNITS

The complete description of map units and references is in the accompanying booklet.

QUATERNARY SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (Recent)**—Consists of one man-made deposit of quarry waste material and crushed limestone stockpiles located in the drainage below the Newett Quarries in the northwest corner of the quadrangle. The material is composed of Leadville Limestone

ALLUVIAL AND COLLUVIAL DEPOSITS

Qac **Alluvium and colluvium (Holocene and Pleistocene)**—Lenticular layers of tan, grayish-yellow-brown, and dark- gray clayey silt, silty sand, sand, pebbly and cobbly silt and sand, and silty and sandy gravel. Contains some interbedded lenses of matrix-supported angular cobbles and pebbles in a clayey to sandy matrix. Commonly organic rich near streams. Occurs 5 m or more above active stream channels

Qls **Landslide deposits (Holocene and Pleistocene)**—Nonstratified, nonconsolidated, poorly sorted heterogeneous debris consisting of boulders, gravel, sand, and silt, in differing proportions

Qdf **Debris-flow deposits (Holocene and Pleistocene)**—Nonsorted, nonstratified, chaotic mixture of silt, sand, pebbles, cobbles and boulders in different proportions deposited near the base of steep to moderate slopes. May include sheetwash deposits or some talus material, and may grade into alluvium at source areas. Generally fan or elongated lobe-shaped

Qc **Colluvium (Holocene and Pleistocene)**—Nonstratified to poorly stratified, poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders, in differing proportions, deposited on and near the base of steep to moderate slopes. May include sheetwash deposits or some talus material, and may grade into alluvium at the base of slopes near modern drainages

Qta **Talus (Holocene and Pleistocene)**—Angular pebbles, cobbles, and boulders that accumulated at the base of cliffs. Commonly derived from outcrop areas of Wall Mountain Tuff (Twm). Also mapped on Kaufman Ridge where fractured Harding Quartzite (Oh) breaks into blocks. Talus may be mixed with colluvium and landslide material at some places

Qes **Eolian sand and silt deposits (Holocene and Pleistocene?)**—Light-tan, tan, and grayish-light-brown, fine-grained sand and silt, silty sand, and interbedded dispersed pebbles in a fine-grained matrix. Deposits cover alluvium and colluvium deposits and are incised by modern alluvial channels

Qao **Older alluvium (Pleistocene)**—Nonconsolidated interbedded layers of silty clay, clayey silt, silt, silty sand, sand, and pebble, cobble, and boulder gravel 5 to 10 m above active stream channels. May form alluvial fans. Boulders are commonly angular to subangular

Pediment deposits (Pleistocene)

Qp₃ **Pediment deposit three (Pleistocene)**—Poorly stratified sand and silt that contains dispersed boulders, cobbles, and pebbles. Alluvial origin. Remnants of this pediment surface are 3 to 9 m above Quaternary alluvium and colluvium (Qac) in Herring Park area in Gribbles Park quadrangle. Correlates with unit T_3 in Salida East quadrangle (Wallace and others, 1997), and correlates with Qp_2 (Wrucke and Dings, 1979) in the Herring Park area

Qp₂ **Pediment deposit two (Pleistocene)**—Poorly stratified sand and silt that contains dispersed boulders, cobbles, and pebbles. Pediment deposits occur about 12 m above Quaternary alluvial and colluvial deposits (Qac) in the Herring Park area of the Gribbles Park quadrangle. In Salida East quadrangle this unit was grouped with T_3 by Wallace and others (1997), and mapped as Qp_1 in the Herring Park area by Wrucke and Dings (1979)

Qp₁ **Pediment deposit one (Pleistocene)**—Nonconsolidated and poorly stratified deposits of subangular, subrounded, and well-rounded, cobbles, pebbles, and small boulders in a silty sand matrix. May be clast-supported. Lower surface is about 25 m above existing drainages

BEDROCK

TERTIARY ROCKS AND DEPOSITS

Tt **Trump Formation (late Miocene)**—Moderate-gray to grayish-white, light-yellowish-gray, to medium-orange-brown, poorly consolidated and nonconsolidated, poorly to moderately sorted, interbedded tuffaceous, commonly calcareous, fine to cobbly, silty, sandy gravel; pebbly, silty sand; and sandy silt. Some conglomerate beds consist almost entirely of pebbles and cobbles of light- to medium- gray vitric tuff (trachyte?). Beds of air-fall tuff are well indurated and contain small crystals of quartz, feldspar, and biotite in a lithified matrix of ash. Silicic tuff is locally opaline. Unusual beds of white, porous, highly calcareous, and well-indurated crystal-lithic tuff is present locally as 2- to 4-m-thick layers. De Voto (1961) showed that the Trump Formation grades vertically and laterally into the Wagontongue Formation to the south and east of the Castle Rock Gulch quadrangle. Unconformably overlies the Antero Formation (Ta), the Belden Shale (IPb), and the Tallahassee Creek Conglomerate (Ttc)

Ta **Antero Formation (early to middle Oligocene?)**—Tuffaceous sedimentary rocks and interlayered grayish-white to grayish-yellow tuff. Tuffaceous sedimentary deposits consist of poorly consolidated grayish-white, light-gray, light-grayish-green, and black volcaniclastic and medium- to coarse-grained arkose; light-gray to grayish-tan pebble-conglomerate; and white, gray-green and brown siltstone and mudstone. Biotite grains are commonly abundant. Discontinuous localized limestone beds were mapped separately at some places (Tal). Unconformably overlies the Tallahassee Creek Conglomerate (Ttc), and probably the Pennsylvanian Maroon and Coffman Formations. Very poorly exposed in the map area

Tal **Limestone beds of the Antero Formation (early to middle Oligocene)**—Discontinuous, lenticular beds of pale-yellowish-white, light-yellowish-gray, and medium-brown limestone. Usually weathers white to light-gray. May be dense or porous. Commonly occurs as oolitic or ostracode packstones or wackestones. Freshwater algal oncolites, ostracodes, and gastropods are locally abundant. Local gray, white, and orange-brown chalcedony as secondary replacement

Tsb **Slide block (middle Oligocene?)**—Cohesive landslide block of Manitou Limestone and Harding Quartzite resting on chaotic but stabilized landslide rubble coeval (?) with the Tallahassee Creek Conglomerate (Ttc)

Ttc **Tallahassee Creek Conglomerate (early Oligocene)**—Contains large sub-rounded clasts of Manitou Limestone, Harding Quartzite, Fremont Dolomite, subrounded to rounded clasts of dacite tuff of Castle Rock Gulch (Tdc) and Wall Mountain Tuff (Twm), and rounded clasts of Early Proterozoic granodiorite as large as 10 m in diameter in a matrix of tuff and tuffaceous sediment. Tuff of weakly welded, light-gray and light-yellowish gray quartz latite that contains phenocrysts of feldspar and less common biotite. Volcanic rock fragments are common

Twm **Wall Mountain Tuff (late Eocene)**—Light-gray, moderate-gray, light-brownish-gray, and grayish-red, eutaxitic, welded, rhyolite ash-flow tuff that contains prominent sanidine and plagioclase phenocrysts. Flow foliation in glassy welded tuff is prominent. Degree of welding varies from pumice-rich flow bands to densely welded glassy tuff. Basal 3 to 4 m of unit consists of black, perlitic glass that contains phenocrysts of quartz and sanidine. Radiometric dates using $^{40}Ar/^{39}Ar$ method resulted in age of 36.64 ± 0.06 Ma (McIntosh and Chapin, 1994)

Tdc **Dacite tuff of Castle Rock Gulch (late Eocene)**—Light-gray, light-tan, light-reddish-gray, and light-orange-gray, moderately welded tuff, that contains abundant pumice fragments, angular volcanic rock fragments, and abundant plagioclase and biotite crystals. The base of the tuff is densely welded and pumice fragments are glassy. Moderately welded tuff is locally foliated. $^{40}Ar/^{39}Ar$ age of 37.18 ± 0.11 Ma determined from biotite in sample K0447.

MESOZOIC OR TERTIARY ROCKS

TKm **Monzonite (Late Cretaceous or Paleocene)**—Large, crescent-shaped sill in the northwestern part of the map area. Equigranular, medium- to coarse-grained, moderate- to dark-green, gray to brownish- gray monzonite. Composed of approximately 30 percent euhedral, elongated prismatic hornblende (1 to 3 mm), 60 percent subhedral feldspar, 3 to 4 percent magnetite, and traces of biotite and pyroxene. Moderately altered. Margin zones are finer grained and more resistant to erosion than the interior, which is generally weathered on the surface to a grus. Intruded between the top of the Leadville Limestone (Ml) and the Belden Shale (IPb) directly west of a major north-northwest-trending, high-angle fault

PALEOZOIC ROCKS

IPco **Coffman Formation (Middle Pennsylvanian)**—Siliceous, micaceous, light-brown, gray, grayish-red, and olive-drab conglomeratic arkose, medium- and coarse-grained arkose, and feldspathic siltstone interbedded with dark-gray to black shale. The basal bed is a reddish-gray to light-gray, medium- and coarse-grained pebbly arkose, which contains a few shale chips and abundant angular fragments of feldspar and quartz up to 2 cm in diameter derived from the erosion of Proterozoic crystalline rocks. Only the lower part of the Coffman Formation is exposed in this quadrangle

IPm **Minturn Formation (Middle Pennsylvanian)**—Dark-gray, gray, olive-drab, grayish-green, greenish-gray, and black shale, argillaceous and micaceous siltstone, silty micaceous shale, fine- and medium-grained feldspathic sandstone, rare coarse-grained arkose, and rare black, fetid limestone and dolomite. Beds are between 1 and 10 m thick. Sandstone and sandy siltstone are more common in the lower part of the unit, and siltstone and shale are more common in the upper part. Coarse-grained arkose marks the base. Sedimentation units are fining-upward sequences that are capped by dark-colored shale. Primary sedimentary structures are small-scale planar crossbeds, ripple cross-lamination, planar lamination, and rib-and-furrow structures. Shallow channels occur at the base of some sandstone beds. Siltstone and shale are laminated and microlaminated, and some beds contain abundant plant fragments. Rare dark-gray and black limestone and dolomite beds are fine-grained, argillaceous, fetid micrite that are generally 2 to 15 cm thick

IPb **Belden Shale, undivided (Middle Pennsylvanian)**—In southwestern part of map area the Belden Shale is not subdivided into informal members. The Belden Shale consists of black, laminated and nonlaminated shale, and black and dark-gray, argillaceous siltstone, interbedded with moderate-gray, rusty-weathering siltstone, and rare gray, fine-grained sandstone. Zones of black shale as thick as 20 m. A fetid, black fossiliferous limestone marks the top in the southwestern part of the map area. Subdivided only in northern part of map area

IPbu **Upper member of the Belden Shale**—Consists of interbedded and intertonguing layers of dark-grayish-brown and black shale, olive-drab to dark-reddish-green micaceous sandy siltstone; fissile, micaceous, silty, fine- and medium-grained arkose; and rare, 0.1- to 0.3-m-thick beds of dark-gray and dark-grayish-brown, fetid limestone. Prominent crossbedded medium- to coarse-grained arkose at base. Exposures are poor to fair

IPbl **Lower member of the Belden Shale**—Dark-gray, brownish-gray, and black shale and calcareous siltstone interbedded with moderate- to dark-gray, dark-brownish-gray, light-gray-weathering, thin-bedded to locally flaggy, fetid limestone and argillaceous limestone. Limestone beds are as thick as 5 m but are generally less than 3 m. Rare, discontinuous lenses of olive-drab to dark-reddish-green, fine- to medium-grained micaceous arkose. This member is poorly exposed

IPk **Kerber Formation (Early Pennsylvanian)**—Grayish-green, olive-drab, olive-gray, moderate-gray, and dark-greenish-gray, conglomeratic, coarse-grained arkose and subarkose interbedded with grayish-green, medium- and fine-grained sandstone, argillaceous and micaceous siltstone, silty micaceous black shale, and moderate-gray, biomicritic limestone that occurs at the lower and upper parts of the unit. Coarse-grained sedimentation units are fining-upward sequences capped by fine-grained sandstone or siltstone. Coarse-grained arkose beds are less than 2 m thick. Fine-grained clastic units are fining-upward sequences capped by dark-colored shale and are 5 to 15 m thick. Primary sedimentary structures in coarse-grained rocks are planar and trough crossbeds, ripple-cross-lamination, planar lamination, rib-and-furrow structures, and parting lineation. Shallow channels occur at the base of coarse-grained, conglomeratic sandstone beds. Primary sedimentary structures in fine-grained sandstone are ripple cross-lamination, climbing ripples, planar lamination, and ripple marks. Siltstone and shale are laminated and microlaminated. Dark-gray and black limestone beds that occur in the lower and upper parts of the Kerber Formation are fine-grained, argillaceous, mottled or laminated, fetid micrite that are generally 1 to 2 m thick. Several limestone beds contain fossil fragments, and some rare thin limestone beds near the top are brachiopod coquina

Ml **Leadville Limestone (Early Mississippian)**—Moderate-gray and dark-gray, massive-weathering, thinly bedded, finely crystalline dolomite, and rare micritic limestone. Beds range in thickness between 7 cm and 2 m. Sandy limestone, calcareous orthoquartzite, flat-pebble conglomerate, and limestone breccia occur in shallow channels at the base. Dolomite is mottled light gray and moderate gray. Black laminated chert nodules and lenticular chert beds occur at some stratigraphic levels. Silica-cemented orthoquartzite beds occur at the top of the Leadville Limestone on east flank of Kaufman Ridge

Dc **Chaffee Formation, undivided (Late Devonian)**—Consists of the Dyer Dolomite Member at the top and the Parting Quartzite Member at the base

Dcd **Dyer Dolomite Member**—Yellowish-gray, light-gray, tan, and pale-yellowish-gray dolomite that is finely crystalline and microcrystalline, laminated and microlaminated, or bioturbated, and flaggy or massive weathering. Contains some lenticular interbeds of light-grayish-green and light-greenish-gray shale and laminated yellowish-gray chert

Dcp **Parting Quartzite Member**—Light-gray, light-grayish-red, pale-brownish-gray, and pinkish-gray, fine-grained, silica-cemented, dense, flinty, conchoidal-fracturing orthoquartzite. Some thin beds of dolomite, green shale, and dolomitic quartzite interbedded with thinly bedded and massive quartzite. Sedimentary structures are masked by extensive recrystallization. Planar lamination and ripple cross-lamination are preserved in some parts of the Parting Quartzite

Of **Fremont Dolomite (Late and Middle Ordovician)**—Dark-, moderate-, and light-gray, fine-grained, fossiliferous dolomite. Mottled light gray and dark gray or laminated and microlaminated. Massive-weathering beds are 25 cm to 3 m thick. Contains rare black chert nodules. Fossils are dolomitized coral and fragments of brachiopods, trilobites, and echinoids

Oh **Harding Quartzite (Middle Ordovician)**—Dark-reddish-gray, dark-grayish-orange, dark-grayish-red, light-gray, moderate-gray, and rusty-orange, fine- and medium-grained, well-sorted orthoquartzite. Bedding and primary sedimentary structures obscured by pervasive replacement by diagenetic silica to form a dense, conchoidal-weathering quartzite. Some exposures contain conglomeratic sandstone at the base

Om **Manitou Limestone (Early Ordovician)**—Dark-, moderate-, and light-gray, thin- to thick-bedded dolomite that contains a few beds of dark-gray limestone. Dolomite and limestone are laminated and mottled, and beds range between 2 cm to 1 m in thickness. Laminated black and light-grayish-white chert lenses and nodules occur parallel to bedding planes

Ꞓs **Sawatch Quartzite (Late Cambrian)**—Light-gray, moderate-gray, and light-grayish-yellow, fine- and medium-grained, well-sorted, silica-cemented orthoquartzite and pebbly orthoquartzite. Pebbly quartzite contains subrounded and rounded vein-quartz clasts. The quartzite is massive weathering and faint crossbeds and ripple cross-lamination are preserved at some places. Absent at most places in map area

PROTEROZOIC ROCKS

YXp **Pegmatite (Early to Middle Proterozoic)**—Consists mainly of large crystals of quartz, microcline and albite. Accessory minerals may include biotite, muscovite, garnet, euxenite, and allanite. The pegmatites may be zoned or unzoned, and range in thickness from less than 1 m to 15 m. Generally less than 50 m long, but discontinuous vein-like bodies can be up to 400 m in length. Pegmatite bodies intrude the Early Proterozoic granodiorite and to a lesser extent the Proterozoic granite

YXgt **Granite (Early to Middle Proterozoic)**—Pale-pinkish-orange to very light-grayish-pink, medium- to coarse-grained, hypidiomorphic-granular granite. Composed of quartz, microcline, altered plagioclase, muscovite, and minor biotite. Non-foliated to moderately foliated. Forms irregular stocks and dikes that intrude older granodiorite

Xgd **Granodiorite (Early Proterozoic)**—Gray, speckled, coarse- to very coarse-grained, nonfoliated massive to moderately foliated granodiorite and augen gneiss. Locally contains phenocrysts or augen of microcline feldspar as long as 6 cm. Locally is quartz monzonite where quartz percentage is low

Xb **Biotite gneiss (Early Proterozoic)**—Dark-gray to black, dense, medium-grained biotite-quartz-plagioclase-hornblende gneiss. Occurs as large xenoliths in granodiorite (Xgd) along Highway 285 and in Mushroom Gulch

CORRELATION OF MAP UNITS

SURFICIAL DEPOSITS

af; Qac, Qdf, Qc, Qta, Qes (UNCONFORMITY)	Holocene	QUATERNARY
Qls, Qao; Qp₃, Qp₂, Qp₁	Pleistocene	QUATERNARY

BEDROCK

UNCONFORMITY		
Tt	late Miocene	TERTIARY
UNCONFORMITY		
Ta, Tal, Tsb, Ttc	Middle to Early Oligocene	TERTIARY
UNCONFORMITY		
Twm	Late Eocene	TERTIARY
Tdc	Middle to Early Eocene	TERTIARY
UNCONFORMITY		
TKm	Paleocene?	TERTIARY
	Cretaceous?	CRETACEOUS
UNCONFORMITY		
IPco, IPm, IPbu, IPbl, IPb	Middle Pennsylvanian	PENNSYLVANIAN
IPk	Early Pennsylvanian	PENNSYLVANIAN
UNCONFORMITY		
Ml	Early Mississippian	MISSISSIPPIAN
UNCONFORMITY		
Dc, Dcd, Dcp	Late Devonian	DEVONIAN
UNCONFORMITY		
Of	Late to Middle Ordovician	ORDOVICIAN
UNCONFORMITY		
Oh	Middle Ordovician	ORDOVICIAN
UNCONFORMITY		
Om	Early Ordovician	ORDOVICIAN
UNCONFORMITY		
Ꞓs	Late Cambrian	CAMBRIAN
UNCONFORMITY		
YXp, YXgt	Early and Middle Proterozoic	PROTEROZOIC
Xgd, Xb	Early Proterozoic	PROTEROZOIC

MAP SYMBOLS

Contact—Dashed where appromimately located

Contact, showing dip

Fault—Dashed where approximately located; dotted where covered by younger deposits. Ball and bar on downthrown block. Arrow shows dip amount and direction

Anticline—Trace of axial surface. Large arrow shows direction of plunge and small arrows show direction of dip away from the axial trace. Dashed where inferred; dotted where covered by younger deposits

Syncline—Trace of axial surface. Large arrow shows direction of plunge and small arrows show direction of dip toward the axial trace. Dashed where inferred; dotted where covered by younger deposits

Strike and dip of beds
- **Inclined**
- **Vertical**
- **Overturned**

Strike and dip of foliation in plutonic rocks
- **Inclined**
- **Vertical**

Strike and dip of foliation in volcanic rocks
- **Inclined**

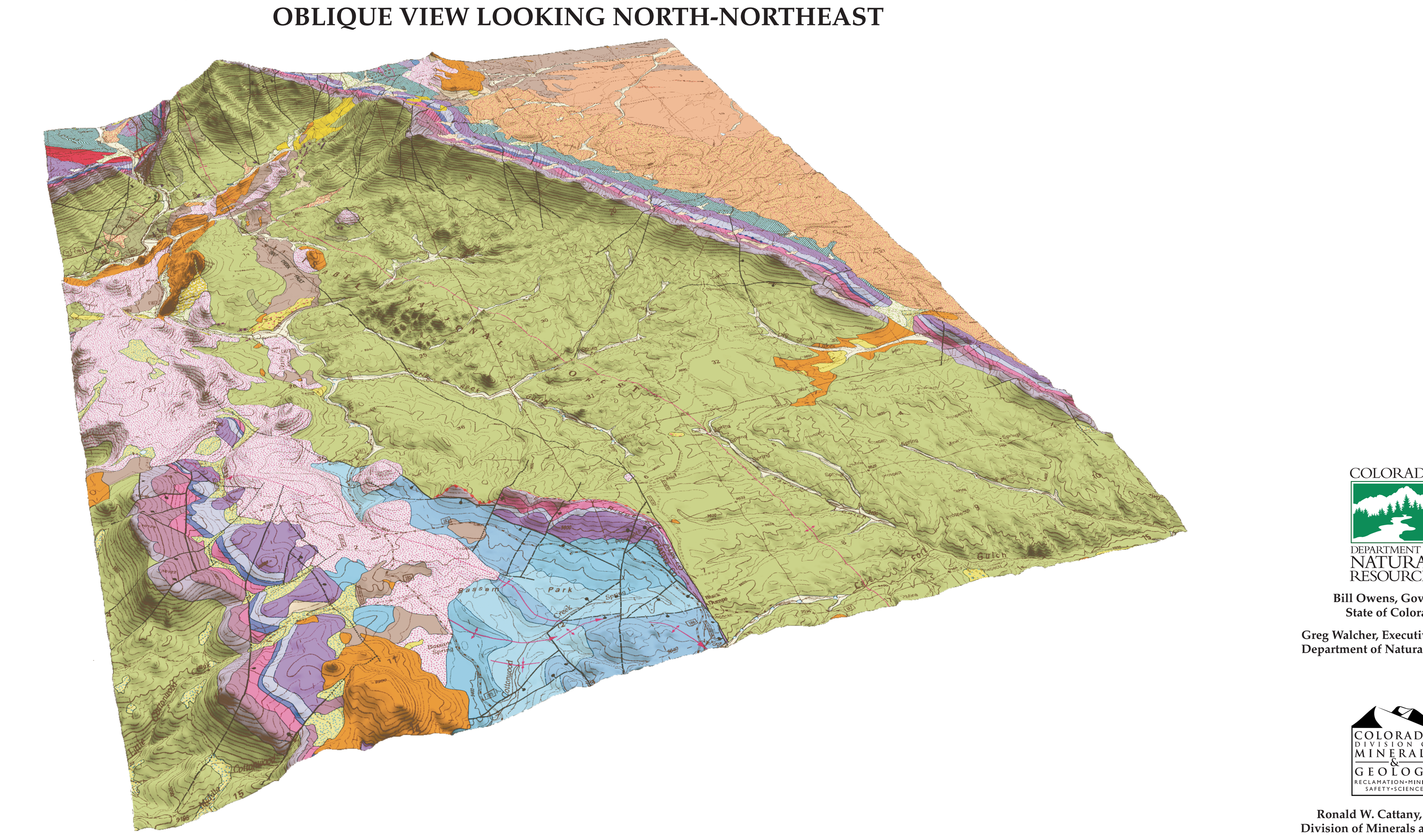
Strike and dip of joints in plutonic rocks
- **Inclined**

★ K0226 **Sample location and sample number**—See Table 1

☆ K0447 **Sample location for radiometric ($^{40}Ar/^{39}Ar$) age**

A——A' **Alignment of cross section**

SHADED-RELIEF MAP OF THE CASTLE ROCK GULCH QUADRANGLE WITH GEOLOGY AND TOPOGRAPHY OVERLAY, OBLIQUE VIEW LOOKING NORTH-NORTHEAST



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Bill Owens, Governor
State of Colorado
Greg Walcher, Executive Director,
Department of Natural Resources
COLORADO DIVISION OF MINERALS & GEOLOGY
Ronald W. Cattany, Director,
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GEOLOGIC MAP OF THE CASTLE ROCK GULCH QUADRANGLE, CHAFFEE AND PARK COUNTIES, COLORADO

By C. A. Wallace and John W. Keller
2003