OPEN-FILE REPORT 06-5

Geologic Map of the Mount Pittsburg Quadrangle, El Paso, Fremont, and Pueblo Counties, Colorado

Bill Owens, Governor,
State of Colorado

COLORADO
DEPARTMENT OF
NATURAL
RESOURCES

Russell George, Executive Director,
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State Geologist and Division Director,
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by
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Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
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Description of Map Units, Structural Geology, Geologic Hazards, Mineral Resources, and Ground-Water Resources

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View from Mount Pittsburg looking west. Outcrops are Proterozoic granite. Photo by Dawn Martin.

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geologic Mapping Program under STATEMAP Agreement No. 05HQAG0064.

Bill Owens, Governor, State of Colorado
Russell George, Director, Department of Natural Resources
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Denver, Colorado
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FOREWORD

The purpose of Colorado Geological Survey Open File Report 06-5, *Geologic Map of the Mount Pittsburg Quadrangle, El Paso, Fremont, and Pueblo Counties, Colorado* is to describe the geologic setting, mineral and water resources, and geologic hazards of this 7.5-minute quadrangle located southwest of Colorado Springs in central Colorado. Staff geologist Matthew L. Morgan, consulting geologist Jay Temple, and field assistant Dawn Martin, completed the field work on this project during the summer of 2005. Matt Morgan wrote the Surficial Deposits, Geologic Hazards, and Ground-Water Resources sections of this book; Jay Temple wrote the Bedrock Unit descriptions and Structural Geology sections; Dawn Martin wrote the Mineral Resources section.

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, award number 05HQAG0064, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist and Division Director
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INTRODUCTION

The Mount Pittsburg 7.5-minute quadrangle is located in El Paso, Fremont, and Pueblo Counties, Colorado, at the southern margin of the Colorado Front Range (fig. 1). The city of Colorado Springs (2000 CENSUS population of 360,890) is located approximately 13 miles northeast of the quadrangle via State Highway 115. Turkey Creek, the major drainage in the quadrangle, flows southward to the Arkansas River west of Pueblo. The highest point in the quadrangle is an unnamed peak in sec. 27 of T. 16 S., R. 68 W. (elevation 9,207 feet), and the lowest point (elevation 5,628 feet) is in the Beaver Creek valley bottom in the southwestern part of the quadrangle.

Geologic mapping of the Mount Pittsburg 7.5-minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Act, which is administered by the U.S. Geological Survey. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource development, and ground-water exploration. Figure 2 shows the status of geologic maps of 7.5-minute quadrangles in the Colorado Springs area. This is the seventeenth quadrangle in this area to be mapped by the CGS.

The geologic interpretations shown on the map were based on (1) field investigations in 2005; (2) prior published and unpublished geologic maps and reports; (3) interpretation of black and white 1:24,000-scale U.S. Geological Survey aerial photography flown in 1992, a 10-meter digital elevation model (DEM), and a 1-meter resolution USGS digital orthophoto quadrangle (DOQ) derived from recent black and white photography. Bedrock geology and surficial deposits were mapped in the field on aerial photographs. The photos were scanned, georeferenced, and imported into ERDAS Imagine OrthoBase, where they were photogrammetrically corrected and rendered in 3D. Line work was traced directly from ERDAS Imagine Stereo Analyst and exported as ESRI shapefiles into ArcGIS 9.1. Universal Transverse Mercator (UTM; North American Datum 1983, Zone 13) coordinates are provided for key geologic areas and photographs.

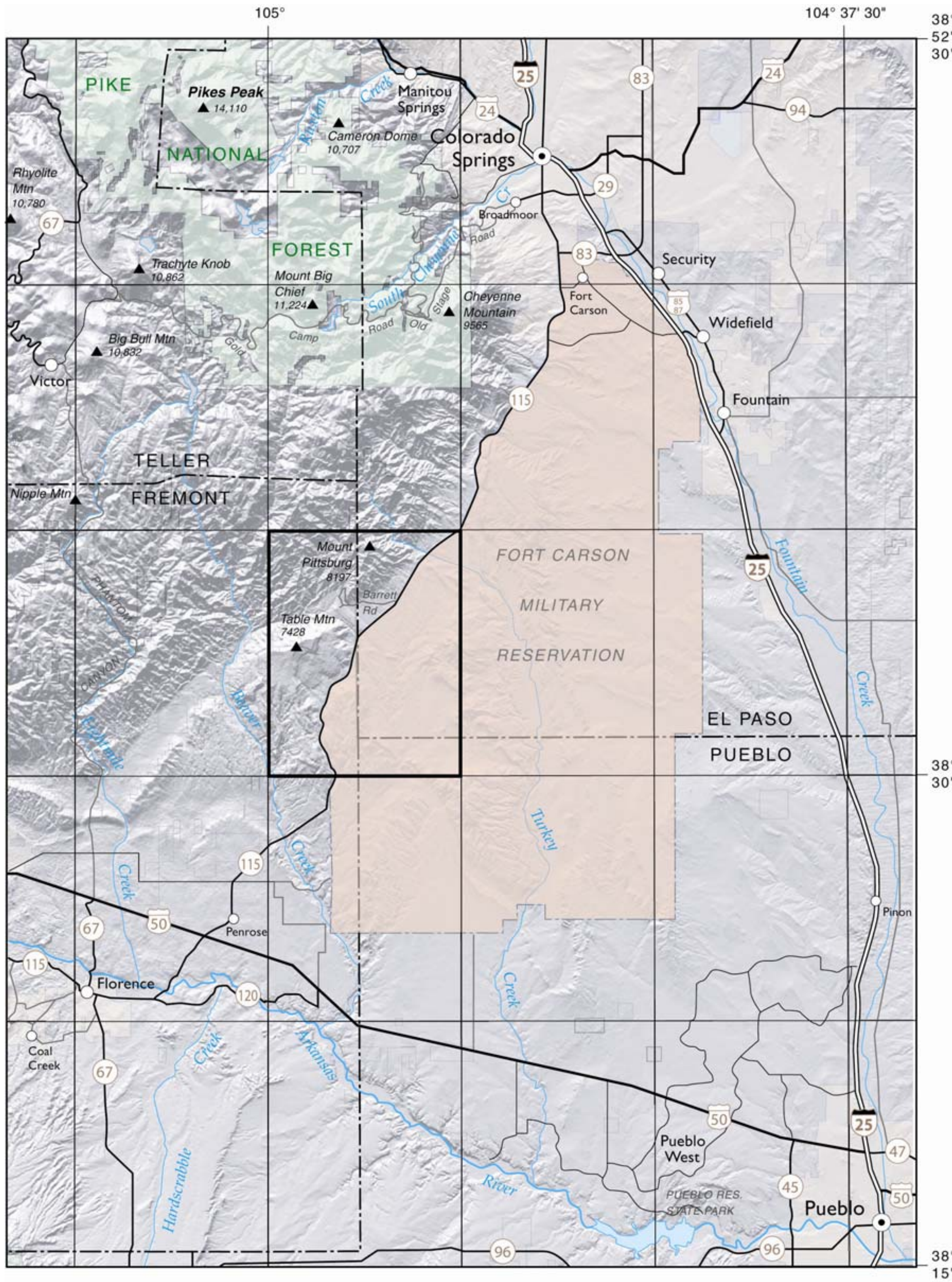

FIGURE 1. Location of the Mount Pittsburg quadrangle (**bold** black outline) in relation to major geographic features.

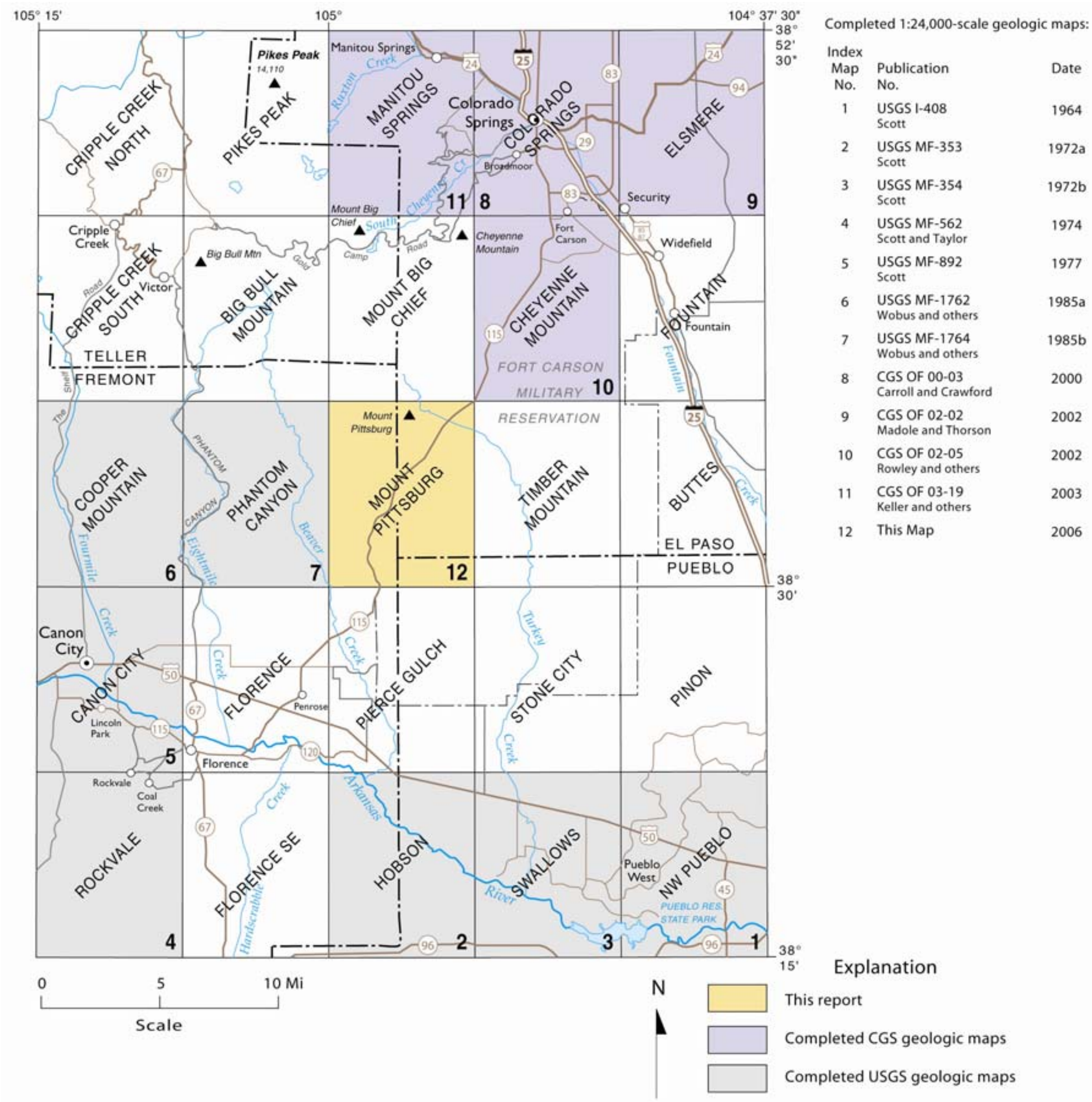

FIGURE 2. Index of published 1:24,000-scale geologic maps near Colorado Springs and Pueblo.

Small-scale geologic mapping of the Mount Pittsburg 7.5-minute quadrangle and surrounding area was done previously by Finlay (1916), and Scott and others (1978). Orr (1976) mapped the quadrangle at 1:24,000-scale as a Master's thesis. The Phantom Canyon quadrangle, which lies to the west of the Mount Pittsburg quadrangle, was mapped in reconnaissance fashion by Wobus and others (1985b). The Cheyenne Mountain quadrangle, which lies to the northeast of the Mount Pittsburg quadrangle, was mapped by Rowley and others (2002).

The boundary between the Southern Rocky Mountain and Great Plains physiographic provinces passes diagonally through the quadrangle from NE to SW. The mountains in the northern part of the mapped area are part of the Front Range. In the mapped area and surrounding region, the range-core rocks are typically Precambrian granite, schist, and gneiss that were exposed by faulting, folding, and erosion. They are flanked by younger Paleozoic and Mesozoic sedimentary rocks and covered in some places by a veneer of Quaternary surficial materials. The Front Range extends southwest to the Canon City area and north to the Wyoming border. The area of Colorado east of the Front Range from south of Pueblo and north to near the Wyoming border is referred to as the Colorado Piedmont. The lower topographic elevation of the Piedmont relative to the High Plains farther east results from erosion by the Arkansas and South Platte Rivers and their tributaries that removed the Miocene sedimentary rocks that now underlie the High Plains. These sedimentary rocks formerly extended to the Front Range and were derived from erosion of the Front Range (Madole, 1995).

ACKNOWLEDGMENTS

Access to private land was graciously arranged and provided by the following persons: Brian Goss; United States Army, Fort Carson; Swede Hanson; Brian and Ivy Emry of the Mountaindale Campground; Bob Stack of the Red Canyon quarry and the personnel at Menzer quarry. Karen Berry (CGS) helped with the soils information for the geologic hazards section of this book. Matt Sares, Ralf Topper, Peter Barkmann, and David Bird supplied valuable information for the ground water resources section.

We thank Jane Ciener (technical editor), Rich Madole (USGS Emeritus geologist), and Vince Matthews (CGS) for reviews of the map and manuscript. Karen Morgan (CGS) provided GIS and cartographic support and the cross-section profiles for the map plate. Larry Scott (CGS) provided assistance with figures for this book. Paula Stokes (consultant) set the digital stereo models in ERDAS. Jacob Baker (CGS) scanned the aerial photographs.

DESCRIPTION OF MAP UNITS

Geologic time divisions used in this report are shown in table 1. Numerical ages were taken from the Geological Survey of Canada (Okulitch, 2002) and the International Commission on Stratigraphy (2005).

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 5 feet thick but may be thinner locally. Residuum, sheetwash, colluvium, and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. Age divisions for the Holocene used in the Mount Pittsburg quadrangle are arbitrary and informal. They are based chiefly on paleontological data compiled for the southwestern United States. Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, degree of dissection and slope degradation, and soil development. Clast size is based on the modified Wentworth scale. The Front Range piedmont stratigraphic nomenclature of Quaternary alluvial deposits was established by Hunt (1954) and Scott (1960). Scott and others (1978) applied this nomenclature to Quaternary deposits in the Pueblo 1° X 2° geologic map, which covers the Mount Pittsburg quadrangle at 1:250,000-scale. To retain consistency with previous Colorado Geological Survey geologic maps in the Colorado Springs area, the formal names for alluvial deposits were not used in the Mount Pittsburg quadrangle. Colors used to describe the deposits are from the Munsell series (wet; Geological Society of America, 2000).

TABLE 1. Geologic time chart used by the Colorado Geological Survey. Numerical ages shown in black are from the Geological Survey of Canada (Okulitch, 2002); ages shown in blue are from the International Commission on Stratigraphy (2005).

Geologic Time Chart adopted by the Colorado Geological Survey

Era	Period		Epoch		Age (Ma)
CENOZOIC	Quaternary		Holocene		0.0118
			Pleisto-cene	upper/late	0.126
				middle	0.781
				lower/early	1.806
	Tertiary	Neogene	Pliocene		5.33 ± 0.05
			Miocene		22.9 ± 0.1
		Paleogene	Oligocene		33.5 ± 0.4
			Eocene		54.8 ± 0.5
			Paleocene		65.0 ± 0.05
MESOZOIC	Cretaceous		Upper/Late		99.0 ± 1.0
			Lower/Early		144.8 ± 3.7
	Jurassic		Upper/Late		156.6 ± 2.7
			Middle		178.0 ± 1.5
			Lower/Early		200 ± 1.0
	Triassic		Upper/Late		231 ± 5
			Middle		244 ± 1
			Lower/Early		253 ± 2
PALEOZOIC	Permian		Upper/Late		258 ± 5
			Middle		229 ± 5
			Lower/Early		300 ± 3
	Carboniferous	Pennsyl-vanian	Upper/Late		306.5 ± 1.0
			Middle		311.7 ± 1.1
			Lower/Early		318.0 ± 1.3
		Missis-sippian	Upper/Late		326.4 ± 1.6
			Middle		345.3 ± 2.1
			Lower/Early		360 ± 2
	Devonian		Upper/Late		383 ± 4
			Middle		394 ± 2
			Lower/Early		418 ± 2
	Silurian		Upper/Late		424 ± 1
			Lower/Early		443 ± 4
	Ordovician		Upper/Late		460.9 ± 1.6
			Middle		471.8 ± 1.6
			Lower/Early		489 ± 1
	Cambrian		Upper/Late		499 ± 5
			Middle		509 ± 1
			Lower/Early		544 ± 1
PRECAMBRIAN	Proterozoic		Neoproterozoic		1,000 ± 50
			Mesoproterozoic		1,600
			Paleoproterozoic		2,500
	Archean		Neoarchean		2,800
			Mesoarchean		3,200
			Paleoarchean		3,600
			Eoarchean		not defined

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)** — Rip rap, engineered fill, and refuse placed during construction of roads, railroads, buildings, dams, and landfills. Generally consists of unsorted silt, sand, clay, and rock fragments. This unit may also include areas of construction and quarrying operations where original deposits have been removed, replaced, or reworked. The average thickness of the unit is less than 30 feet. Artificial fill may be subject to settlement and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

Silt, sand, and gravel deposited in stream channels, on flood plains, on pediments, and as sheetwash along valley sides of drainages. Terrace alluvium and related pediment deposits along these drainages were deposited mostly during periods of effective wetter climate that coincide with Pleistocene glaciations (Madole, personal commun., 2005). The approximate terrace heights reported for each unit are the elevation differences measured between the creek bed and the top of the original or remnant alluvial surface adjacent to the creek. Thickness reported is the maximum exposed thickness of the unit.

Qa_1 **Alluvium one (latest Holocene)** — Brownish-gray to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and boulders in stream terrace deposits above the currently active stream channel or in undissected swales or low-lands in valleys. The alluvium commonly forms gently sloping walls in stream channels. Clasts are subangular to well rounded and are typically granite or sandstone. The deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Soil development is absent. In Turkey Creek, the unit forms two terraces that reach maximum heights above current stream level of 3 feet and 5 feet, respectively. Madole (1989) described two surfaces at approximately the same levels in Turkey Creek in the Timber Mountain quadrangle. Maximum exposed thickness of the unit locally exceeds 8 feet. A nearly complete skeleton of *bison bison* was found at a depth of 3 feet from the top of Qa_1 in Turkey Creek, N 1/2 sec. 3 T. 17 S., R. 67 W. A bulk ^{14}C sample of organic-rich sediment taken from immediately below the skeleton yielded a conventional age of 1,170±40 ^{14}C yr. B.P. (2#Sigma = AD 770-980) (Beta Analytic Sample #210607) suggesting the upper 3 feet of the unit was deposited within the last 1000 years. The unit in which the *bison bison* was found may be the buried upper unit of Qa_2 because the date is similar to the 1,150± 60 yr. B.P. conventional ^{14}C age of Madole (1989). The unit is a potential source of commercial sand and gravel.

Qa_2 Alluvium two (late Holocene to late Pleistocene) — Pinkish-brown to grayish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, gravel, and boulders in stream terrace deposits and in undissected alluvium in valley headwaters. The alluvium commonly forms nearly vertical walls in stream channels. Alluvium two is composed of three distinct alluvial units (figure 3); however, due to the uppermost younger unit overlying the two lower older units, the three units could not be mapped separately. Clasts are subangular to well rounded and have varied lithology but are typically granite or sandstone. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 10 feet above current stream level. Maximum exposed thickness of unit locally exceeds 15 feet. The lowermost unit is approximately 10 feet thick and consists of layers of clay and silt overlying 2-4 feet of weakly stratified sand and gravel. The gravel is composed of granite, gneiss, and sandstone. Stream cutbanks of the lowermost unit have a columnar structure and much redder color compared to overlying units because much of the sediment is derived from Pennsylvanian and Permian redbeds. The soil profile of the lowermost consists of a 15-inch-thick A-horizon over C-horizon. The middle unit is less than 3 feet thick and consists of weakly stratified layers, about 6 inches thick, of silt and sand; the sand becomes pink lower in the unit. Local clay-rich zones with root casts are also present. These reach a maximum thickness of 1-foot and are interpreted to be overbank deposits. The soil profile of the middle unit consists of a weakly developed, humic-rich, 15-inch-thick A-horizon and 30-inch-thick C-horizon. The upper unit is less than 2 feet thick and consists of weakly stratified layers of sand and silt. The soil profile of the upper unit consists of a very weakly developed, humic-poor, 5-inch-thick A-horizon over a C-horizon. The stratified parts of these units represent the main axes of paleochannels. Madole (1989) reported an age of 4,400± 80 ^{14}C yr. B.P. taken from detrital charcoal sampled approximately 15 inches below the contact between the lower and middle units; another charcoal sample near the top of the upper unit yielded an age of 1,150± 60 ^{14}C yr. B.P. (Madole, 1989). Both samples were from Turkey Creek in the adjacent Timber Mountain quadrangle (fig. 2). On the basis of these ages, Madole (1989) suggested the unit is middle to early Holocene in age; however the basal gravel may be as old as late Pleistocene. The unit is a potential source of commercial sand and gravel.

Qac Alluvium and colluvium, undivided (Holocene and late Pleistocene) – Stream channel, terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and colluvium along valley sides. May interfinger with stream alluvium (Qa), fan deposits (Qf), colluvium (Qc), colluvium and sheetwash (Qcs), and sheetwash (Qsw) along valley margins. Alluvium is typically composed of poorly to well sorted, stratified, interbedded, pebbly sand, sandy silt, and sandy gravel. Colluvium may range from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Clasts have a wide range of lithologies dependent upon the local bedrock or surficial unit sources. Maximum thickness of the unit is approximately 20 feet.

Qsw Sheetwash alluvium (Holocene and late Pleistocene) — Reddish-brown, poorly sorted sandy silt, clayey silt and sand with minor amounts of pebble-sized rock fragments. The sediment of this unit was transported and deposited principally by sheet flow. Lithology of sediments is dependant upon the local bedrock or surficial unit sources; however, a majority of the sheetwash deposits are derived from the Fountain Formation. Sheetwash alluvium grades into stream, alluvial-fan, and landslide deposits and may include local loess deposits that are too small to show separately. The unit locally includes residuum. Maximum thickness of this unit is about 10 feet. The unit is most extensive in Sullivan Park, which acts as a basin catching sediment from the surrounding hills; residuum derived from the Pennsylvanian-Permian formations is common in this area. The unit is also common along the foot slopes of valley sides and topographic depressions on slopes. Areas mapped as sheetwash are susceptible to runoff following large precipitation events. Sheetwash deposits may be sources of aggregate.

Qf_1 Alluvial-fan deposit one (late Holocene) — Yellowish- to brownish-gray, poorly to moderately sorted, poorly consolidated clay, silt, sand, and gravel deposited in/on alluvial fans at the mouths of perennial streams. They have a fan shape and consist of subangular to well-rounded clasts of varied lithology; however, sediment derived from the Morrison Formation is a major constituent. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. These fans have little vegetation and often divert the streams in valleys into which the fans are building. Deposits locally exceed 10 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

Qf_2 Alluvial-fan deposit two (early Holocene) — Dark-yellowish-gray to dark-gray, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel deposited as alluvial fans at the mouths of perennial streams. Clasts are subangular to well rounded and have varied lithology; however, sediment derived from the Morrison Formation is a major constituent. They have a fan-like shape but are higher in the landscape and more dissected than younger Qf_1 deposits. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. The apex of the fan is as much as 50 feet above modern streams. Deposits locally exceed 20 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

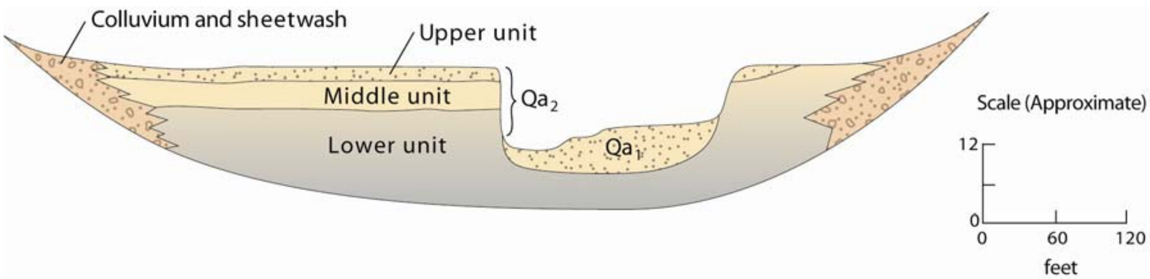

FIGURE 3. A diagrammatic profile of Turkey Creek showing the relationships of the two alluvium units, Qa_1 and Qa_2. Alluvium Qa_2 is composed of lower, middle, and upper subunits of different ages. The lower unit of Qa_2 is probably late Pleistocene in age and can be differentiated from the overlying units; however, it was not mapped separately because it is covered by the younger middle and upper units. Alluvium Qa_1 fills the currently active channel and may form low terraces. After Madole (1989).

Gravel deposits (late to early Pleistocene) — Partly dissected remnants of three levels of older gravel deposits are preserved on the piedmont. Soil profiles of units Qg_1-Qg_3 are very similar with the defining factor being the amount of accumulated $CaCO_3$ in the Bk-horizon and clast coatings; the older deposits have greater accumulations of $CaCO_3$. Each unit's soil profile typically consists of an 8- to 12-inch thick A-horizon, 12- to 20-inch thick Bt-horizon, and a 20- to 24-inch thick Bk-horizon. The deposits may form terraces and in many places the surface underlying the deposit forms a pediment.

**Qg_1	Gravel deposit one (middle Pleistocene)** — Reddish-brown, poorly sorted, moderately to poorly stratified sand, pebble, and cobble gravel derived from granitic, gneissic, and sandstone bedrock. Clasts are subrounded to rounded and coated with thin (less than 0.02-inch), discontinuous rinds of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered granite and sandstone clasts and bedrock. Top of pediment gravel or terrace is 20 to 60 feet above adjacent modern streams. The unit locally exceeds 10 feet in thickness and in many places forms a thin, sometimes discontinuous, veneer over bedrock. Carbonate Stage I (Machette, 1985) is typical for Qg_1 in the mapped area. Unit is correlated with the Slocum Alluvium (Scott and others, 1978) by virtue of height above stream level and soil characteristics. Pediment gravel one is considered to be late to middle Pleistocene in age on the basis of local stratigraphic position and soil development. Scott and Lindvall (1970) collected a bison horn core from the lower part of the Slocum Alluvium near the Arkansas river; the core yielded calibrated uranium-series age of 190 ± 50 ka (Szabo, 1980). The deposit forms a stable building surface, but excavations may be prone to slumping. The unit is a potential source of sand and gravel.

Qg_2 Gravel deposit two (middle Pleistocene) — Reddish-brown, poorly sorted, moderately to poorly stratified sand, pebble, and cobble gravel derived from granitic, gneissic, and sandstone bedrock. Many clasts are coated with thin (less than 0.05-inch), discontinuous rinds of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered granite and sandstone clasts and bedrock. Becomes richer in boulders and less stratified toward mountain front. Top of the gravel deposit is 85 to 200 feet above adjacent modern streams. The unit locally exceeds 20 feet in thickness and in many places forms a thin, sometimes discontinuous, veneer over bedrock. Carbonate Stages I and I+ (Machette, 1985) are typical for Qg_2 in the mapped area. Unit correlates with the Verdos Alluvium (Scott and others, 1978) by virtue of height above stream level and soil characteristics. Near Denver, the upper part of the Verdos Alluvium contains Lava Creek B ash which was dated at about 640,000 yr. B.P. (Lanphere and others, 2002). The unit is considered to be early middle Pleistocene on the basis of local stratigraphic position, soil development, and contained Lava Creek B ash. This unit forms a stable building surface; however, excavations may be prone to slumping. The unit is a potential source of sand and gravel.

Qg_3 Gravel deposit three (early Pleistocene) — Reddish-brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel primarily derived from granitic, gneissic, and sandstone bedrock. Clasts are highly weathered and are coated with a 0.05-inch, rind of calcium carbonate. The matrix typically consists of feldspar and quartz pebbles derived from weathered granite and sandstone clasts and bedrock. Iron oxide staining of the matrix is common. Boulders become larger and more abundant and the deposit becomes less stratified toward the mountain front. Top of pediment gravel is 250 to 300 feet above modern streams. The unit locally exceeds 20 feet in thickness and in many places forms a thin, sometimes discontinuous, veneer over bedrock. Carbonate Stages I and I+ (Machette, 1985) are typical for Qg_3 in the mapped area. Unit is correlated with the Rocky Flats Alluvium (Scott and others, 1978) by virtue of height above stream level and soil characteristics. The unit is considered to be early Pleistocene in age on the basis of local stratigraphic position and soil development. Forms a stable building surface, but excavations may be prone to slumping. The unit is a potential source of sand and gravel.

Qg Gravel deposits, undivided (middle to early Pleistocene) — Reddish-brown to light brown, poorly sorted, moderately to poorly stratified pebble and cobble gravel, derived from granitic, gneissic, and sandstone bedrock. Clasts are subangular to rounded. Lithology consists of sandstone, granite, and gneiss. Top of pediment gravel is 55 to 65 feet above modern streams. The unit locally exceeds 10 feet in thickness; however, in many places it only forms a thin veneer over bedrock. The maximum age of the unit is considered to be late Pleistocene on the basis of local stratigraphic position; due to poor exposure, soil profiles were not examined. Forms a stable building surface, but excavations may be prone to slumping. The unit is a potential source of sand and gravel.

MASS-WASTING DEPOSITS – Earth materials that were transported downslope primarily by gravity and not within or under another medium, such as water or ice. Some of these deposits have moved by creep, which is a slow, gradual, progressive downslope movement of earth materials.

Qcs Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene) — Weathered bedrock fragments that have been transported downslope primarily by gravity and sheetwash. Colluvium ranges from unsorted, clast-supported, pebble to boulder gravel in a silty sand matrix to matrix-supported gravelly, clayey, silty sand. It is generally unsorted to poorly sorted, contains angular to subangular clasts, and is weakly stratified. Colluvial deposits derived from alluvial deposits contain rounded to subrounded clasts. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. The units may contain landslides of limited extent. Sheetwash is common on slopes with less than a 10 percent grade. Sheetwash and colluvium were not mapped separately in this unit because of difficulties determining the mode of transport; many locations had combinations of alluvial and colluvial processes. Clast lithology is variable and is dependant upon the local source rock. Colluvium and sheetwash alluvium grade into and interfinger with stream, alluvial-fan, and landslide deposits. Maximum thickness of this unit is about 20 feet. Areas mapped as colluvium and sheetwash are susceptible to future colluvial and sheetwash deposition and locally are subject to debris flows and rockfall. Colluvium and sheetwash deposits may be sources of aggregate.

Qc Colluvium deposits (Holocene and late Pleistocene) — Weathered bedrock fragments that consist of reddish-brown to yellowish-brown, poorly sorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Unit contains angular to subangular clasts and is weakly stratified. Colluvial deposits derived from alluvial deposits contain rounded to subrounded clasts. Lithology is dependant on local bedrock sources. Significant deposits of colluvium occur on the slopes of Wild Mountain and Table Mountain that are mantled with cobble- and boulder-sized blocks of Dakota Sandstone. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. Deposits locally exceed 25 feet in thickness. Areas mapped as colluvium are susceptible to future rockfall events.

Qls Landslide deposits (Holocene to middle Pleistocene) — Heterogeneous deposits consisting of unsorted and unstratified clay, silt, sand, and angular, boulder-size rock fragments. Unit includes rotational slides, translational slides, complex slide-flow mass movements, and Toreva blocks. In most places, landslides show obvious geomorphic expression that disrupts the profile of the slopes. Generally, head scarps (near-vertical detachment scars exposed at the top of and sides of the landslides) are readily recognizable. Other common diagnostic features include hummocky topography, closed depressions, fissures, terracettes, tension cracks, and pressure ridges at the toe of the mobilized mass. Several of the landslides in the quadrangle cover unit Qg_2 (middle Pleistocene), suggesting they are younger than middle Pleistocene. Where present, the soil profile is highly variable; some locations show no pedogenesis while other locations have a 1- to 3-foot-thick Bt-horizon, suggesting a maximum age of middle Pleistocene. In general, the younger landslides are located around Wild Mountain and the eastern part of the mapped area. Most landslides in the mapped area are mixtures of sandstone, shale, and mudstone derived from the Dakota Sandstone, Purgatoire Formation, and Morrison Formation. Exposures reveal that blocks of Dakota Sandstone are as much as 10 feet across. See the “Geologic Hazards” section for a discussion of landslides within the mapped area.

Landslide areas are subject to future movement during episodes of heavy rain or snowfall or may be reactivated by human-made disturbances such as cutting of slopes for roads, quarries, housing developments, irrigation systems, and septic systems. Landslide deposits are prone to settlement when loaded or wetted. Deposits may contain expansive soils where derived from shale and mudstone formations. Thickness of landslide deposits in the quadrangle locally exceeds 10 feet.

BEDROCK UNITS

Kcg Graneros Shale (Upper Cretaceous) — The Graneros Shale is composed of soft dark-gray to black marine shale beds containing several bentonite layers and thin tan and brown silt beds. It commonly weathers to small platy chips. The exposed thickness of the unit in the mapped area is approximately 20 feet.

Kd Dakota Sandstone (Lower Cretaceous) — The Dakota Sandstone is the uppermost sandstone unit of the Dakota Group. Erosion has removed the upper section of the Dakota Group and much of the Dakota Sandstone throughout the quadrangle. The most complete section of the sandstone outcrops in the southernmost part of the quadrangle in sec. 8, T. 18 S., R. 67 W., where it is estimated to be about 100 feet thick. It consists of a lower, fine-to medium-grained, white to tan to light-brown, subangular to subrounded, well sorted, quartz-rich sandstone about 10 feet thick. This grades upward into about 50 feet of white to tan to pink, fine- to medium-grained, subangular to subrounded, quartz-sandstone with local iron stains and cross bedding. This unit also has spectacular channels along the northeastern face of Wild Mountain. The upper part of the sandstone consists of about 35 feet of very fine-grained, silty to clayey, tan to light-green, thin-bedded sandstones that locally contain ripple marks and burrows. The most extensive outcrop of the Dakota Sandstone is along the top of Table Mountain in the west-central part of the quadrangle. Here, the sandstone forms the resistant caprock throughout the northeast-southwest trend of the mountain and further to the south approaching Patton Canyon. The physical properties of the Dakota Sandstone at Table Mountain are substantially different than those in other parts of the quadrangle. The sandstone is light pink to light purple, contains medium-sized quartz grains that are rounded to subrounded, and is well sorted. The rock is extremely hard and brittle and is referred to as “quartzite” by aggregate companies.   Thin section studies by Orr (1976) indicate that the Table Mountain sandstone is highly packed and completely silicified. Hematite coatings are found on most grains. Previous studies suggest that the high degree of silicification of the Dakota Sandstone on Table Mountain is a result of authigenic, diagenetic, and tectonic processes that reflect the sedimentary environment and post-depositional history (Orr, 1976). Physical attributes of the sandstone, such as grain size, roundness, and sorting, combined with environmental factors, such as pressure, temperature, and migrating fluids, have contributed to the unique lithology of the sandstone

(Maxwell, 1959). This caprock is also highly jointed and is estimated to be about 40 feet thick. Although the sandstone on Table Mountain does not crop out elsewhere in the quadrangle, substantial amounts of the distinctive, purple-weathered, dense, sharp-edged material have weathered to float along the flanks of Timber Mountain in the east-central part of the quadrangle. The paleoenvironmental setting for the Dakota Sandstone has been interpreted by Weimer (1970) as a marine regression represented by the increase in clastic sedimentation due to shifting in the distributary channels on the coastal plain.

Kpu Purgatoire Formation (Lower Cretaceous) — The Purgatoire Formation is subdivided into the lower Lytle Sandstone Member and the upper Glencairn Shale Member. The Glencairn Shale Member is weakly resistant and forms slopes covered with talus from the Dakota Group. The best exposures of the Glencairn are on the southeast and northeast flanks of Table Mountain in sec. 23 of T. 17 S., R. 68 W., and in the southernmost part of Red Creek in sec. 5, T. 18 S., R. 67 W. At these locations, the Glencairn is a yellow, to gray to olive-green, very fine-grained, thin-bedded sandstone, interbedded with gray to dark-gray, thinly bedded shales. The Glencairn is approximately 90 feet in thickness and is interpreted to be a marine shale (Weimer, 1970). The Lytle Sandstone Member crops out extensively in the southern and southwestern parts of the quadrangle, around Wild Mountain, Table Mountain, and Patton Canyon. It consists of a lower pebble conglomerate, a middle very fine grained sandstone and siltstone, and an upper fine- to very fine grained sandstone. The basal conglomeratic sandstones are white to tan, poorly sorted, subrounded to subangular, quartz rich, and show lenticular channels and abundant cross stratification along Wild Mountain. The middle part consists of white to tan, fine- to very fine grained, quartz-rich to argillaceous sandstones and siltstones, with occasional cross beds. The upper Lytle is made up of white to buff to tan, medium- to fine-grained, subangular to subrounded, moderately well sorted, quartz-rich sandstone with local cross stratification. The thickness of the Lytle Member as measured by Orr (1976) south of Camp Red Devil is 60 feet. It is interpreted to represent a series of fluvial channels and overbank deposits by Weimer (1970).

Jmr Morrison Formation and Ralston Creek Formation, undifferentiated (Upper Jurassic) — The Morrison and Ralston Creek Formations are mapped as a single unit in the Mount Pittsburg quadrangle. The Morrison Formation consists of thinly layered claystones, siltstones, fine-grained sandstones, and limestones. The siltstones are primarily slope formers consisting of gray to greenish-gray or maroon, thinly-bedded, fissile, loosely consolidated sediments. The sandstones are gray to tan, very fine grained, and cemented with calcium carbonate. The limestones are gray, very fine grained, thinly bedded, and more strongly cemented than the clastic material. The Morrison is more than 300 feet thick in the southern part of the quadrangle, as measured by Orr (1976). The Ralston Creek Formation is composed of white, gypsiferous beds that contrast sharply with the underlying orangish beds of the Lykins Formation and the overlying tan sandstones of the Purgatoire Formation. The best exposures are along the western slopes of Timber Mountain. The formation is almost totally obscured by landslide deposits along the perimeters of Wild Mountain and Table Mountain on the south and west sides of the quadrangle. Where exposed, the Ralston Creek Formation is composed of interbedded gypsum, siltstone, and sandstone. The gypsum is white to light gray, fine to coarsely crystalline, and thinly bedded. The gypsum is locally jointed, and silts and muds fill the joints, suggestive of dessication. The Ralston Creek Formation is approximately 75 feet thick in the quadrangle and appears to be conformable with the overlying Morrison Formation and disconformable with the underlying Lykins Formation. Both the Morrison and Ralston Creek Formations are considered to be continental in origin; the Morrison Formation is suggestive of an environment of meandering channels and overbank deposits, and the Ralston Creek is representative of shallow-water lacustrine deposits. Infiltration of water in the siltstones of the Morrison Formation and in the gypsum of the Ralston Creek Formation cause the beds to become less competent which has resulted in the abundance of landslides throughout the quadrangle. These landslides are discussed in the structure section of this report.

ŦPl **Lykins Formation (Lower Triassic? and Upper Permian)** — The best exposures of the Lykins Formation occur on the east side of the quadrangle along the western flanks of Timber Mountain. Outcrops are also found to the south, along the north flank of Wild Mountain and to the west along the east flanks of Table Mountain, but are often obscured by landslide debris. The formation is about 140 feet thick in the mapped area and is composed of distinct orangish-red siltstones, sandstones, and shales, interbedded with thin layers of gray to white, dolomitic limestones and gypsum. The limestones and dolomites commonly contain algal structures . The lower part of the formation consists of about 60 feet of thinly bedded, orange to reddish-brown siltstone that contains localized gypsum veins. The middle part of the formation contains about 40 feet of siltstones and mudstones with significant amounts of thinly laminated gypsum, dolomites, and limestones. The upper 40 feet of the formation consists of orange, red, and mottled-gray, gypsiferous siltstones and fine-grained sandstones. The depositional environment is generally interpreted as one of changing conditions between shallow marine, intertidal, supratidal, and terrigenous environments.

Ply **Lyons Sandstone (Upper and Middle? Permian)** — The Lyons Sandstone is a distinct red to reddish-orange, medium- to fine-grained, moderate to well sorted, quartz-rich sandstone that crops out primarily in the eastern part of the mapped area and along Highway 115 south of the Red Creek anticlinal axis. The lower part of the formation contains interfingering sandstones, siltstones, and shales. The sandstones exhibit small scale cross stratification (on the order of 6 to 12 inches). The upper part of the formation contains more massive sandstones that are highly cross bedded with sets up to 3 feet in thickness. The formation is approximately 250 feet thick in the mapped area. The depositional environment of the Lyons Formation was most likely fluvial, with periods of subaerial exposure. The basal shales and siltstones, combined with the smaller cross-bedded sets in the lower sandstones, suggest lower flow regimes. The more massive cross-bedded sets in the sandstones of the upper formation are indicative of higher energy, braided stream deposits. Subaerial exposure is indicated by high concentrations of iron oxide throughout the formation and local deposits of well sorted, fine-grained, quartz-rich sandstones suggestive of eolian dunes.

PPf **Fountain Formation (Lower Permian and Pennsylvanian)** — The Fountain Formation is the thickest and most dominant of the sedimentary rock types in the Mount Pittsburg quadrangle. Orr (1976) reported the formation to be about 2,000 feet thick where measured just north of the mapped area. The formation is primarily a dark-red to red to pink, fine- to coarse-grained, arkosic sandstone and pebble conglomerate. Clasts are subangular to rounded and consist of quartz and coarse-grained intrusive rocks. Cross bedding and graded bedding are common. Locally, the formation contains beds of dark-red to red to reddish-brown, thinly bedded shales and mudstones. The upper part of the Fountain Formation contains a distinctive limestone unit that appears to be continuous throughout the quadrangle. This limestone is gray, dense, finely crystalline, non-fossiliferous, and about 3 feet thick. Above the limestone unit, the Fountain Formation contains sandstone facies similar to the Lyons Formation. These sandstones are orangish red, fine to medium grained, quartz rich, and are up to 25 feet thick. They are interfingered with the arkosic, maroon conglomerates characteristic of the Fountain Formation. This interfingering of the two facies sometimes causes difficulty in the determination of the contact between the two formations. The contact of the upper Fountain Formation with the Lyons Formation was mapped at the top of the uppermost observed arkosic conglomerate. The depositional environment for the arkosic sandstones and conglomerates of the Fountain Formation was one of fluvial channels, overbank deposits, and alluvial fans. The source is material from the uplift of the Ancestral Rocky Mountains. The upper limestone unit is indicative of a lacustrine environment. The finer grained sandstones and siltstones, and Lyons-type facies of the upper Fountain Formation, reflect lower energy conditions of declining stream gradients, overbank deposits, and eolian dune fields.

Of Fremont Formation (Middle Ordovician) — The Fremont Formation crops out only to the southwest of the Red Rock quarry (sec. 1 of T. 17 S., R. 68 W.), along the strike of a stream valley known as Banta Gulch. The formation consists of pink to red, fine-grained, massive, dense dolomite to dolomitic limestone, which locally contains coarse to medium, well-rounded quartz sand grains and zones of brecciation. The Fremont Formation averages less than 40 feet in thickness along Banta Gulch and pinches out completely in the extreme western part of the area. The absence of this formation along the mountain front to the northeast is probably a result of post-Fremont and pre-Fountain erosion, suggested by the absence of Silurian, Devonian, and Mississippian deposits. The lithology and fauna of the Fremont Formation suggest a high-energy environment of deposition in a warm, shallow sea (Monk, 1954).

Oh Harding Formation (Lower Ordovician) — The Harding Formation is exposed in the same general areas as the Fremont Formation, in the northwest part of the quadrangle paralleling Banta Gulch. The formation consists of a pink to red, slightly calcareous, basal conglomeratic sandstone, a white to pink, fine- to very fine grained quartz sandstone, a red to reddish-brown sandy shale, and an upper white to tan, fine- to very fine grained quartz sandstone. The formation averages about 100 feet thick and is highly fractured. The lithology in the mapped area is consistent with the lithology reported in areas near Canon City, where it has been interpreted to be the result of deposition in a stable, shallow-shelf, marine environment (Gerhard, 1967).

Om Manitou Formation (Lower Ordovician) — The Manitou Formation is exposed discontinuously in the northeastern part of the mapped area and continuously in the northwestern part. It rests unconformably on the Proterozoic crystalline rocks, where the contact is displayed on a remarkably planar erosional surface (fig. 4). The Manitou Formation measured in the Red Canyon quarry (sec. 1, T. 17 S., R. 68 W.) is 110 feet thick. Here, the base of the formation contains a calcareous, dark-red to maroon, conglomeratic zone less than a foot thick. The conglomerate consists of subrounded to subangular, fine- to medium-grained, quartz sandstones and subrounded clasts as much as an inch in size. This grades upward into about 12 feet of massive, fine-grained, pink to maroon, dolomite to dolomitic limestone. Above this lies about 20 feet of thinly bedded (less than 3 inch beds), light-red to maroon, fine-grained, dolomitic limestone. The next 10 feet consists of a pink to light-red, fine-grained limestone that contains thin chert layers. The upper 65 feet contains massive layers (as much as 4 feet in thickness) of dark-pink to maroon, fine- to medium-grained, locally fossiliferous, dolomitic limestone. In the northeastern part of the mapped area (secs. 5 and 6, T. 17 S., R. 67 W., and secs. 32, T. 16 S., R. 67 W.) the Manitou Formation has a distinctly different lithology at its base. At these locations, the basal member consists of less than 10 feet of light-gray to cream-colored, highly silicified claystone, interbedded with dark-red to maroon, very fine grained sandstones and siltstones. When outcrops of this basal member occur without the upper, distinctive pink dolomite, it can be confused with the Harding Formation. However, a continuous section of these basal siltstones and siliceous claystones in stratigraphic contact with the main pink dolomites and dolomitic limestones crops out in an abandoned quarry in the eastern part of sec. 32 of T. 16 S., R. 67 W (UTM83: 568049.5, 4273672.0). We suggest that these basal clastic deposits represent a low-energy, reworking of intertidal-supratidal sediments during the advance of shallow seas that ultimately resulted in deposition of the Manitou Formation carbonates.

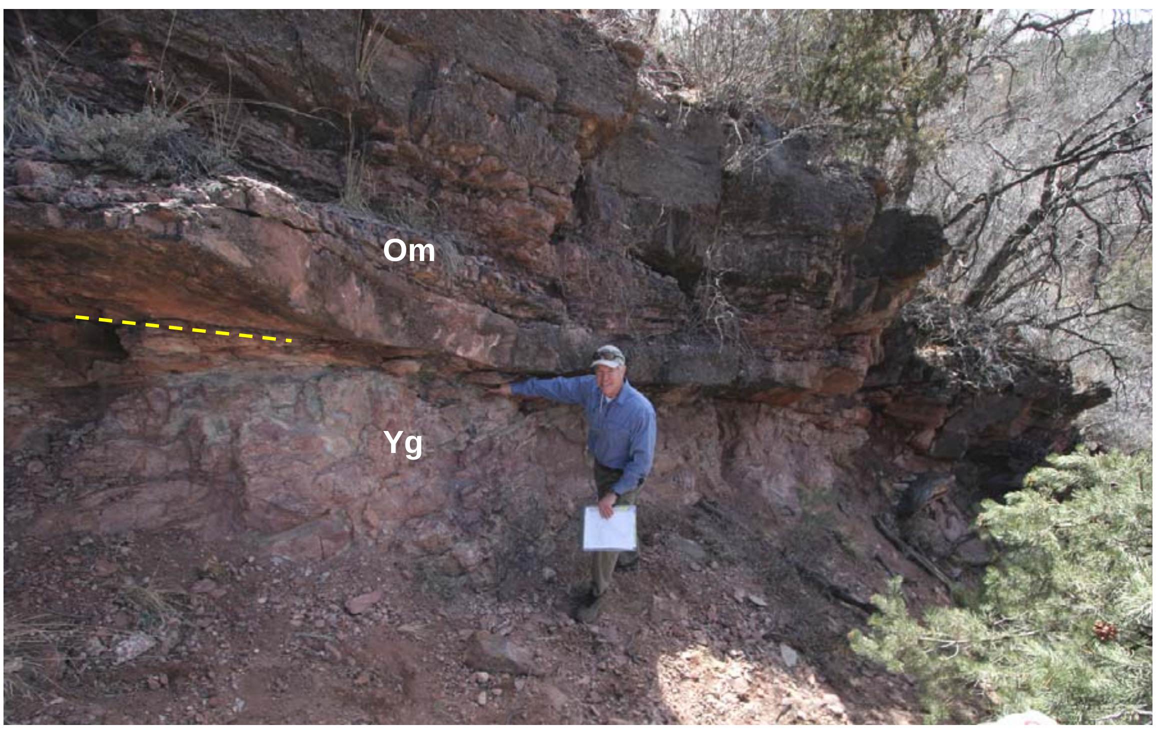

FIGURE 4. Geologist Jay Temple points to the Great Unconformity between the Lower Ordovician Manitou Formation and the Proterozoic granite. Yellow dashed line gives the approximate location of the contact. UTM83: 508167.9, 4274175.2. V. Matthews photo.

Yg Granite, undifferentiated (Middle Proterozoic) — Strongly resistant, medium- to coarse-grained granitic intrusions. Thin sections were made and examined from samples taken throughout the crystalline exposures. All of these samples showed high to moderate amounts of microcline, high to moderate amounts of quartz, and relatively low amounts of plagioclase. Classified as a granite according to the IUGS classification by Streckeisen (1976). This unit contains significantly higher amounts of biotite (3.5 to 5 percent) and hornblende (about 1 percent) and lower microcline than the Pikes Peak Granite, but the unit contains significantly less biotite and hornblende than the granodiorite (Xgd) mapped in the Cheyenne Mountain quadrangle (Rowley and others, 2002) and the Manitou Springs quadrangle (Keller and others, 2003). Locally, this unit contains xenoliths up to twenty feet in size consisting of biotite schists and amphibolite gneisses resembling descriptions of the Early Proterozoic migmatitic gneiss (Xgn) mapped in the Manitou Springs quadrangle. The Yg unit is lithologically similar to the Silver Plume Granite of the central Front Range, which has an age of about 1.4 Ga (Hedge, 1969; Nyman and others, 1994). This Yg unit has, therefore, been correlated with the Silver Plume Granite by Scott and Wobus (1973) and Trimble and Machette (1979).

STRUCTURAL GEOLOGY

The structural geology of the Mount Pittsburg quadrangle is dominated by (1) high-angle, northeast-southwest striking faults in the Proterozoic rocks in the north and northwestern parts of the quadrangle, (2) the north-south striking Red Creek Canyon fault in the north-central part of the quadrangle, (3) the Red Creek anticline, which trends northwest-southeast through the central part of the quadrangle, and (4) the previously discussed post-Laramide landslides and earth flows in the west and west-central parts of the quadrangle (see the Geologic Hazards section).

High-Angle Faults in Proterozoic Rocks

High-angle, northeast-southwest-striking faults transect the Proterozoic and lower Paleozoic rocks in the north and northwestern parts of the quadrangle as identified from the topographic map, DEM, aerial photographs, and outcrop observations. Excluding the Red Creek Canyon fault and its associated splays, the high-angle faults in the Proterozoic rocks are up-to-the-northwest, which results in the progressive increase in surface elevations towards the northwest. Outcrop observations at or near the mapped fault zones reveal intense fracturing, significant weathering, and occasional slickensides. The modest amount of fracture and joint data that were accumulated in the Proterozoic rocks are depicted on the map and cumulatively plotted on a stereonet diagram (fig. 5). These data suggest a preferred strike direction of northeast-southwest, with a secondary east-west trend, and moderate-to-steep inclinations. Although more data are required to definitively identify the preferred strike directions, the consistent high angles of inclination measured on these fractures and joints is suggestive of a high-angle direction of stress.

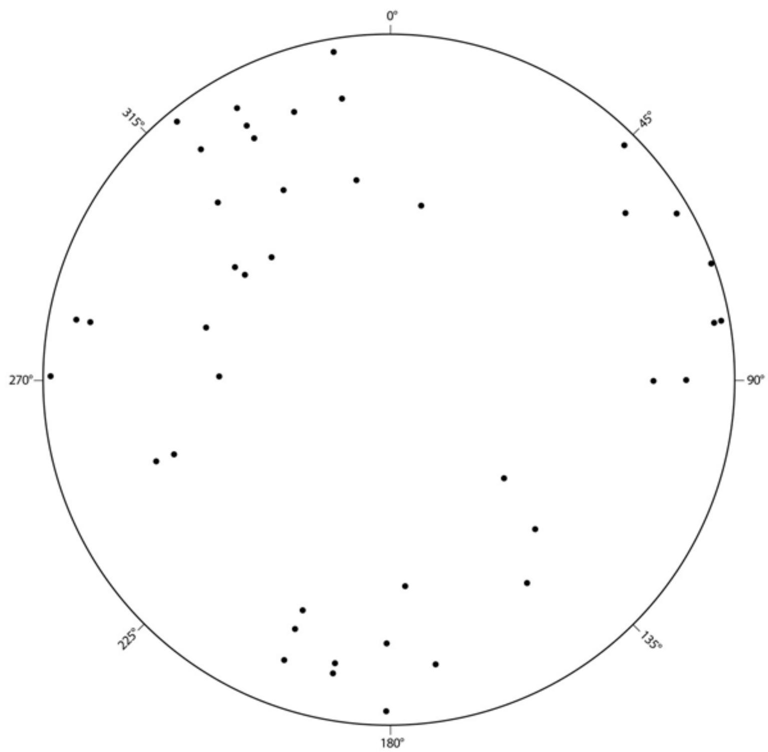

FIGURE 5. Stereonet diagram of poles to fracture planes in Proterozoic granite of the Mount Pittsburg quadrangle (lower hemisphere projection).

The strike directions of faults in the Proterozoic rocks in the Mount Pittsburg quadrangle are consistent with the strikes of faults mapped in the Proterozoic rocks about 5 miles to the northeast on the Cheyenne Mountain quadrangle (Rowley and others, 2002). However, the Cheyenne Mountain quadrangle map shows a dominant fault zone (the Ute Pass Fault Zone) responsible for the juxtaposition of the Proterozoic crystalline rocks to the west with the

Phanerozoic sedimentary rocks to the east. No evidence of a major fault zone of this type was observed in the Mount Pittsburg quadrangle. An unconformable stratigraphic contact, specifically a nonconformity, exists in many locations where the overlying Ordovician Manitou Formation is in contact with the underlying Proterozoic crystalline rocks. This unconformity and the absence of faulting in the sedimentary strata east and southeast of the mountain front, strongly suggests that the Ute Pass fault either dies out within a few miles southwest of the Cheyenne Mountain quadrangle, or splays into numerous smaller faults within the crystalline rocks before reaching the Mount Pittsburg area. Mapping in the Mount Big Chief quadrangle could aid in understanding how these two structural styles converge. The timing of movement on the faults in the Proterozoic rocks of the Mount Pittsburg quadrangle is thought to be Laramide. However, the absence of Phanerozoic sedimentary rocks does not allow a determination of the relative timing of fault initiation or any later rejuvenation. Several late Proterozoic and post-Proterozoic deformational events that have occurred along the Front Range could be responsible.

One low-angle reverse fault involving Proterozoic rocks was observed in the abandoned quarry in the SE 1/4 of sec. 32, T. 16 S, R. 67 W (fig. 6) (UTM83: 507990.9, 4273667.4). This fault places intensely fractured and highly weathered Proterozoic granite in the hanging wall over the Ordovician Manitou Formation in the footwall. The fault is easterly directed and only observed at this location. The low-angle nature of this fault (estimated at about 25 degrees) is anomalous for Laramide deformation and could possibly be representative of ancestral Rocky Mountain deformation. Due to the limited extent of this fault, it is not easily visible on the accompanying map plate; however, it is visible on the included GIS shapefiles.

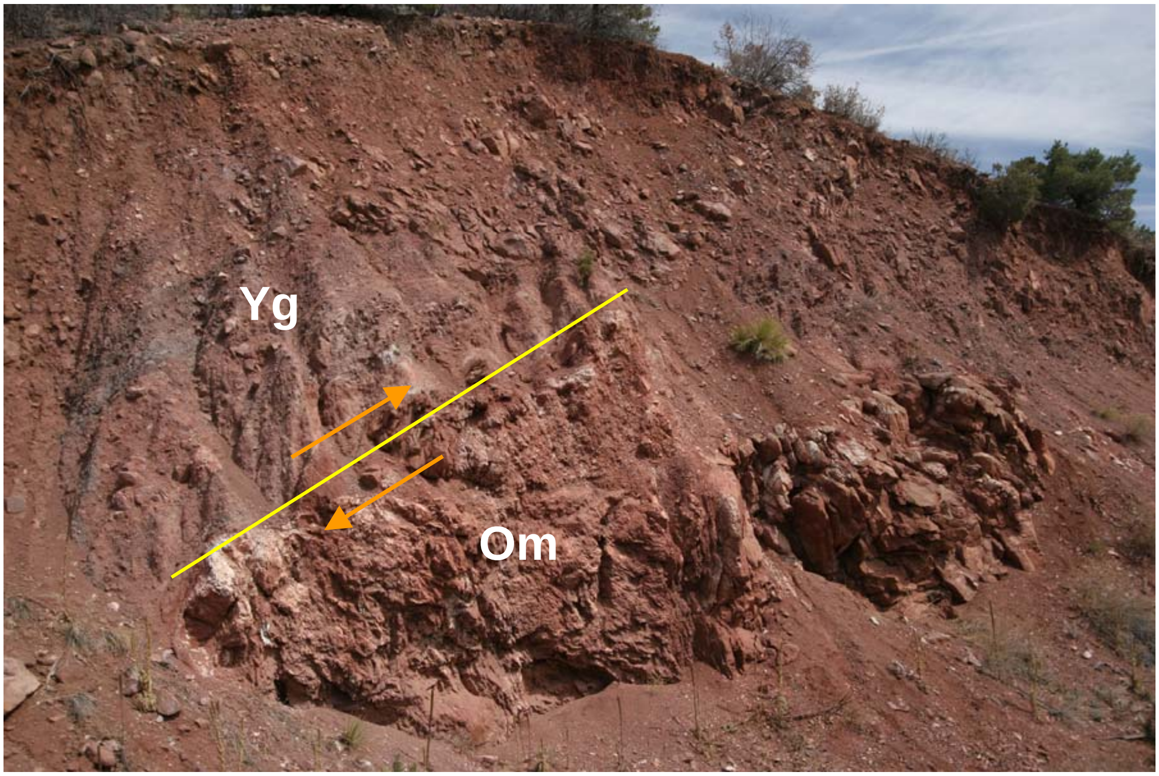

FIGURE 6. Photo of a low-angle reverse fault that places Proterozoic granite over the Ordovician Manitou Formation. Yellow dashed line is the approximate fault plane and orange arrows indicate relative movement. The dip of the fault plane is about 25 degrees. East is at the right side of image; height of image is approximately 30 feet. UTM83: 507990.9, 4276667.4. V. Matthews photo.

Red Creek Canyon Fault

The Red Creek Canyon fault zone is a north-south-striking, high-angle fault zone that is exposed at the surface in the north-central part of the quadrangle. At the Red Canyon quarry (sec. 1, T. 17 S., R. 67 W.; UTM83: 504731.7, 4272857.7), the fault distinctly offsets the Proterozoic crystalline rocks and the lower Paleozoic sedimentary rocks in the eastern, hanging-wall side from the same rocks in the western, footwall side of its strike. The fault continues to the south through the northeast quarter of sec. 12, T. 16 S., R. 67 W (UTM83: 504447.1, 4271072.5). where the Proterozoic rocks of the hanging wall are in close proximity to rocks of the Pennsylvanian-Permian Fountain Formation in the footwall block. The actual fault contact between these two units is concealed by Quaternary deposits. The fault is interpreted to continue in the subsurface, but with a southeasterly strike, through the central part of the quadrangle as suggested by the forced folding of the middle to upper Paleozoic sedimentary strata over the lineament to form the Red Creek anticline.

Immediately south of the Red Canyon quarry, in the upthrown, hanging wall of the Red Creek Canyon fault, a tightly folded syncline is exposed in outcrops of the Ordovician

Manitou and Harding Formations and the Pennsylvanian-Permian Fountain Formation. The southeastern limb of this fold is bordered by a high-angle fault which juxtaposes the upthrown, crystalline rocks to the southeast with the downthrown Manitou Formation to the northwest. Along this fault contact, the Manitou is turned upwards into vertical and near-vertical orientations. North of this syncline and on the east side of the Red Canyon quarry, the Proterozoic crystalline rocks are faulted over the Manitou section by a high-angle, up-to-the-southeast, reverse fault measured at about 65 degrees dip to the southeast. This fault has been interpreted as a backthrust (Glockzin and Roy, 1945). These authors continue this backthrust to the southwest and into the Red Creek Canyon fault footwall block where it continues along the mountain front paralleling Banta Gulch through secs. 1, 2, 11, and 10 of T. 17 S., R. 68 W. We recognize this fault in our mapping; however, we offer two different interpretations. Our first idea suggests that the fault through Banta Gulch in the Red Creek Canyon fault footwall block is a separate entity and not a continuation of the same faulting in the upthrown, hanging-wall block. The evidence for this lies in the exposures of different stratigraphic sections at each of the faults. The stratigraphic section involved in the fault east of the quarry is Proterozoic granite over the Ordovician Manitou Formation. The fault through Banta Gulch to the west of the quarry involves the Manitou in the hanging wall over the Manitou and Harding Formations in the footwall. Additional support for this interpretation is also suggested by a structural style in the western, footwall block of the Red Creek Canyon fault that is in contrast to the structural style of the eastern, hanging-wall block of the fault. The fault paralleling Banta Gulch, west of the Red Canyon quarry, shows no associated folding or drag in either the hanging wall or footwall strata. In contrast, the upthrown, hanging wall of the Red Creek Canyon fault contains the tight, southeasterly trending syncline. We believe the northeast-striking, high-angle fault north of the northwest limb of the syncline and the northeast striking fault bounding the southeast limb of the syncline to be upthrown splays associated with the main Red Creek Canyon fault. This imbricate fault geometry could have produced the combination of compressional stress orientations and fault drag responsible for the tight syncline in the Manitou, Harding, and Fountain Formations (cross section A-A'). This interpretation would also explain the apparent confinement of the syncline to the upthrown, hanging-wall block of the Red Creek Canyon fault. The timing of movement on the Red Creek Canyon fault could only be placed as post-Pennsylvanian-Permian (?) on the basis of folding of the Fountain Formation in the syncline. However, evidence discussed later addressing the Red Creek anticline suggests a Laramide age for this fault.

A second interpretation for the faulting and synclinal development in the Red Creek quarry area involves considering that the fault on the southeast limb of the syncline, the fault north of the northwest limb of the syncline, and the fault through Banta Gulch, are all one system that predates the Red Creek Canyon Laramide faulting. Low- to medium-angle, southeasterly dipping faults have been observed throughout the Rocky Mountain Foreland and are interpreted to be the result of deformation possibly related to the Ancestral Rocky Mountain uplift (Pennsylvanian-Permian) (V. Matthews, oral commun., 2005). The observed northeast-southwest-trending syncline would be the result of lower plate drag from the southeasterly dipping fault on the southeast limb of the syncline. The continuation of this synclinal fold to the west would be concealed beneath the upper plate of the fault paralleling Banta Gulch. The fold is only exposed in the upthrown, hanging wall of the Red Creek Canyon fault as a result of more extensive erosion of the upper plate of the older fault system. This interpretation also requires the synclinal fold development to be synchronous or nearly synchronous with the ancestral Rocky Mountain deformation because the Fountain Formation sediments involved in the folding are interpreted to be the debris eroded from that same mountain system.

Red Creek Anticline

The Red Creek anticline is a northwest-southeast-trending anticlinal fold that plunges to the south-southeast. The fold is asymmetrical with the western limb of the fold having steeper dips (30 degrees near the mountain front) than the eastern limb (20 degrees near the mountain front). This anticline continues to the southeast for nearly 30 miles and is the defining lineament separating the Denver Basin from the Canon City Embayment (Boos and Boos, 1957). The steeper dips of the western limb of the anticline and the anticline's origin near the last surface expression of the Red Creek Canyon fault suggest that the anticline is the result of forced folding of the Paleozoic strata over the underlying continuation of the Red Creek Canyon fault (cross section B-B'). Further evidence exists in the form of the Wild Mountain syncline, which parallels the Red Creek anticline. Forced folds of this type often display synclinal forms on the downthrown side of the fault responsible for the folding of the strata. If this interpretation is correct, a more accurate time of movement on the Red Creek Canyon fault can be determined. The southern part of the quadrangle contains rocks as young as the Upper Cretaceous Graneros Shale (Kcg) that dip away from the anticlinal axis, suggesting a post-Graneros Shale age for the movement. This would be more consistent with a Laramide age for the main Red Creek Canyon fault movement and folding of the Red Creek Anticline.

GEOLOGIC HAZARDS

Bedrock structure, hydrogeology, topography, surface drainage, and lithology are important controls on the development of geologically hazardous areas within the mapped area. Landslides derived from shale and mudstone formations affect most of the southern and western parts of the Mount Pittsburg quadrangle. Although poorly characterized, other significant and potentially damaging hazards in the mapped area include earthquakes, swelling soils, hydrocompactive soils, and erosion.

Landslides

Landslides are prevalent around Table Mountain, Wild Mountain, and Timber Mountain where resistant Dakota Sandstone overlies less-competent shales and mudstones of the Purgatoire, Morrison, and Lykins Formations. Morgan (2006) further described these landslides. The Dakota Sandstone is highly jointed at these locations; the jointing allows water to seep into and mobilize the underlying shales and mudstones. The failures are rotational slumps where failure typically occurs along a vertical or nearly vertical fracture that intercepts a gently dipping shear plane. The headscarps can be extremely tall; some reach 100 feet in height on the southeast side of Table Mountain (fig. 7). Pressure ridges and terracettes may reach heights of 10 feet. The two large landslide masses on the southeast side of Table Mountain cover an area of roughly 2.3 square miles with a conservative estimated depth of 10 feet; the result is over 635,000,000 ft^3 of mobilized debris. Landslides surrounding Wild Mountain and Timber Mountain are also rotational slumps but the mobilized material covers a much smaller area when compared to the slumps surrounding Table Mountain. Toreva blocks, which are undisturbed slabs of bedrock that have slid and are tilted back toward the source area, occur along the eastern slopes of Wild Mountain (fig. 8). Some of these Toreva blocks may reach 150 feet in length and several feet in height. Small earthflows of clayey material occur at the toes of many of the landslides in the quadrangle. Rockfall deposits are common near the headscarps of landslides. Soil profiles examined in the landslide deposits on the south side of Timber Mountain have multiple buried A-horizons indicating repeated movements during the late Quaternary and Holocene. Landslides on the south side of Table Mountain have various soil profiles; some locations have little or no pedogenesis while other locations have thick Bt-horizons. This suggests either some of the masses have not moved since the middle to late Pleistocene or the soil profile may predate landslide movement. However, all of the landslides in the quadrangle have the potential to remobilize, especially if the toe is excavated and not properly stabilized.

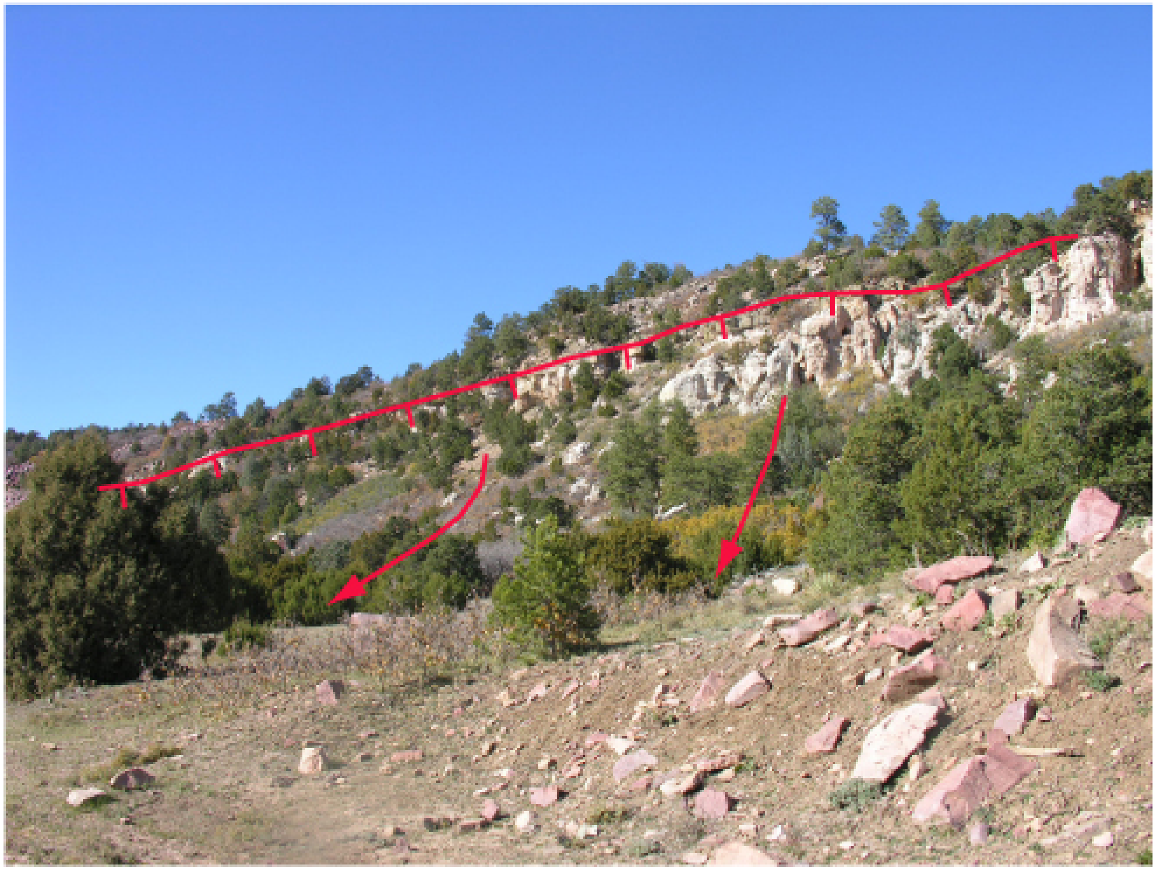

FIGURE 7. Photo of a landslide headscarp on the south side of Table Mountain. Red hachured line shows the approximate location of the headscarp; red arrows indicate movement of the landslide mass. The headscarp is approximately 100 feet high in this location. UTM83: 502285.0, 4268061.7. M. Morgan photo.

FIGURE 8. Toreva blocks (black arrows) on the east slope of Wild Mountain. These large blocks of Dakota Sandstone have slid and rotated back toward the source area. Some in the mapped area reach 150 ft in length and may be several feet high. UTM83: 505419.8, 4266015.2. V. Matthews photo.

Debris Flows

Debris flows are dense, heterogeneous mixtures of mud, rock fragments, and plant materials that typically follow preexisting drainages (Varnes, 1978). As the debris flow moves down its valley, its size and power increases, and it incorporates additional materials into the flow. Once the flow reaches an area of lower gradient, the flow drops its load and the suspended sediment is deposited at the mouth of the drainage (Varnes, 1978). Debris flows can form at any point along a drainage including on the sides of valleys. Debris flows are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993). Hazard analysis should take into account denuded forest conditions, such as after a wildfire. Such conditions may exist in areas mapped as alluvial fans (Qf), colluvium (Qc), sheetwash (Qsw), colluvium and sheetwash (Qcs), and landslides (Qls). Small debris flows occur in areas mapped as Qls, Qa_1, Qa_2, Qf_1 and Qf_2. These are of limited extent and are not mapped separately; however, residents should be aware of the possibility of large precipitation events triggering future debris flows that may inundate these areas with dangerous amounts of water and sediment.

Rockfall

Rockfall deposits are included in the colluvium unit (Qc) in the Mount Pittsburg quadrangle. Much of the rockfall hazard is in the Fort Carson Military Reservation where residential building is unlikely. There are isolated areas of rockfall in the northwest quarter of the mapped area where blocks of granite (Yg) may reach several feet in size. Large precipitation events and freeze-thaw processes may trigger rockfall or rock avalanches. Areas mapped as Qc are susceptible to future rockfall events; developers and homeowners should be cautious when building in proximity to these areas.

Earthquakes

Minor seismic activity has been recorded near Colorado Springs, possibly occurring from movement along the Rampart Range or Ute Pass fault zones. To date, no earthquakes are centered within the Mount Pittsburg quadrangle. In April of 1991, MicroGeophysics Corporation (1991) measured an earthquake swarm with magnitudes 2.6 to 2.8 on the south end of the Rampart Range fault zone. A magnitude 3.6 earthquake occurred near Manitou Springs on December 25, 1995 (Kirkham and others, 2004). Epicentral coordinates in the National Earthquake Information Center (NEIC) database suggest an epicentral location near the east flank of the Rampart Range about 21 miles north of Manitou Springs. The December 25 earthquake was felt at intensity IV at Victor, Cripple Creek, and Manitou Springs (Kirkham and others, 2004). On November 13, 1963, a magnitude 2.6 earthquake was felt with intensity IV near the northern limits of Pueblo (Hadsel, 1968); however, no other information is given.

Additional information on faulting and earthquakes in this are is described in the CGS' Colorado Earthquake Map Server (Kirkham and others, 2004) or the Colorado Late Cenozoic Fault and Fold Database and Internet Map Server (Widmann and others, 2002). Both are available for no charge on-line at *http://geosurvey.state.co.us*.

Swelling Soils and Heaving Bedrock

Expansive or swelling soils and heaving bedrock are one of the most costly geologic hazards along the Front Range, and account for tens of millions of dollars in damage (Noe and others, 1997; Noe, 1997). The swelling in surficial materials is caused by the expansion of clay minerals due to wetting. Heaving bedrock occurs where highly expansive clay layers within upturned bedrock are found at shallow depth below the ground surface. When wetted, these layers may heave at markedly different rates over small lateral distances. Such differential ground movements can cause significant damage to houses, roads, sidewalks, and other constructed media (Noe and others, 1997; Noe, 1997).

According to the National Resources Conservation Service (NRCS) soil survey data for the Mount Pittsburg quadrangle, the mapped area is given a low (0 Linear Extensibility Percentage (LEP)) to slightly moderate (3-6 LEP) swell potential. These categories are derived from the linear extensibility of the soil. Linear extensibility refers to the change in length of an unconfined clod as moisture content is decreased from a moist to a dry state. It is an expression of the volume change between the water content of the clod at 1/3 or 1/10 bar tension (33 kilo Pascals (kPa) or 10kPa tension) and oven dryness. The volume change is reported in the table as percent change for the whole soil (LEP). The amount and type of clay minerals in the soil influence volume change (NRCS, 2005).

Areas particularly susceptible to expansion are the deposits derived from the Purgatoire and Morrison Formations. According to the NRCS Soil Survey (2005), the north slopes surrounding Table Mountain and some of the Qg units underlain by Fountain Formation on the west side of the quadrangle are given a slightly moderate swell potential. Proper investigation and engineering practices, with a focus on expansive clays and heaving bedrock, should be applied during construction in these areas.

Hydrocompactive Soils

Soils that are susceptible to hydrocompaction (settlement or collapse due to the addition of water) may exist in areas mapped as alluvial fans (Qf), colluvium (Qc), colluvium and sheetwash (Qcs), sheetwash (Qsw), and landslides (Qls). However, no cases of damage from hydrocompaction have been reported in the mapped area (J. White, personal commun., 2005).

According to the National Resources Conservation Service (NRCS) soil survey data for the Mount Pittsburg quadrangle, the mapped area is given a 0% to 1% concentration of gypsum. These values are on the conservative side as many outcrops of Morrison Formation and Lykins Formation contain discontinuous gypsum beds in excess of 5 feet thick. These beds are prone to localized collapse and karsting. Gypsum is partially soluble in water and can be dissolved and removed by water. Soils with more than 10 percent gypsum may collapse if the gypsum is removed by percolating water. Gypsum is corrosive to concrete. Corrosion of concrete is most likely to occur in soils that are more than about 1 percent gypsum when wetting and drying occurs (NRCS, 2005).

Erosive Soils

Wind and water runoff are the biggest causes of erosion; however, these are amplified by development and grazing of vegetated lands where the soil is exposed and easily eroded. Exposed bedrock of the Pennsylvanian-Permian Fountain Formation is susceptible to moderately high erosion, especially where vegetation has been removed (NRCS, 2005). The NRCS estimates that 86 tons per acre per year of soil erosion is possible from the Fountain Formation and Dakota Sandstone. The least susceptible areas of erosion correspond to the landslides, sheetwash, and colluvium derived from the Morrison and Purgatoire Formations and also areas mapped as Yg.

There is a close correlation between wind erosion and the texture of the surface layer, the size and durability of surface clods, rock fragments, humus, and amount of $CaCO_3$ in the soil. Soil moisture and frozen soil layers also influence wind erosion. The estimates for erosion are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (NRCS, 2005).

Wind erosion may adversely affect the respiratory functions of humans and livestock by reducing air quality by increasing airborne dust. Furthermore, soil erosion increases the risk of pollution to surface and ground waters due to the use of pesticides from agricultural and residential treatment of vegetation.

MINERAL RESOURCES

There are three active aggregate quarries in the Mount Pittsburg quadrangle: (1) the Menzer quarry; (2) the Red Canyon quarry; and (3) the Table Mountain quarry. Several abandoned oil and gas wells were drilled from the 1920s through the 1940s on the flanks of the Red Creek anticline. Production data for these wells was not reported and therefore the wells probably were not successful.

Construction Aggregates

The three fully active operations in the area are mining for sand and gravel and road aggregate. The other operation in the area is intermittent in its production.
The Menzer quarry is located in sec. 32, T. 16 S., R. 67 W. This quarry, operated by the Schmidt Construction Company, produces aggregate for cement from the Proterozoic granite. Estimated production is 880,000 tons per year.

The Red Canyon quarry is located in sec. 1, T. 17 S., R. 68 W. This quarry produces sand and gravel from limestones in the Manitou Formation and Proterozoic granite and is operated by Red Canyon, LLC. Production from this mine was not reported (Guilinger and Keller, 2004).

The Table Mountain quarry is located in the southernmost part of the quadrangle, in sec. 22, T. 17 S., R. 68 W. has an estimated production of 150,000 tons per year. This quarry is the source of dense, highly silicified sandstone that is used for riprap, road base, and aggregate. It is extremely high in SiO_2; however it has minimal amounts of Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, and CrO3. The sandstone resource is in excess of 100,000,000 cubic tons and is approximately 60-80 feet thick. Due to the inherent strength of the sandstone, cement can be made with little aggregate. This quarry is operated by the Castle Concrete Company (Guilinger and Keller, 2004).

The only non-active quarry is located in sec. 14 T.17 S., R. 68 W., and when active it is operated by High Plains Stone Company. Production comes from blocks of moss-covered Dakota Sandstone found on the surface that is used for decorative stone (Guilinger and Keller, 2004).

Oil and Gas

From 1925 through1946, six oil and gas wells were drilled and subsequently abandoned within the mapped area (COGCC website at http://oil-gas.state.co.us/). They were located in secs. 17 and 19, T. 17 S., R. 67 W., and sec. 4, T. 18 S., R. 67 W. All of the wells were drilled on the flanks of the Red Creek anticline where oil may be trapped by that structure. No production information is listed for any of the wells so it is doubtful they were successful, thus it is unlikely that the area will yield any future production. Additional information on oil and gas production may be obtained from the Colorado Oil and Gas Conservation Commission.

GROUND-WATER RESOURCES

Ground water is the primary water source for agricultural and domestic purposes throughout the Mount Pittsburg quadrangle. Depending on location, ground water can be found in one or two hydrogeologic units: (1) consolidated bedrock aquifers found in the Pennsylvanian Fountain Formation, or (2) fractured crystalline aquifers in Precambrian rocks. The following sections describe each of these hydrogeologic units and provide information about general hydrogeologic characteristics of the units gathered from available literature. The scope of this discussion is limited to providing a general description of the ground-water resources that might be available within the quadrangle; further details, such as specifics about water quality, surface water, and current water level data can be obtained from available literature. Additional information on ground water in Colorado is in the CGS' Ground Water Atlas of Colorado (Topper and others, 2004).

Fountain Aquifer

The Fountain aquifer belongs to the Western Interior Plains Confining System, a sequence of limestone, sandstone, shale and anhydrite beds of Late Mississippian through Jurassic age that covers about one-third of eastern of Colorado and parts of several surrounding states (Miller and Appel, 1997; Robson and Banta, 1987). The Western Interior Plains Confining System provides ground water to domestic, commercial, municipal, agricultural, and governmental users in and around the mapped area. In eastern Colorado and the surrounding Great Plains states, ground water in the Western Interior Plains Confining System is highly mineralized and is not suitable for domestic use (Miller and Appel, 1997).

The Fountain Formation, the primary rock unit defining the aquifer, generally consists of dark-red to pink, fine- to coarse-grained, arkosic sandstone and pebble conglomerate with localized beds of shale and mudstone. The porosity of the sandstone and conglomerate beds ranges from 3 to 12 % and averages approximately 7 % (Robson and Banta, 1987). The thickness of the aquifer ranges from 1,000 to 4,000 feet and is probably about 1,500 feet thick in the mapped area. It extends roughly 30 to 50 miles southeast from the outcrops of the Fountain Formation along the Front Range (Robson and Banta, 1987).

Water-level data for the Fountain aquifer can be obtained from the Division of Water Resources (DWR) well permit files. Well-completion reports and pump-installation reports for wells often list the water levels that existed when the wells were completed. These data are one-time measurements and thus, water-level is not necessarily representative of static conditions in the well. Water levels in the Fountain aquifer can be expected to vary considerably depending on location and elevation; values listed in the DWR permit database are between 7 and 745 feet below the surface. Although these water levels have remained relatively constant over the 40 years since the first well permit in the area was issued, the average well depth has increased from 225 feet in the 1960s to nearly 500 feet, presently. Well yields within the quadrangle typically range from 1 to 100 gal/min. Ground water from the Fountain aquifer is considered “tributary” and is thus subject to the State of Colorado surface water appropriations system.

Water-quality data for the Fountain aquifer are scarce and data from within the quadrangle are non-existent. In general, the water quality of the Fountain aquifer near the

Front Range is adequate for domestic use with total dissolved solids (TDS) values ranging from 200-500 mg/L; however, values may reach as high as 2000 mg/L (Robson and Banta, 1987). Total dissolved solids concentrations increase eastward to the Colorado-Nebraska/Kansas state lines, making Fountain aquifer ground water in these areas not suitable for domestic use.

Precambrian Crystalline Rock Aquifer

Much of the northwestern part of the mapped area is dominated by Precambrian crystalline rocks that act as important aquifers for mountain homes. As a result of structural deformation, these rocks are highly fractured, faulted, and folded, creating openings for water storage. Water from snowmelt and rain are the only means of recharging these aquifers. Porosity is very low, generally less than 1% and well yields are typically 15 gal/min or less (Topper and others, 2003).

According to the DWR well permit files, water levels in the Precambrian crystalline aquifer within the mapped area range from 12 to 375 feet below the surface. These have decreased steadily over the last 40 years at an average rate of over 5 feet per year. The first permitted well was drilled to 40 feet in 1964, and the most current well drilled in 1998 was to depth of 640 feet; these cover the range of well depths in the mapped area.

Water-quality data for the Precambrian crystalline aquifer within the quadrangle is non-existent. In general, the water quality of the Precambrian crystalline rock aquifer is adequate for domestic use except in areas of mineralization where metallic or acidic waters may be present (Topper and others, 2003). Ground water from the Precambrian crystalline rock aquifer is considered “tributary” and is thus subject to the State of Colorado surface water appropriations system.

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