OPEN-FILE REPORT 03-18

Geologic Map of the Cascade Quadrangle, El Paso County, Colorado

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COLORADO DIVISION OF MINERALS & GEOLOGY
RECLAMATION•MINING SAFETY•SCIENCE

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 03-18, *Geologic Map of the Cascade Quadrangle, El Paso County, Colorado*. Its purpose is to describe the geologic setting, mineral resource potential, and geologic hazards of this 7.5-minute quadrangle located immediately west of Colorado Springs.

The principal geologists for the mapping project were Matt Morgan (CGS staff geologist), Christine Siddoway (Associate Professor of Geology at Colorado College), Peter Rowley (consulting geologist), Jay Temple (consulting geologist), and John Keller (CGS staff geologist).

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds are competively awarded through the STATEMAP component of the National Cooperative Geologic Mapping Program (Agreement No. 02HQAG0050). The program is authorized by the National Mapping Act of 1997. The CGS matching funds come from the Severance Tax Operational Account that is funded by taxes paid on the production of natural gas, oil, coal, and metals.

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Many of the structural interpretations presented here are an outgrowth of those proposed by E.J. "Ned" Sterne for Garden of the Gods in 1999. The mapping program in 2002–2003 benefited greatly from a pre-season field trip arranged and presented by Vince Matthews and Bob Kirkham (consulting geologist). Karen Morgan (CGS) provided GIS and cartographic support and the cross-section profiles for the map plate.

Access to private land and closed or limited-use areas was graciously provided by: the U.S. Forest Service Pikes Peak Ranger District, Colorado Springs Utilities, Castle Concrete Company (Pikeview and Snyder quarries), Eagle Lake Camp, Blodgett Ranch, Flying "W" Ranch, the Mountain Shadows home subdivision, the U.S. Air Force Academy, and The Navigators.

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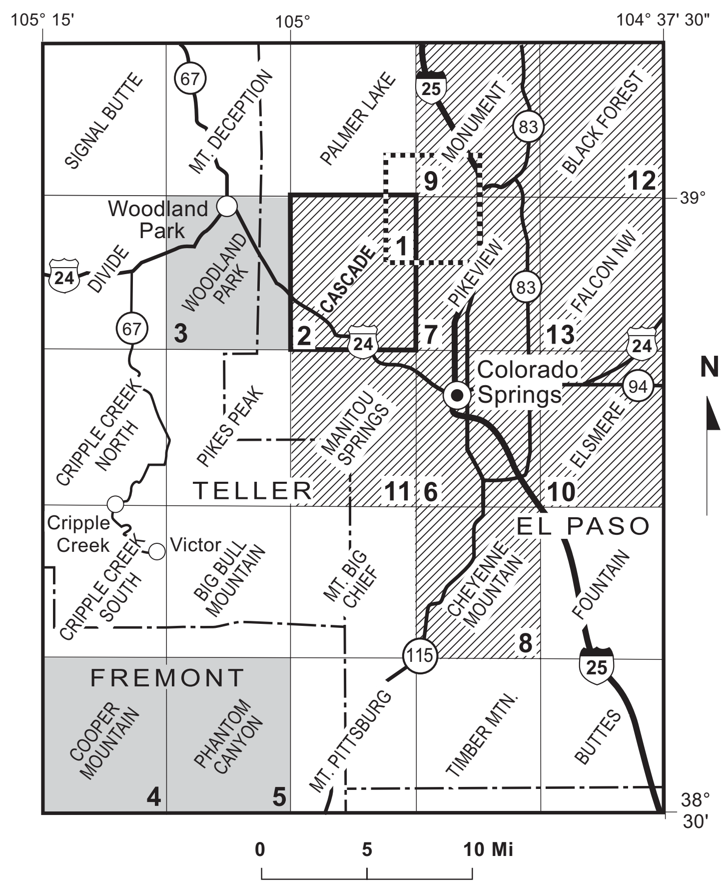
INTRODUCTION

The Cascade quadrangle, Colorado, is located in El Paso County, in the southern Rampart Range, on the eastern margin of the Colorado Front Range. The town of Cascade (population 1,479) is located in the southwestern part of the quadrangle along U.S. Highway 24, approximately 10 mi northwest of Colorado Springs. Fountain Creek, the only major drainage in the quadrangle, flows to the southeast to Colorado Springs, where Monument Creek drains into it. Rampart Reservoir (approximately 1 sq mi in "areal" extent and at elevation 9,000 ft), located in the northwestern part of the quadrangle, is one of the major sources of culinary water for the Colorado Springs metro area. U.S. Forest Service (USFS) lands surrounding the reservoir are used for recreation; they provide stunning views of Pikes Peak (elevation 14,110 ft) to the south. The highest peak on the quadrangle is Ormes Peak (elevation 9,727 ft), and the lowest point (elevation 6,358 ft) is in the southeastern part of the quadrangle.

Geologic mapping of the Cascade 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 1 shows the status of geologic maps of 7.5-minute quadrangles in the Colorado Springs area. This is the seventh quadrangle in this area to be mapped by the CGS.



EXPLANATION

This report

CGS 1:24,000-scale geologic maps

USGS 1:24,000-scale reconaissance geologic maps

USGS 1:12,000-scale geologic map of the U. S. Air Force Academy

Completed 1:24,000-scale and larger geologic maps:

Index Map No.	Publication No.	Date	Scale
1	USGS PP 551 Varnes and others	1967	1:12,000
2	USGS OF 77-138 Wobus and Scott	1977a	1:24,000
3	USGS MF-842 Wobus and Scott	1977b	1:24,000
4	USGS MF-1762 Wobus and others	1985a	1:24,000
5	USGS MF-1764 Wobus and others	1985b	1:24,000
6	CGS OF 00-3 Carroll and Crawford	2000	1:24,000
7	CGS OF 01-3 Thorson and others	2001	1:24,000
8	CGS OF 02-5 Rowley and others	2002	1:24,000
9	CGS OF 02-4 Thorson and Madole	2002	1:24,000
10	CGS OF 02-2 Madole and Thorson	2002	1:24,000
11	CGS OF 03-19 Keller and others	2003	1:24,000
12	CGS OF 03-6 Thorson	2003	1:24,000
13	CGS OF 03-8 Madole	2003	1:24,000

Figure 1. Index of published geologic maps near Colorado Springs and vicinity.

The geologic interpretations shown on the map were based on (1) prior published and unpublished geologic maps and reports; (2) study of: color 1:24,000-scale USFS aerial photography flown in 1995, black and white 1:40,000-scale NAPP aerial photography flown in 1999, a 10-meter digital elevation model (DEM), and a 1-meter resolution USGS digital orthophoto quadrangle (DOQ) derived from 1999 black and white photography; and (3) field investigations in 2002. Quaternary deposits over the entire quadrangle and bedrock geology of the southern part of the quadrangle were mapped in the field on aerial photographs. The photos were scanned, georeferenced, and imported into ERDAS Imagine Stereo Analyst, where they were photogrammetrically corrected and rendered in 3-D. Line work was traced directly from ERDAS Imagine Stereo Analyst and exported as ESRI shapefiles into Avenza MaPublisher. Other areas were mapped directly onto a USGS 1:24,000-scale topographic map and subsequently digitized in ESRI ArcView.

Reconnaissance mapping of the Cascade 7.5-minute quadrangle was done previously by Varnes and others (1967), Scott and Wobus (1973), and Wobus and Scott (1977a). These maps were used as a guide to our mapping, especially in areas of intense urbanization.

Field mapping for the Cascade quadrangle was undertaken during the summer of 2002. Quaternary deposits were mapped primarily by Matt Morgan (CGS). Jay Temple (consulting geologist) mapped the area east of the Rampart Range fault zone and south to Glen Eyrie. Christine Siddoway (Colorado College) and Bonnie Hawkins Archuleta (field assistant, Colorado College) mapped the area east of Highway 24 and south of Palmer Reservoir. John Keller (CGS) mapped the region south of Highway 24. The remainder of the quadrangle was mapped by Peter Rowley (consulting geologist). Sections for this booklet were written by the following: structural geology by Christine Siddoway, Peter Rowley, Jay Temple, and John Keller; geologic hazards by Matt Morgan, John Himmelreich Jr., and Christine Siddoway; mineral resources by John Keller and Peter Rowley. Unit descriptions are written by the authors except for those of the Dawson Formation, lower member of the Laramie Formation, and Fox Hills Sandstone, which were modified from the Pikeview quadrangle of Thorson and others (2001) in order to maintain consistency with extensive outcrops of those units to the east.

BACKGROUND GEOLOGY

The Cascade quadrangle covers the southern end of the Rampart Range part of the Front Range uplift. The Rampart Range fault zone forms the range-bounding structure and a tectonic boundary with the Colorado Piedmont to the east. The fault juxtaposes Precambrian rocks on the west against steeply dipping Paleozoic and Mesozoic rocks to the east. The Rampart Range consists mainly of Precambrian crystalline rocks, with Phanerozoic cover rocks limited to its southern end. These rocks lie within the structural and topographic reentrant of the Manitou Springs embayment, where displacement along the Rampart Range fault zone is transferred to the Ute Pass fault zone. The "Great Unconformity" (i.e. the nonconformity between Precambrian crystalline rocks and Phanerozoic sedimentary rocks) is well exposed in deep canyons of the southern Rampart Range, with the sedimentary Cambrian Sawatch Sandstone overlying Proterozoic plutonic igneous and metamorphic rocks. Coarse clastic sediments of Tertiary and Quaternary age are widespread along the mountain front, resting in angular unconformity upon strata of Cretaceous or older age. At higher elevations, dissected remnants of Tertiary gravels cover the gently rolling topography of the Rampart erosion surface that was cut into less resistant granitic bedrock probably during the late Eocene and Miocene (Steven and others, 1997). The Colorado Piedmont (Leonard, 2002; McMillan and others, 2002) contains tributaries of the Fountain Creek watershed of the Arkansas River system.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than five feet thick but may be thinner locally. Residuum, slope wash, colluvium, and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally include deposits of another type. 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 Scott (1960; 1963b). Varnes and others (1967), Scott and Wobus (1973), and Trimble and Machette (1979) applied this nomenclature to Quaternary deposits in the Cascade quadrangle (Table 2).

Because of correlation uncertainties between the deposits in the Cascade quadrangle and those in areas where this nomenclature was developed, the formal names for alluvial deposits were not used. Surficial geologic mapping on the U.S. Air Force Academy by Varnes and others (1967) at 1:12,000 scale was used with minor modifications for this map.

HUMAN-MADE DEPOSITS

af — **Artificial fill (late 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 ft. Artificial fill may be subject to settlement and erosion if not adequately compacted.

mw — **Mine waste (late Holocene) —** Waste rock excavated from mines and prospecting pits. Mine waste typically consists of pebble- to cobble-size angular fragments of Precambrian granite, gneiss, Paleozoic sandstone and limestone, Cretaceous sedimentary rocks, and Quaternary gravels. The deposits may be as much as 100 ft thick. Mine waste 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 Fountain and Monument Creeks and associated tributary

Table 1. Time divisions for the Quaternary from Madole and Thorson (2002).

FORMAL TIME DIVISIONS		INFORMAL TIME DIVISIONS	AGE(sidereal years)
Quaternary period	Holocene Epoch		
			~11,700
	Pleistocene Epoch	late Pleistocene	
			~127,000
		middle Pleistocene	
			~778,000
		early Pleistocene	
			~1,806,000
Tertiary period(part)	Pliocene Epoch		

drainages. Terrace alluvium and related pediments along these mainstem creeks were deposited mostly during late-glacial and early-interglacial stages. 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 near the creek edge of the terraces. Thickness is measured on the maximum exposed thickness of the unit.

Qa **Stream-channel, flood-plain, and terrace alluvium, undivided (Holocene and late Pleistocene) —** Clast-supported, pebble, cobble, and rare boulder gravel in a sandy silt matrix. Terrace alluvium rests a maximum of 10 ft above modern stream level. May be locally interbedded with and commonly overlain by sandy silt and silty sand. Clasts are subangular to well rounded and of varied lithology, reflecting the diverse types of bedrock within their provenance. Locally, unit may include organic-rich sediments. Deposits may be interbedded with fan deposits (Qf, Qfy, Qfo), colluvium-sheetwash (Qcs), and alluvium-colluvium (Qac). Maximum thickness of this unit may exceed 20 ft. Areas mapped as Qa may be prone to flooding, erosion, and sediment deposition. The unit is a potential source of commercial sand and gravel.

Qa_1 **Alluvium one (late Holocene) —** Yellow to medium-dark-brown, poorly to moderately sorted, unconsolidated clay silt, sand,

Table 2. Nomenclature of Quaternary stratigraphic names for alluvium units used in the Colorado Springs area.

Varnes and others, 1967	Scott and Wobus, 1973; Trimble and Machette, 1979	Carroll and Crawford, 2000	Thorson and others, 2001	This map	Possible age
flood-plain alluvium	Post-Piney Creek and Piney Creek Alluvium	terrace alluvium one	alluvial and colluvial deposits	alluvial and colluvial deposits (Qac, Qa); Alluvium one and two (Qa_1)	late Holocene
Husted Alluvium			terrace alluvium one	alluvium two (Qa_2)	early Holocene
Monument Creek Alluvium	Broadway Alluvium	terrace alluvium two	terrace alluvium two	None	late Pleistocene
Kettle Creek Alluvium	Louviers Alluvium	terrace alluvium three	terrace alluvium three	None	late Pleistocene
Pine Valley Gravel	Slocum Alluvium	pediment gravel one	pediment gravel one	pediment gravel one (Qg_1)	middle Pleistocene
Douglass Mesa Gravel	Verdos Alluvium	pediment gravel two	pediment gravel two	pediment gravel two (Qg_2)	middle Pleistocene
Lehman Ridge Gravel	Rocky Flats Alluvium	pediment gravel three	pediment gravel three	pediment gravel three (Qg_3)	middle? to early Pleistocene
None	Nussbaum Alluvium	None	None	pediment gravel four (QTg_4)	late Pliocene-early Pleistocene

gravel, and sparse boulders deposited as clast- or matrix-supported alluvium in modern creek beds. Clasts are subangular to well rounded and of varied lithology. Maximum thickness of this unit may exceed 10 ft. Deposits may include localized organic- and sand-rich layers and may include terraces as much as five feet above the modern creek bed. Remnants of historical town sites and Native American campsites found on alluvium one suggest that the upper one foot of the deposit dates to less than 250 YBP (M. Van Ness, oral commun., 2002). Areas mapped as Qa_1 may be prone to flooding, erosion, and sediment deposition. The unit is a potential source of commercial sand and gravel.

Qa_2 **Alluvium two (late to early Holocene) —** Dark-yellow to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and sparse boulders deposited as river terraces above the currently active flood plain or as non-terrace forming alluvium in valley headwaters. Clasts are subangular to well rounded and have varied lithology. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 15 ft above current stream level. Maximum thickness of unit locally exceeds 15 ft. The unit is generally correlative, by virtue of height and soil characteristics, with the Husted Alluvium of Varnes and others (1967) on the U.S. Air Force Academy, the Piney Creek Alluvium of the Denver area (Scott and Wobus, 1973), and unit Qt_1 of Carroll and Crawford (2000) and Thorson and others (2001) in the Colorado Springs and Pikeview quadrangles, respectively. Recent charcoal samples from a fire pit buried three feet below the alluvium in Garden of the Gods Park yielded a calibrated carbon-14 date of 3,280 YBP (M. Van Ness, personal commun., 2002). The unit is a potential source of commercial sand and gravel.

PEDIMENT GRAVELS (MIDDLE PLEISTOCENE TO LATE PLIOCENE) — Partially dissected remnants of four levels of older gravel deposits are preserved along Fountain and Monument Creek and the piedmont. Finlay (1916) recognized two of these "mesa gravels" on the basis of on their distinctive topographic form and suggested a fluvial origin. Varnes and others (1967) identified a third partially dissected gravel deposit at lower elevation and from youngest to oldest formally named them the Pine Valley Gravel, Lehman Ridge Gravel, and Douglass Mesa Gravel (Table 2). They classed them as "pediment gravels." Scott and Wobus (1973) referred to all three deposits as "alluvial terrace or pediment gravel" and correlated them with similar deposits in the Denver area that were formally named the Slocum Alluvium, Verdos Alluvium, and Rocky Flats Alluvium by Scott (1960, 1963b). Additionally, a higher and fourth level of gravel, the "Nussbaum Formation" near Pueblo was reinterpreted by Scott (1963a, 1982) and renamed the "Nussbaum Alluvium" of possible late Pliocene to early Pleistocene age. This is the highest and oldest deposit in the sequence of alluviums described by Scott (1960, 1963a, 1963b), and is located 450 ft above modern streams in the Denver area. By definition, the deposits on this map with designation Qg or QTg meet the definition of "pediment" as supplied by the American Geological Institute's Glossary of Geology (Bates and Jackson, 1997):

> A broad gently sloping rock-floored erosion surface or plain of low relief, typically developed by subaerial agents (including running water) in an arid or semiarid region at the base of an abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but are more often partly mantled with a thin discontinuous veneer of alluvium derived from the upland masses and in transit across the surface.

Additionally, Worcester (1948) described pediments in the Front Range of Colorado as "sediment-topped, fan-shaped pediments.

The map designations (Qg_1, Qg_2, Qg_3) are similar to those used by Carroll and Crawford (2000) and Thorson and others (2001) in the Colorado Springs and Pikeview quadrangles, respectively. Pediment gravel four (QTg_4) corresponds to the highest (oldest) gravel deposit in this sequence.

Qg_1 **Pediment gravel one (middle Pleistocene) —** Light-red to brown, poorly sorted, moderately to poorly stratified pebble and cobble gravel primarily derived from granitic bedrock, as well as layers of clay, silt, sand and clay clasts derived from shaly bedrock. Clasts are subrounded to rounded, moderately to highly weathered, and are coated with a thin (less than 0.02 in.), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered clasts. Richer in boulders and less stratified toward the mountain front. Top of pediment gravel is 30 to 75 ft above adjacent modern streams. The unit locally exceeds 20 ft in thickness. Unit correlates with Qg_1 of Thorson and others (2001), the Pine Valley Gravel at the U.S. Air Force Academy (Varnes and others, 1967), and with the Slocum Alluvium (Scott and Wobus, 1973). Pediment gravel one is considered to be middle Pleistocene in age on the basis of local stratigraphic and physiographic position and soil development. Scott (1960) considered the Slocum Alluvium to be Illinoian or Sangomon in age on the basis of stratigraphic position, mollusks, and pre-Wisconsin age soil profile (Varnes and Scott, 1967). The deposit forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

Qg_2 **Pediment gravel two (middle Pleistocene) —** Medium-red to brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel primarily derived from granitic bedrock. Basal portion of unit contains layers of clay and silt interbedded with coarse-grained sand, cobble, and rare boulder gravels. Clasts are highly weathered and are coated with a thin (0.05 in.), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered clasts. Becomes richer in boulders and less stratified toward mountain front. Top of pediment gravel is 130 to 215 ft above adjacent modern streams. The unit locally exceeds 70 ft in thickness. Unit correlates with Qg_2 of Thorson and others (2001), with the Douglass Mesa Gravel at the U.S. Air Force Academy (Varnes and others, 1967), the Verdos Alluvium of the Denver area (Scott and Wobus, 1973). The unit is considered to be middle Pleistocene on the basis of local stratigraphic and physiographic position and soil development. In the Denver area, the upper part of the Verdos Alluvium contains Lava Creek B ash (Scott, 1960), which was recently dated at 640,000 YBP (Lanphere and others, 2002). This unit forms a stable building surface; however, excavations may be prone to slumping. Unit is a source of sand and gravel.

Qg_3 **Pediment gravel three (middle? to early Pleistocene) —** Red to brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel primarily derived from granitic bedrock. Clasts are highly weathered and are coated with a 0.03 in., discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz pebbles derived from weathered clasts. Boulders become larger and more abundant and the deposit becomes less stratified toward the mountain front. Top of pediment gravel is 230 to 300 ft above modern streams. Unit locally exceeds 50 ft in thickness. Unit correlates with Qg_3 of Thorson and others (2001), the Lehman Ridge Gravel of the U.S. Air Force Academy (Varnes and others, 1967), and with the Rocky Flats Alluvium of the Denver area (Scott and Wobus, 1973). The unit is considered to be middle to early Pleistocene in age on the basis of local stratigraphic and physiographic position and soil development. Forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

QTg_4 **Pediment gravel four (early Pleistocene to late Pliocene) —** Dark-red to brown, well-sorted, moderately to well-stratified sand, pebble, and cobble gravel derived from Precambrian granite and gneiss and lower Paleozoic sandstone and limestone. Clasts are extremely weathered and commonly coated with a discontinuous rind of calcium carbonate more than 0.05 in. thick. A calcareous soil horizon is locally present in the top three feet of some deposits. Matrix typically consists of feldspar, quartz, and limestone pebbles derived from weathered clasts; clay is also abundant. Boulders become more frequent and deposit becomes less stratified toward the mountain front. Top of pediment gravel is 500 to 700 ft above modern streams. The unit locally exceeds 100 ft in thickness. The unit was correlated with the Nussbaum Alluvium of the Denver area by Scott and Wobus (1973).

The deposit is considered to be late Pliocene to early Pleistocene in age on the basis of local stratigraphic and physiographic position and presence of mollusks. Vertebrate fossils of late Pliocene age (3.0 m.y.) were identified in the lower part of the Nussbaum Alluvium near Baculite Mesa, about 50 mi to the southeast of Colorado Springs (Scott, 1982). However, Luiszer (1997) dated the QTg_4 deposits north of Manitou Springs using amino acids taken from mollusks and determined the maximum age of the deposit to be 1.9 +0.4/-0.2 Ma; thus, this unit may not be correlative with the Nussbaum Alluvium described by Scott (1982) near Baculite Mesa. The unit forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

Tg

Gravel (Upper Tertiary) — Soft, pink and light-gray, unconsolidated, fluvial bouldery and cobbly pebble gravel exposed in the area of the Rampart Reservoir. Clasts, as large as four feet in diameter, consist mostly of rounded to subrounded Precambrian rocks, predominantly fine-grained phases of the Windy Point Granite, and aplite of the Pikes Peak Granite. Unit includes clasts of metasedimentary Precambrian rocks derived from areas perhaps to the south and volcanic rocks probably derived from the latest Eocene-early Oligocene Thirtynine Mile volcanic field about 20 mi west of the mapped area (Scott and Wobus, 1973; Mertzman and others, 1994; Steven and others, 1997). The deposit occupies stream channels in a paleovalley. The erosion surface at the base of the deposit represents the surface widely reported capping the Rampart Range (for example, Epis and others, 1980; Steven and others, 1997). This surface could be early Tertiary (Epis and others, 1980) or, more probably, late Tertiary (Steven and others, 1997). Taylor (1975), and more recently Steven and others (1997), considered the deposits to be the lateral equivalent of the latest Miocene Ogallala Formation of the Great Plains. The deposit extends just west of the quadrangle, underlying widespread sage- and grass-covered slopes along the Rampart Range road, such as at and north of Bald Mountain. Two soil profiles examined northwest of Rampart Reservoir on a gently rolling surface consist of a 3 in. thick A horizon underlain by a well-developed Bt horizon more than one foot thick. Munsell colors (wet; Geological Society of America, 2000) range from 10R 4/6 (dark brick red) for the Bt horizon, to 5-YR 6/2 (brown-gray) for the A horizon. The structure of the Bt horizon is angular to subangular blocky with clay films coating the faces of peds (soil structure unit) and individual grains. Soil development on these deposits is much stronger than soils developed on late Pliocene-early Pleistocene QTg_4. Weathering rinds on granitic clasts range from greater than 0.02 to 0.08 in. and as much as 0.2 in. on volcanic clasts. Degree of soil development, weathering rinds, stratigraphic position, and presence of volcanic clasts suggest this deposit is most likely Upper Tertiary. Thickness in the mapped area as much as 50 ft.

ALLUVIAL AND COLLUVIAL DEPOSITS — Gravel, sand, and silt in alluvial fans, stream channels, flood plains, tributary stream channels, and lower parts of hillslopes. Alluvial processes are predominant in stream channels and flood plains, whereas colluvial and sheetwash processes are predominant on alluvial fans and along the hillslope-valley floor boundary.

Qac

Alluvium and colluvium, undivided (Holocene to late Pleistocene) — Stream channel, terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and colluvium deposits along valley sides. Interfingers with stream alluvium (Qa), fan deposits (Qf), and colluvium (Qc) 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 ft.

Qcs

Colluvium and sheetwash deposits, undivided (Holocene to 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 sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. 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 small landslides of limited extent. Sheetwash is common on slopes with less than a 10 percent grade below hills of granitic bedrock. Clast lithology is variable. Colluvium and sheetwash deposits grade into and interfinger with alluvium, alluvial-fan, and landslide deposits. Maximum thickness of this unit is about 20 ft. 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, especially grus derived from the weathering of Pikes Peak Granite.

Qf **Alluvial fan deposits (Holocene to late Pleistocene) —** Poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported, pebble and cobble gravel in a sandy silt or silty sand matrix. Clasts are mostly angular to subrounded and typically composed of granitic bedrock. Sediments are deposited primarily by streams; input from sheetwash, debris flows, and hyperconcentrated flows is minor. Deposit locally is dissected and has a thin, weakly to moderately developed pedogenic soil. The maximum estimated thickness for fans along Fountain Creek locally exceeds 50 ft. These fans form on slopes with greater than 10 percent grade and lack fan-shaped morphology. Large precipitation events may trigger future deposition in areas underlain by alluvial fan deposits. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded. Deposit is a source of sand and gravel.

Qfy **Young alluvial fan deposits (Holocene) —** Poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported, pebble, cobble and boulder gravel in a sandy silt or silty sand matrix. Clasts are mostly angular to subrounded with varied lithologies. Sediments are deposited primarily by streams; input from sheetwash, debris flows, and hyperconcentrated flows is less prevalent. Fan-shaped deposits form where tributary drainages with steep gradients join lower gradient streams. Soil development is extremely weak to absent. Subject to flooding and future debris-flow, hyperconcentrated-flow, and sheetwash deposition. Deposit is a source of aggregate.

Qfo **Old alluvial fan deposits (late to middle? Pleistocene) —** Poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported pebble, cobble, and boulder gravel in a sandy silt or silty sand matrix. Clasts are mostly angular to subrounded and typically composed of granitic bedrock. Very bouldery near mountain front, with clast size commonly exceeding two feet in diameter. Deposit is highly dissected by small streams and has a thin, moderately well developed pedogenic soil. The town of Cascade (sec. 23, T. 13 S., R. 68 W.) is built on an old fan deposit that exceeds 60 ft in thickness. Deposit is a 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.

Qls **Landslide deposits (Holocene to late Pleistocene) —** Heterogeneous deposits consisting of unsorted and unstratified clay, silt, sand, and angular, boulder-size rock fragments. Unit includes rotational slides, translational slides, and complex slide-flow mass movements. 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, and pressure ridges at the toe of the mobilized mass. Most landslides on the eastern margin of the quadrangle post-date deposition of Qg_2 (middle Pleistocene). Most are heterogeneous mixtures of reworked bedrock and very coarse-grained sand and pebble gravel derived from Qg_2 gravels. The landslides mapped in the Cascade quadrangle demonstrate the wide variety of types of landslides and lithologies susceptible to landsliding, unlike most other mapped quadrangles in the Colorado Springs area. 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, 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 formations. Maximum thickness of landslide deposits in the quadrangle locally exceeds 80 ft.

BEDROCK GEOLOGY

TKda

Upper part of the Dawson Formation (Paleocene and Upper Cretaceous) — White to light-gray, crossbedded, massive, coarse arkosic sandstone, and arkosic pebble conglomerate beds, in the extreme northeastern part of the mapped area. The unit contains rare interbeds of thin-bedded gray claystone, sandy claystone, or dark-brown to brownish-gray, organic-rich siltstone to coarse sandstone containing abundant plant fragments. Westward, toward the mountain front, the unit can be buff, gray, or pink and become tan, brown, or reddish-brown dependant on potassium feldspar content and iron cementation. Grain size alternates from 0.04 in. to 0.2 in. in beds 4 in. to 40 in. in thickness. Coarse grained beds contain pebbles and cobbles from 0.2 in. up to 3.2 in. in diameter. The pebbles and cobbles are well-rounded and are composed of quartz and potassium feldspar. Abundant cross-bedding is prevalent in the finer-grained zones. Dark red to rust colored bands, rich in iron oxide, accentuate the cross-beds. The unit can be jagged and angular in outcrop and form distinctive overhangs, caves, and hoodoos. Near-source, conglomerate beds in the Cascade quadrangle represent synorogenic sediments shed from the Rampart Range; these coarse clastic fluvial facies contain progressive unconformities (unconformities where sedimentation and deformation occur simultaneously) (Kluth and Nelson, 1988). Maximum thickness of the unit in this quad exceeds 1,000 ft. The character of the sediments and sedimentary structures of the upper Dawson Formation suggest deposition in a near-shore fluvial environment dominated by braided streams that were fed by drainages with steep topographic gradients. The map unit correlates with the Dawson Formation facies unit one of Thorson and others (2001). A complete description and depositional history of the Dawson Formation and associated facies are given by Thorsen and others (2001), Thorson and Madole (2002), Thorson (2003a,b), Madole (2003), and Raynolds (2002). Further information on the depositional setting for this unit comes from the Denver Basin project of the Denver Museum of Nature and Science (Johnson and Raynolds, 2002). This unit is generally permeable, well drained, and has good foundation characteristics. Excavations may be prone to slumping because the arkoses are friable and easily eroded. The finer grained interbeds may be less stable and may have greater shrink-swell properties. The block-failure of cliffs in this unit pose a significant slope stability hazard in some residential areas.

Kll

Lower member of the Laramie Formation (Upper Cretaceous) — Light-gray to light-brownish-gray, very fine-grained sandstone beds, interbedded with gray sandy shale, brown organic-rich shale, and coal as much as 10 ft thick. The map unit is exposed near Mount Saint Francis along the easternmost margin of the mapped area (sec. 3, T. 13 S., R. 67 W.). Here, the unit is composed of light-gray to light-brownish-gray, fine-grained sandstone beds, interbedded with gray sandy shale and minor organic-rich brown shale. The sandstone beds are thin bedded to structureless and the shales are thin bedded. Thinner bedded units have fine internal laminations, cut and fill structures, low-angle cross laminations, and low-angle cross-bedding. Ironstone ledges of limonite-cemented sandstone are common. The brown shales are moderately organic-rich and contain small chips of coaly plant material. The map unit is approximately 115 ft thick. The conformable lower contact of the Laramie Formation with the top of the Fox Hills Sandstone is somewhat arbitrary, but it has been placed at the bottom of a light-gray, very fine-grained sandstone interbedded with brown, organic-rich shale. Below this contact, in the top of the Fox Hills Sandstone, the sandstone is light olive gray and orange gray, lacks the organic-rich beds, and has few ironstone ledges. The coal beds and brown organic-rich shales of the lower member of the Laramie Formation were deposited in swampy areas with heavy vegetation growth. The fine-grained sandstones and sandy shales were deposited in a low energy environment, including swamps transitional with the shoreline environment of the Fox Hills Sandstone. A likely environment of deposition is a series of protected lagoons between barrier islands on one side of the lagoon and swampy marshes and forests on the other. The lower member of the Laramie Formation is relatively soft and easily excavated and has relatively stable foundation characteristics. The main hazard to structures and human beings related to the unit is subsidence over abandoned coal mine workings, none of which have been mapped in the Cascade quadrangle but are abundant to the east in the Pikeview quadrangle. Subsidence features related to abandoned coal mines was not observed in the field. Maps of the underground workings can be found in the CGS Subsidence Library.

Kfh

Fox Hills Sandstone (Upper Cretaceous) — Light-olive-gray, fine-grained sandstone beds in the upper part and thin to thick massive beds of greenish-gray to orange-brown, micaceous, poorly sorted, fine-grained to medium-grained sandstone beds in the lower part. The Fox Hills Sandstone is exposed near Mount Saint Francis (sec. 3, T. 13 S., R. 67 W.). At this location, the upper part of the Fox Hills Sandstone is approximately 140 ft thick and is light-brownish-gray, olive-gray, and orange-gray, fine-grained, micaceous sandstone and sandy shale. The lower part of the Fox Hills Sandstone is 150 ft thick and consists of fine- to medium-grained sandstone in thin to thick bedded, greenish-gray, orange-brown, micaceous, poorly sorted sandstone. The sandstone in the upper part of the section contains abundant dark chert grains (5 to 7 percent), light- to dark-brown phosphate pebbles, and large oval sandstone concretions as much as 12 to 18 in. in size. The Fox Hills Sandstone was deposited in an environment that was transitional between marine conditions, as represented by the Pierre Shale, and fluvial, lagoonal, and swampy environments, as represented by the Laramie Formation. Coarse sandstone beds in the lower part of the Fox Hills Sandstone were apparently deposited in either off-shore sand bars or beaches. Fine-grained deposits in the upper part of the Fox Hills Sandstone appear to represent deposits from wash-over-fans and lagoonal back-beach sand environments.

Kp

Pierre Shale (Upper Cretaceous) —Medium to dark gray to black shale beds containing rare thin beds of tan siltstone and beds of fine-grained sandstone. Commonly weathers to soft, friable clay with a distinct olive- to pea-green color. The formation contains abundant thin and discontinuous layers of bentonite that range from a few inches to as much as 8 in. thick. Scott and Cobban (1986) subdivided the formation into seven units and determined they were deposited from early Campanian to early Maastrichtian time on the basis of ammonites, clams, and oysters (see also Larson and others, 1997; Cobban and others, 1994). The thickness of the Pierre Shale in the Colorado Springs area exceeds 5,000 ft (Grose, 1961). In the Cascade quadrangle, the unit is faulted, eroded, and poorly exposed so that partial sections, perhaps totaling a thousand feet, underlie eastern parts of the quadrangle. Three of these units were recognized in the mapped area, in isolated, widely separated outcrops but were not mapped separately here. The upper unit (Scott and Cobban, 1986) is composed of sandy shale beds and fine-grained sandstone beds mapped in the Mount St. Francis area (sec. 3, T. 13 S., R. 67 W.). The gradational contact between this upper sandy shale and the overlying Fox Hills Sandstone is only moderately exposed in this area. The middle unit is a distinctive olive-green to pea-green weathered shale containing abundant bentonite layers from 3 to 5 in. thick. This unit makes up the bulk of the Pierre Shale exposures in the mapped area. Local, thin, steeply overturned calcareous shale layers of the middle unit were mapped just north and east of the Pikeview Quarry. The basal unit of Scott and Cobban (1986) consists of dark-gray to black, highly fractured shale beds containing thin bentonite layers that are less than two inches thick. It is exposed inside the Pikeview Quarry (NE 1/4 of sec. 4, T. 13 S., R. 67 W.) and in the Glen Eyrie area. The contact with the underlying Smoky Hill Shale Member of the Niobrara Formation is not exposed but is reported to be gradational and conformable (Thorson and others, 2001). The Pierre Shale correlates with the Mesaverde and Lewis Shales of western Colorado and Utah. The unit is considered to be of marine origin deposited in a shallow epicontinental sea. The shale and derived clasts typically possess a moderate to high shrink-swell potential and can cause heaving bedrock near the surface (Himmelreich and Noe, 1999). The Pierre Shale is susceptible to slope instability and landsliding on moderate to steep slopes. These characteristics make the formation very problematic as a foundation for buildings, roads, and housing developments throughout the eastern parts of the quadrangle.

Kn

Niobrara Formation (Upper Cretaceous) — Consists of two members of marine origin, the Smoky Hill Shale Member and the underlying Fort Hayes Limestone Member, which are not mapped separately here. Weathering characteristics between the two members of the Niobrara Formation are distinctive with the Fort Hayes Limestone Member commonly supporting a low hogback and the Smoky Hill Shale Member underlying valleys marked by soils containing light-gray and buff shale chips. Berman and others (1980) noted that in Colorado the contact of the Niobrara Formation with the overlying Pierre Shale is generally conformable and transitional from shaly chalk beds of the Smoky Hill Shale Member to slightly calcareous silty shale beds of the Pierre Shale. The Smoky Hill Shale Member is made up of soft, light- to dark-gray, yellowish-orange, and brown, thin-bedded and laminated, limey shale and local thin beds of slightly resistant, gray and white chalk and limestone, about 400 ft thick. The Fort Hayes Limestone Member consists of light- to medium-gray, well-bedded, fine-grained limestone approximately 100 ft thick. Inoceramus shells (pelecypod) are common in the Fort Hayes Limestone Member. Thin interbeds of light-gray shale form strong partings. Fish scales may be present in the chalk.

Kcgg

Carlile Shale, Greenhorn Limestone, and Graneros Shale, undivided (Upper Cretaceous) — Soft, poorly exposed marine units comprising the Carlile Shale, Greenhorn Limestone, and Graneros Shale, from top to bottom, respectively, were formerly called the Benton Group (Grose, 1961); however, Carroll and Crawford (2000) resurrected the name Colorado Group of Gilbert (1897). The Carlisle Shale is a black, thin-bedded shale that consists of several members only one of which, the Codell Member, is exposed in the mapped area. The Codell Member is a yellow-brown, bioturbated, calcareous sandstone bed, weathers to light tan, and may contain stringers of limonite and sharks teeth. The Carlisle Shale and the Codell Member reach a combined thickness of approximately 220 ft. Locally, the Codell Member and the Fort Hayes Member of the Niobrara Formation support a subdued hogback. The Greenhorn Limestone consists of thinly interbedded dark-gray shale and medium-gray, fossiliferous limestone beds. The unit forms light-gray to light-tan soils and commonly contains outcrops of dense, white-weathering limestone beds approximately two feet thick. Total thickness of the Greenhorn Limestone is approximately 50 ft. The Graneros Shale is composed of soft dark-gray to black shale beds containing several bentonite layers and thin tan and brown silt beds. It commonly weathers to small platy chips. Total thickness of the Graneros Shale is approximately 250 ft.

Kd

Dakota Sandstone (Lower Cretaceous) — Interbedded buff, yellow, and gray quartz sandstone and gray shale beds, approximately 160 ft thick. Thin-bedded sandstone and shale beds in the upper one-third of the unit give way to two medium- to massive-bedded resistant sandstones in the lower part of the unit. Upper shale beds are organic-rich to lignitic and alternate with thin beds of sandstone containing clay pellets, phosphatic nodules, and chert granules. The unit is interpreted as a shoreline regressive sequence (Weimer, 1970). The unit locally contains ironstone concretions. In the mapped area, the sandstones are steeply dipping and support a prominent, continuous hogback or double hogback. The hogback-supporting sandstones weather to a distinctive green-gold color. Deformation bands that are resistant to weathering (Davis, 1999) are common in the Dakota sandstone and define a fracture fabric that is apparent from some distance. Refractory clays have been mined from the Dakota Sandstone in sec. 22, T. 13 S., R. 67 W. (Himmelreich, 2000) and the cemented sandstone may have uses as riprap or building stone.

Kpu

Purgatoire Formation (Lower Cretaceous) — Consists of the Glencairn Shale Member and underlying Lytle Sandstone Member (Grose, 1961) not mapped separately here. The Glencairn Shale Member consists of dark shale and siltstone beds with thin brown sandstone beds and tan siltstone beds near the top. Thickness of the Glencairn Shale Member ranges from 25 to 45 ft. The Lytle Sandstone Member is composed of moderately resistant, white to light-gray, weakly cemented, massive, coarse-grained sandstone beds ranging in thickness from 40 to 80 ft. Conglomeratic sandstone beds containing black chert pebbles are diagnostic of the member, which correlates with the Cedar Mountain Formation in Utah (Cobban, 1987; Molenaar and others, 2002). The Glencairn Shale Member represents marine deposition with a transition to fluvial channel and overbank deposition in the Lytle Sandstone Member (Weimer, 1970).

Jmr

Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic) — The Morrison Formation consists of soft, variegated claystone and mudstone beds containing thin beds of marl, limestone, sandstone, and minor conglomerate. Cumulative thickness is approximately 300 ft. Variegated colors include pale green, red, purple, white, tan, and light gray. The underlying Ralston Creek Formation consists of mostly soft, thin-bedded, gray and red sandstone, siltstone, and shale. Massive gypsum beds within the Ralston Creek Formation range in thickness from 20 to 70 ft. The Ralston Creek Formation is approximately 80 ft thick. Both formations are continental in origin.

TRPl

Lykins Formation (Lower Triassic? and Upper Permian) — Soft to moderately resistant, thin-bedded, reddish-brown and light-tan, sandy siltstone and shale beds containing two or more prominent beds of light-gray to tan, stromatolitic dolostone beds (Broin, 1957; Grose, 1961). Thickness of the unit is approximately 120 ft. The carbonate beds exhibit a closely laminated texture indicative of algal mats from a shallow, hypersaline, marine environment.

Plu

Plm

Pll

Lyons Sandstone (Permian) — Three distinct units including an upper, white to red, moderately cemented, strongly cross-bedded sandstone bed (Plu); a middle unit (Plm) of crimson-red to white arkosic conglomerate and micaceous silty sandstone beds; and a lower massive red eolian sandstone (Pll) bed containing poorly defined large-scale crossbedding. The upper and lower ridge-forming units of well-sorted, fine-grained sandstone form the spectacular vertical fins in the Garden of the Gods Park in the southeastern corner of the Cascade quadrangle. The soft, easily erodable, middle member (Plm) forms an intervening strike valley. The middle member (Plm) is rarely exposed in the mapped area. The unit is of dune and stream origin (Noblett and others, 1987). Maximum thickness of the Lyons Sandstone reaches 700 ft in the Colorado Springs area (Grose, 1961). Representative thicknesses of upper and lower units of the Lyons Sandstone are approximately 150 ft in the mapped area; the middle unit is 100 ft thick or less in the mapped area. Due to faulting, the true stratigraphic thickness of the unit is not observed in the area of the Cascade quadrangle.

PIPf

Fountain Formation (Lower Permian and Pennsylvanian) — Red and white coarse-grained arkosic sandstone and pebble to boulder conglomerate beds (Suttner and others, 1984; Maples and Suttner, 1990). Maroon micaceous siltstone beds alternate with the medium- and thick-bedded conglomeratic sandstone beds. The thick-bedded arkosic sandstone and thin-bedded silty sandstone beds weather to form comparatively low, slabby to knobby hogbacks and, less commonly, thin strike ridges and spires. Subangular to subrounded conglomerate clasts include predominantly quartz granules, microcline, vein quartz, and polycrystalline granite. Suttner (1989) interpreted the Fountain Formation as a marine delta and nonmarine (subaerial) alluvial-fan system deposited eastward off the Frontrangia uplift of the "Ancestral Rockies," bounded by the ancestral Ute Pass fault zone (Kluth, 1997). The formation is 4,000 ft thick (Suttner, 1989, and references therein) at its type locality (Cross, 1894) along Fountain Creek in the Colorado Springs area.

PIPfg **Glen Eyrie Member of the Fountain Formation (Lower Pennsylvanian) —** Black to steel-gray shale containing lesser volumes of varicolored blue-green to purple shale and orange-buff sandstone beds. Echinoderm fossil fragments indicate an Early Pennsylvanian or possibly Mississippian age (crinoids and Archaeocidaris dininnii; Chronic and Williams, 1978). Sandstone beds are typically less than three feet thick and are interbedded with shale; however, one fine-grained, well-sorted white sandstone sequence in the Cedar Heights and Snyder Quarry areas reaches approximately 15 ft in thickness. The sandstone beds weather to an orange-red color and provide a useful marker for determining structural discontinuity. Suttner (1989) interpreted the Glen Eyrie as transitional from marine deposition to non-marine deposition. The Glen Eyrie shales form a substrate of low strength, prone to slope instability and landsliding. Some of the shales and derived clay soils also possess a high-shrink swell potential. The maximum thickness of the unit is 360 ft (Grose, 1961).

MDlh **Hardscrabble Limestone Member of the Leadville Limestone and the Williams Canyon Formation, undivided (Devonian and Mississippian) —** Tan to gray, sandy dolomitic limestone beds of the Hardscrabble Limestone Member, underlain by buff-gray to red and lavender, thin-bedded, sandy limestone and dolomite beds of the Williams Canyon Formation. The contact between the two units is a disconformity (Grose, 1961). The Hardscrabble Limestone Member consists of well-indurated karst breccia in the upper part that is underlain by massive-bedded carbonate beds in the lower part. The lower sequence is sandy, cherty, or oolitic. Thickness ranges widely but does not exceed 100 ft. The Hardscrabble Limestone Member correlates with the Madison Limestone (Maher, 1950). The Williams Canyon Formation type locality (Brainerd and others, 1933) is located in the southernmost part of the mapped area in Williams Canyon. It is distinguished by its thin bedding and bright color. The unit is approximately 30 ft thick. Minor constituents are shale, sandstone, and siltstone. The Hardscrabble Limestone Member and Williams Canyon Formation were probably deposited in shallow marine and near shore environments (Conley, 1972).

Om **Manitou Limestone (Lower Ordovician) —** Consists of fine-grained dolostone and limestone beds of marine origin. The unit is resistant, pinkish gray to tan, and thin- to medium-bedded, with approximately 40 ft of cliff-forming, medium-bedded dolostone beds overlying 145 ft of thin, wavy bedded to medium-bedded carbonate beds. The type locality (Brainerd and others, 1933) lies immediately south of the southern boundary of the Cascade quadrangle, in the Manitou Springs quadrangle. The unit rests in angular unconformity on the Sawatch Sandstone (Myrow and others, 1999).

€s **Sawatch Sandstone, undivided (Upper Cambrian) —** Fine-grained, deep purple and green, 45 ft thick, glauconitic, dolomitic sandstone beds, locally cross-bedded and bioturbated, that are underlain by a lower, resistant, white to light-gray-green, medium to coarse-grained, 15 ft thick, conglomeratic arkosic sandstone bed. Unit is exposed between Queens Canyon and Williams Canyon in the southern Rampart Range. The glauconitic member is identified as the middle Sawatch Sandstone by correlation with a unit in the Sawatch Range that contains Upper Cambrian trilobite fossils (Myrow and others, 1999). Long-wavelength, low-amplitude dunes reflect deposition of the middle Sawatch by tidal currents (Myrow and others, 1999). Tectonically disrupted sandstones tentatively identified as Sawatch Sandstone exist within a fault-bounded panel in one location in the mapped area, along an eastern fault of the Rampart Range fault zone on the southwestern side of the Pikeview Quarry.

Similar relationships were reported outside the quadrangle along the Ute Pass fault zone (see also Trimble and Machette, 1979). The arkosic sandstones are unsorted or poorly sorted and have mottled maroon and white coloration. Fault-bounded blocks of the Sawatch Sandstone within Precambrian crystalline bedrock slopes were mapped by Rowley and others (2002) at several places along the Ute Pass fault zone in the Cheyenne Mountain quadrangle. In some other parts of the Front Range, such subvertical beds of sandstone have been interpreted as clastic dikes of Sawatch Sandstone (Harms, 1965; Kupfer and others, 1968).

Ym **Mafic dikes (Middle Proterozoic) —** Medium-gray to dark-gray, fine- to locally medium-grained dikes that intrude granitic rocks of the Pikes Peak batholith. Dikes are commonly linear and have planar contacts but may also form irregular, discontinuous masses and pods in a web-like pattern. Dikes are generally 3 to 20 ft in width, and most have steep dips. Mafic dikes are concentrated in the southwestern part of the mapped area where they intrude Pikes Peak Granite and Windy Point Granite. Detailed geochemical studies by Smith and others (1999) show that the dikes vary in composition and include lamprophyre, diabase, and quartz diorite.

Ywp **Windy Point Granite (Middle Proterozoic) —** Resistant, red and pink, fine- to coarse-grained granitic and quartz monzonitic intrusions. These intrusions have the form of dikes, sills, and irregularly shaped plugs that intrude the Pikes Peak Granite in a north-trending belt that occupies the central to eastern part of the mapped area. Sills are mapped mostly along the eastern side of the mapped area; perhaps they represent upper parts of the Windy Point intrusive complex that has been downthrown along younger faults concentrated on the eastern side of the quadrangle. The unit is classified as granite according to the IUGS classification (Le Bas and Streckeisin, 1991). On the basis of thin section petrography, the map unit is characterized by porphyritic textures in which red microcline phenocrysts as long as 1.2 in. make up as much as 40 percent of rock volume and rest in a red, fine- to medium-grained matrix of microcline, subordinate but abundant quartz, moderate to low plagioclase, low biotite, and 1 to 5 percent hornblende. The biotite is generally much more abundant than in the Pikes Peak Granite and commonly occurs as clots as large as 0.5 in. The quartz appears in hand specimen to be less abundant than in the Pikes Peak Granite because the crystals are smaller. A significant accessory mineral is fluorite. Generally, the microcline phenocrysts stand out in relief on weathered surfaces, creating a “knobby” appearance. Windy Point Granite is generally more resistant than Pikes Peak Granite so that in most places it defines ridges or peaks, although in some places it occupies valleys between ridges of Pikes Peak Granite. The unit was referred to as porphyritic granite by Grose and Heinrich (1965). It was named and described over a large area of the Pikes Peak batholith by Wobus (1976), who suggested that the Windy Point Granite is a potassic late-stage variant of the Pikes Peak Granite. Petrology of the igneous systems are summarized by Smith and others (1999). The unit was mapped in reconnaissance in the Cascade quadrangle and other areas by Scott and Wobus (1973) and mapped in detail in the adjacent Manitou Springs quadrangle by Keller and others (2003). The intrusive contacts of most bodies are gradational over at least 100 ft, such that fine-grained and phenocryst-poor phases of Windy Point Granite generally are in the interior parts of their intrusive bodies. The Pikes Peak Granite commonly is mildly hydrothermally altered (propylitic grade or less) along intrusive contacts with the Windy Point. The gradational nature of the contacts suggests that intrusion of the Windy Point Granite took place while the Pikes Peak Granite was still a crystal mush. Some of the few dike outcrops within the Windy Point Granite where the high-angle contact is sharp reveal subparallel hornblende phenocrysts as long as one inch, oriented parallel to the intrusive contact. Dikes of Windy Point Granite too small to be mapped are commonly exposed within the main Windy Point outcrop belt; these generally have sharp contacts with the Pikes Peak Granite. Most of these small (less than 10 ft wide) dikes are fine grained and superficially resemble aplites of the Pikes Peak Granite except that they are coarser grained (crystals in the Windy Point Granite are rarely less than 0.08 in. across), significantly higher in ferromagnesian minerals, and significantly lower in quartz. Like the aplites, however, the strikes of these narrow dikes generally parallel the dominant joint direction, which regionally is northeast to east-northeast, with a subordinate direction of north-northwest. This suggests that the regional joint directions are Middle Proterozoic and may have been young enough to control emplacement of Pikes Peak Granite aplites and Windy Point dikes. Wobus (1976), however, suggested control on the emplacement of Windy Point dikes by prevailing northwest-striking Precambrian faults.

Ypp

Pikes Peak Granite (Middle Proterozoic) — Resistant, red, pink, and locally pinkish-gray and greenish-gray, coarse-grained granite intrusions. Classified as granite according to the IUGS classification (LeBas and Streckeisen, 1991). On the basis of thin section petrography, the unit is characterized by generally equigranular but locally porphyritic textures made up mostly of microcline crystals, commonly about 1 in. long, subordinate quartz, moderate plagioclase, low hornblende, and low (about 3 percent) amounts of biotite. The rock is part of the Pikes Peak batholith, a huge anorogenic plutonic mass that is accompanied by several late-stage alkalic phases from several intrusive centers (Barker and others, 1975; Wobus, 1976; Smith and others, 1999). Some of these centers are bounded by all or parts of large oval- to circular-shaped ring faults and dikes (Wobus, 1976; Scott and others, 1978), perhaps the deep expression of calderas that have long been eroded away. One of these late-stage alkalic phases is the Windy Point Granite, well exposed in the mapped area. It and other late-stage phases are also well exposed in the adjacent Manitou Springs quadrangle (Keller and others, 2003). The Pikes Peak Granite has sharp intrusive contacts, as opposed to older intrusive masses. The map unit includes uncommon aplite dikes, quartz veins, and pegmatite dikes and sills. Most aplites, dikes, and quartz veins are less than a foot across and dip at high angles, although most pegmatite bodies dip at low angles. Aplite dikes strike parallel to the dominant joints in the area, which generally strike northeast to east-northeast, with a subordinate trend at north-northwest. Dozens of small exploration pits and shafts and occasional adits were placed in the quartz veins and pegmatites aimed at extracting gold or quartz crystals, but gold was rarely found. Several dark-gray, generally altered andesitic (lamprophyre) dikes less than 5 ft across were noted during field work, and these also have been explored for metals con-tained in sulfides. Two andesites examined in thin section are porphyritic with an aphantic groundmass made up mostly of plagioclase, with high to moderate pyroxene, hornblende, and biotite. The Pikes Peak Granite commonly weathers to grus, especially on north-facing slopes; deeper weathering, through processess described by Blair (1976), can result in a residuum cover as much as 150 ft thick (Blair, 1976; Moore and others, 2002). The age of the Pikes Peak Granite is about 1.08 to 1.02 Ga (Bickford and others, 1989; Smith and others, 1999).

Xgn

Migmatitic gneiss (Early Proterozoic) — Potassium feldspar-biotite migmatite, quartzose gneiss, biotite schist, and amphibolite gneiss that are intruded by the Pikes Peak Granite. Sillimanite and garnet are locally present in the biotite gneiss. Gneiss forms an extensive area of outcrop between Queens and Williams Canyons in the southern Rampart Range; it is sharply intruded by the Pikes Peak Granite. Thin panels of the gneiss also occur as xenoliths and pendants within the Pikes Peak Granite at Queens Canyon. The migmatitic gneiss is part of a large belt of metamorphosed sedimentary and volcanic rocks that underwent deformation as they were added to the southern edge of the Archean Wyoming craton along a convergent margin between 1.66 and 1.79 Ga (Reed and others, 1987). The original sedimentary and volcanic protoliths are interpreted to be products of arc magmatism (Reed and others, 1987). The gneiss has been previously identified as Idaho Springs Formation (Grose, 1961 however, recent work on amphibolite gneiss in the southern Front Range (Folley and Wobus, 1997) suggests that gneiss in the vicinity of Pikes Peak to the south are tectonically distinct from gneiss in the Idaho Springs locality, further north. Aeromagnetic anomalies (Oshetski and Kucks, 2000) over the bedrock offer a general means of distinguishing gneiss from granitoids in areas of dense vegetation or in the subsurface.

STRUCTURAL GEOLOGY

Two major fault zones transect the Cascade quadrangle. These are the northwest-striking Ute Pass fault zone in the southwestern part of the quadrangle, and the generally north-striking Rampart Range fault zone along the eastern edge of the map area. High-angle, north-northwest- to north-northeast-striking faults are abundant within the Precambrian units of the Rampart Range. Some of these high-angle faults are subparallel to and associated with the major fault zones. The Fountain Creek drainage (a conduit for part of the Colorado Springs culinary water supply) and State Highway 24 follows the Ute Pass fault zone. North-south-trending hogback ridges and strike valleys were eroded upon steeply dipping strata in the downthrown block east of the Rampart Range fault zone. The U.S. Air Force Academy lies along the Rampart Range fault zone, as do many of the new housing subdivisions.

UTE PASS FAULT ZONE

The Ute Pass fault zone strikes northwest across the southwestern part of the Cascade quadrangle with a linear trace that suggests a near-vertical attitude. Precambrian Pikes Peak Granite forms the bedrock on both sides of the fault, with no distinct geological markers to indicate magnitude and sense of fault displacement. To the south and north in adjoining quadrangles, the geometry of the Ute Pass fault zone differs. To the south, the Ute Pass fault zone corresponds to a broad north-striking zone of high-angle reverse faults that forms the frontal structure of the southern Front Range (Kupfer and others, 1968; Carroll and Crawford, 2000; Rowley and others, 2002; Keller and others, 2003). The faults dip to the west and are downthrown on the east. Near Fountain Creek, the strike of the fault changes to northwest and it cuts into and across the Front Range, through the southwestern corner of the Cascade quadrangle. The Rampart Range fault zone arises at this latitude and is the principal bounding structure separating the Front Range from the Denver Basin in the Cascade quadrangle.

Several miles to the northwest, along its trace in the adjoining Woodland Park quadrangle, the Ute Pass fault zone returns to a northerly trend, passing through the town of Woodland Park. The Ute Pass fault zone forms the west side of the Woodland Park graben and continues north of the town for more than 10 mi (Scott and others, 1978; Epis and others, 1980; Dickson and others, 1986). The segments of the Ute Pass fault zone are variously interpreted as reverse (Carroll and Crawford, 2000; Rowley and others, 2002), thrust (Keller and others, 2003), strike slip (Kupfer and others, 1968; Epis and others, 1980), and normal (Epis and others, 1980). The disparate senses of motion may reflect reactivation of Precambrian faults during later tectonic events.

Because units as young as Late Cretaceous are involved in the footwall of the Ute Pass fault zone (Rowley and others, 2002; Keller and others, 2003), it is evident that the Ute Pass fault zone has an important Laramide history (Late Cretaceous to early Cenozoic). Because a Pennsylvanian depocenter for the orogenic sediments of the Fountain Formation exists immediately adjacent to the Ute Pass fault zone, an earlier phase of fault activity is interpreted to have occurred during uplift of the Ancestral Rocky Mountains in Pennsylvanian time (Kluth, 1997). Boulder-sized clasts derived from a local Precambrian rock source of the “Frontrangia” uplift exist in fan deposits of the Fountain Formation (Suttner and others, 1984).

The post-Laramide Tertiary history of the Ute Pass fault zone is evident at Woodland Park, where red basin-fill sediments were deposited in grabens bounded by the Ute Pass fault zone and other parallel faults. At Woodland Park the widespread erosion surface that caps the Rampart Range (Epis and Chapin, 1975) is cut and displaced by Tertiary faults, creating the Woodland Park graben (Steven and others, 1997). The age of this erosion surface has been established as late Eocene or early Oligocene (Epis and others, 1975; Trimble, 1980) because Tertiary volcanic rocks locally rest upon the surface. The oldest of these volcanic rocks is the 36.6 Ma Wall Mountain Tuff

(Leonard and others, 2002); therefore, the movement on the graben-forming faults postdates 36.6 Ma. The Tertiary gravel of the Cascade quadrangle probably also represents a late Tertiary deposit on the erosion surface. In the Woodland Park quadrangle, similar gravels are down-dropped 1,100 ft across a graben-bounding fault, which led Steven and others (1997) to interpret the timing of Tertiary normal faulting to be middle Miocene to Pliocene. Epis and others (1980) interpreted the Ute Pass fault zone and associated faults to be Precambrian and Cretaceous structures that were reactivated in the early Miocene as extensional block faults. The fault zone could have initiated during the Ancestral Rockies event or earlier, for example in Late Proterozoic time (e.g., Marshak and others, 2000; Kluth, 1997).

RAMPART RANGE FAULT ZONE

The Rampart Range fault zone is a north-striking, high-angle reverse fault that places upthrown Precambrian igneous and metamorphic rocks on the west against downthrown Paleozoic and Mesozoic sedimentary rocks to the east, along most of its trace through the Cascade quadrangle. Rugged mountain topography formed on resistant crystalline rocks in the upthrown block averages 9,000 ft in elevation. On the downthrown side, soft clastic and carbonate strata form hogbacks and strike valleys at an average elevation of 6,500 ft. Erosion has removed the sedimentary cover from the upthrown Precambrian block, except at the southernmost part of the Rampart Range. Near Highway 24, the Rampart Range fault zone is within Pennsylvanian Fountain Formation and cuts up section northward into the upper Lyons Formation in the Garden of the Gods Park. Along a portion of the fault in the Garden of the Gods Park, the fault juxtaposes Fountain Formation on the west with Cretaceous Dakota Formation on the east. However, along much of its length in the mapped area, the fault juxtaposes Precambrian granite on the west against Fountain Formation on the east. A parallel fault or faults places Fountain Formation against Cretaceous units, cutting out the intervening strata.

The Paleozoic strata provide a structural marker for estimation of structural offset on the Rampart Range fault zone. At the Glen Eyrie estate, the basement nonconformity, the Cambrian Sawatch Sandstone, and the Ordovician Manitou Limestone on the west are in tectonic contact with upper Fountain Formation and Lyons Sandstone on the east. Structural throw is approximately 4,300 ft, using representative thicknesses (including 4,000 ft for the Fountain Formation) from the nearby, uninterrupted stratigraphic sequence above the basement nonconformity. The fault gains throw to the north and, in the northern part of the mapped area, Pikes Peak Granite of the upthrown Rampart Range block is juxtaposed against the Upper Cretaceous and Paleocene Dawson Formation. This suggests a structural displacement in excess of 12,000 ft.

One measurable exposure of the Rampart Range fault zone was identified during our study. In the western half of sec. 28 of T. 12 S., R. 67 W., the fault is exposed in a spectacular brecciated outcrop of Precambrian granite, on the northern side of the electrical generating plant of the McCullough Water Treatment Center on U.S. Air Force Academy grounds. At this location, the fault strikes 10º and dips 74º to the west. The geometry of the downthrown sedimentary strata to the east, including the Cretaceous Niobrara and Pierre Shale Formations, suggest a monoclinal fold slightly overturned to the east, consistent with a steep westerly fault dip (cross section A-A').

Further information on fault attitude comes from the northern edge of Queens Canyon Quarry, where subsidiary faults (possibly splays off the major structure) offset the Great Unconformity and the basal Sawatch Sandstone from 3 to 10 ft, across fault planes striking 176º and dipping 50º to the west. The fault slickenlines plunge 34º and trend 325º, and together with offset bedding indicate left oblique reverse.

A dominant structural feature of the eastern part of the Cascade quadrangle is near vertical to overturned Paleozoic and Mesozoic sedimentary strata forming hogbacks that strike north-south on the downthrown side of the Rampart Range fault zone. Bedding strikes are within a few degrees of due north along most of the range front, with local variations to north-northeast and north-northwest. Bedding dips are very consistent; for example, bedding in the continuous hogback ridges of Dakota Sandstone consistently dips 75º to 80º to the east. The greatest map width of steeply inclined strata is near Mount St. Francis, where the Laramie Formation more than 1 mi away from the Rampart Range fault dips at 80º to the east. Consistently overturned beds in the Niobrara Formation and Pierre Shale occur along a strike distance of 5 mi between the Glen Eyrie estate and the McCullough Water Treatment Center to the north.

A straightforward interpretation of the structural relationships is that the vertical to overturned bedding dips developed by rotation of bedding in the downthrown block of a fold-thrust system (cross section A-A'). During initial stages of tectonic uplift of the western upthrown block along this fault, the sedimentary cover conformed to the underlying crystalline basement geometry by folding. With continued fault movement of the basement fault, the master fault propogated up into the cover rocks, and sedimentary strata were faulted and downthrown in the footwall of the basement block (Mitra and Mount, 1998). This style of deformation and development of "forced fold" fault-propagation monoclines has been described throughout the Rocky Mountain Foreland Province by Berg (1962), Stearns (1971, 1978), and Brown (1984), where the vertical component of fault movement exceeds lateral translation. In cross section A-A', overturned bedding attitudes in the downthrown block result from the rotation of strata in the downthrown footwall block. A splay fault (the easternmost fault in the cross section A-A') interpreted to have a westerly dip, truncates bedding at a high angle.

The fault relationships along cross section B-B', reflect the propagation of faults from the basement into the cover rocks. Extensive bedrock exposures reveal a complex pattern of close-spaced minor faults in the footwall of the range-bounding fault. These faults are mapped in the southeast corner of the quadrangle, corresponding to Garden of the Gods Park, and are well-exposed due to post-glacial erosional stripping of Quaternary gravels (Qg_2). Offset bedding in clear fault exposures indicates that the minor faults are upthrown to the west, with a sense of offset opposite to that on the Rampart Range fault[1] . The minor fault geometries and sense of offset provide a record of deformation within the steeply inclined middle limb of the monoclinal fold developed in cover rocks of the Rampart Range. An interpretation of the fault complexities is provided in the following section.

In the footwall of the Rampart Range fault, several secondary, northwest-striking faults cut the steeply dipping Phanerozoic strata in the footwall of the Rampart Range fault zone. One of these faults, trending southeastward from the Pikeview Quarry, separates the Paleozoic to Middle Cretaceous hogback ridges from the more subdued topography resulting from the Pierre Shale to the north. A second northwest-trending fault farther to the north is concealed beneath the McCullough Water Treatment Center. This fault is interpreted to continue southeastward to separate the anomalous vertical dips of the Laramie Formation from the shallow easterly dips of the Dawson Formation 0.25 mi to the north.

Possible evidence for drag folding consistent with a sinistral component of slip along one fault exists near the Mountain Shadows subdivision (NE¼ of sec. 22 of T. 13 S., R. 67 W.; SE¼ of sec. 15 of T. 13 S., R. 67 W.). There, the strike of the Codell Sandstone Member of the Carlile Shale changes from north to northwest with approach to the fault. The southernmost splay of this fault in sec. 22 of T. 13 S., R. 67 W. was exposed while excavating a foundation through landslide material as reported by Himmelreich (written communic., 1987) and recorded in photographs that reveal the fault dipping steeply to the west, cutting the Carlile Shale and creating spectacular drag folds.

The geometry of bedding adjacent to the fault

[1] In this discussion, the term "Rampart Range fault" refers to the fault located just east of the "Colorado Springs corporate boundary" indicated on the quadrangle. The term "Rampart Range fault zone" used elsewhere in this booklet refers to that structure plus associated secondary faults along the eastern edge of the quadrangle.

in the Mountain Shadows subdivision resembles the geometry of a fold in mostly unfaulted strata in the Cretaceous Niobrara through Dakota Sandstone at the western end of Garden of the Gods Road (west of the MCI business facility in SW1/4, SE1/4 of sec. 22, T. 13 S., R. 67 W.). At this location, steeply dipping beds strike north in throughgoing hogback ridges, then over a short distance, abruptly change to a northwest strike and assume overturned westerly dips. The measured attitudes define a mesoscopic-scale "S"-fold when seen in plan view (Fig. 2). The similarity in geometry of folds adjacent to faults with folds suggests that the faults formed locally in response to a north-south buckling of footwall strata. Alternatively, the northwest-striking faults are splays that make part of the Rampart Range fault zone.

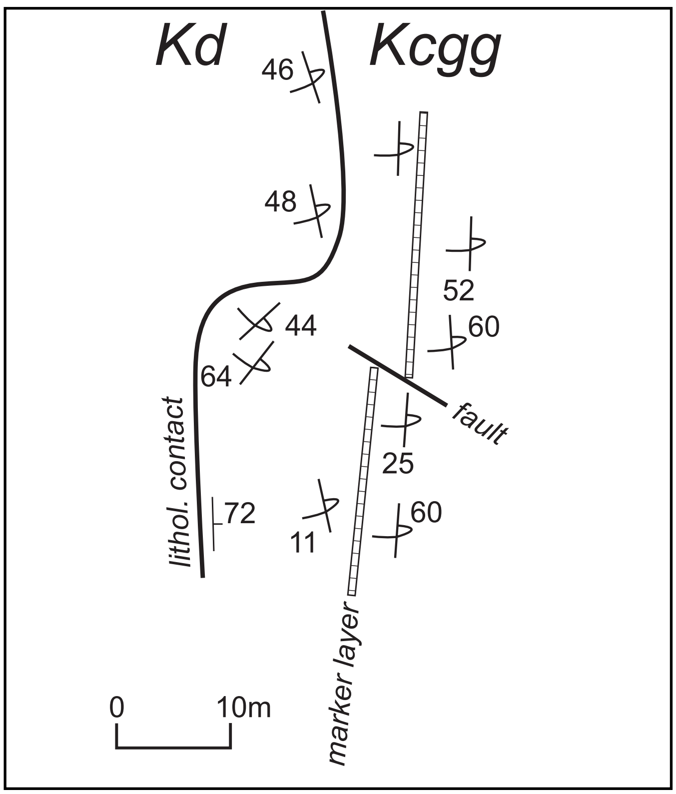


Figure 2. Overturned beds and a tight fold of the Kd-Kcgg contact, which is unbroken by a fault. A thin carbonate marker layer to the east is broken by a small fault and bedding orientations here are irregular in the surrounding shale beds. The absence of faulting along the contact suggests that here the shale beds behaved plastically.

GARDEN OF THE GODS PARK AND GLEN EYRIE

The dramatic landforms contained within Garden of the Gods Park and the Glen Eyrie estate are colorful fins and spires of vertically inclined, Upper Paleozoic sandstones. The superb bedrock exposures in these locations show that brittle deformation pervades the rock within the footwall of the Rampart Range fault. Minor faults, shear fractures, joints and veins affect the competent sandstone units of Upper Paleozoic and Cretaceous age. A complex fault mosaic developed at the interface between Upper Paleozoic massive competent sandstones and the Mesozoic sequence dominated by incompetent shales and siltstones. This section of the booklet discusses the brittle deformation features in Garden of the Gods Park and Glen Eyrie, corresponding to approximately 1 sq mi area in the southeastern Cascade quadrangle. Cross section B-B' and Figure 3 portray the fault relationships. The structural complexities offer important insights about structural relationships that are concealed by extensive Quaternary deposits farther north along the Rampart Range fault.

The Cascade quadrangle shows only a portion of the structures in Garden of the Gods Park. The faults and fault-bounded panels within the Garden of the Gods Park (Fig. 3) continue on to adjoining geologic maps, specifically, the Pikeview (Thorson and others, 2001), Colorado Springs (Carroll and Crawford, 2000), and Manitou Springs (Keller and others, 2003) quadrangles. Finlay (1916) and Grose (1961) produced structural maps of Garden of the Gods Park, and their findings were incorporated in a regional map by Trimble and Machette (1979). Wilcox (1952) completed a masters thesis on the faults in the Garden of the Gods Park. Siddoway and others (1999) conducted kinematic analyses of the profuse brittle structures.

In Garden of the Gods Park, the Rampart Range fault juxtaposes gently to steeply east-dipping (27° to 78°) strata of the Fountain Formation on the west, up to the east over steeply dipping beds of Pennsylvanian through Cretaceous rocks. Hanging wall strata strike northeast and dip gently southeast to form a

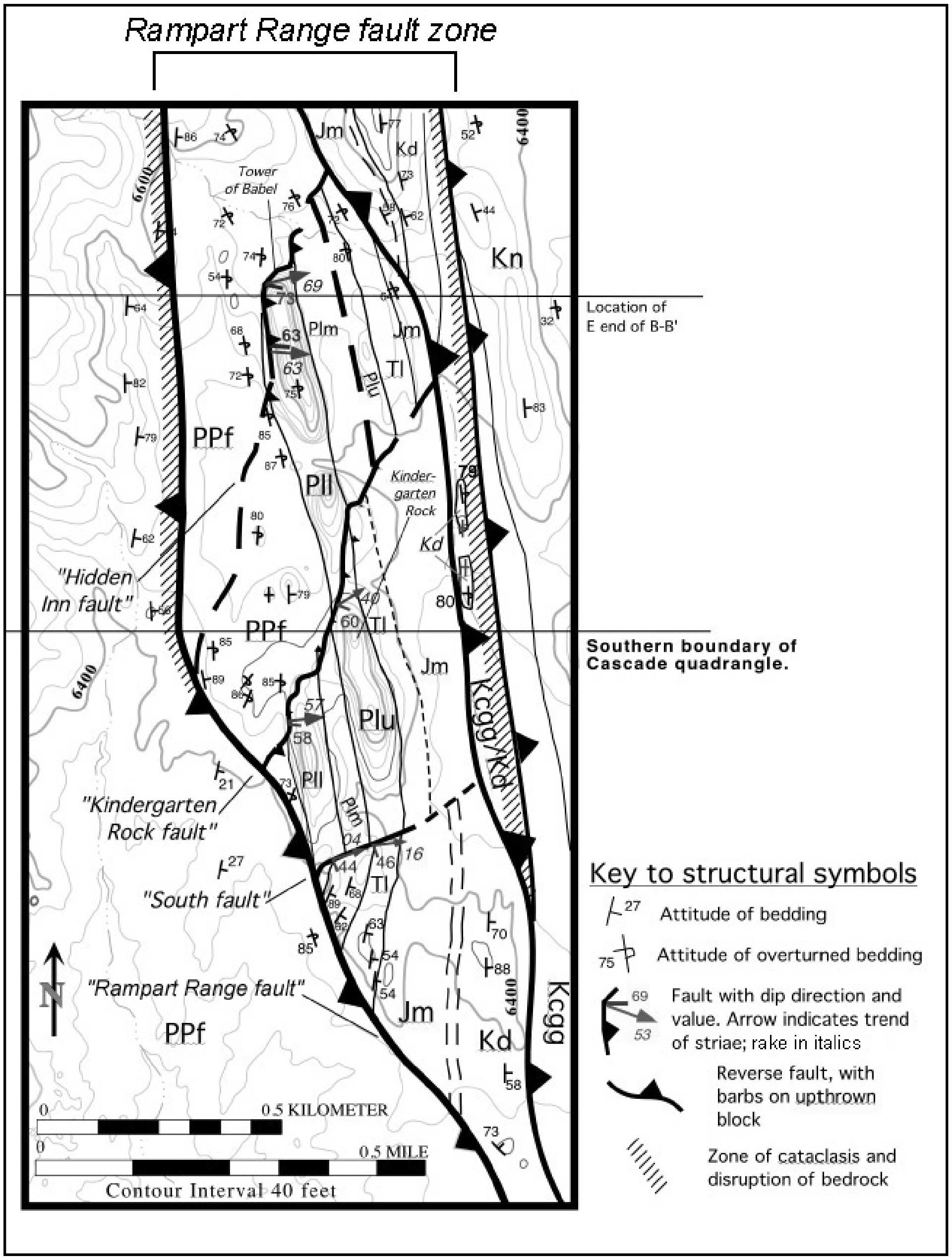


Figure 3. Simplified structural map of Garden of the Gods Park. The complex fault pattern developed at the interface between upper Paleozoic massive competent sandstones and the Mesozoic sequence dominated by incompetent shales and siltstones. The figure provides structural data on secondary faults and bedding attitudes that could not be provided at the 1:24,000 scale of the quadrangle map. The figure portrays structures that are continuous onto adjoining quadrangles (four quadrangle corners meet within the boundaries of Garden of the Gods Park). Informal names for faults and rock formations in Garden of the Gods Park are indicated by leader lines. Surficial units are not shown.

homocline on the south end of the Rampart Range (see quadrangle map and cross section B-B'). Bedding dips steepen very close to the Rampart Range fault (within 500 ft of the fault). Along 1 mi of its length in Garden of the Gods Park and Glen Eyrie, upright Fountain Formation in the hanging wall is faulted against overturned Fountain Formation in the footwall. A zone of brittle cataclasis and shearing, corresponding to the Rampart Range fault, separates the upright from the overturned beds. The width of this zone locally exceeds 10 ft along the Garden of the Gods Park loop road, northwest of Gateway Rock (Fig. 3).

Although the main fault is not exposed, it is interpreted to strike north and dip moderately to the west on the basis of the north-south trace of the fault in the quadrangle and the west-side-up juxtaposition of Proterozoic against younger units along the fault. Three secondary, moderately dipping faults cut vertical to overturned Fountain Formation in the footwall of the Rampart Range fault (see also Trimble and Machette, 1979; Grose, 1961; Finlay, 1916). From north to south they are the Hidden Inn fault, Kindergarten Rock fault, and the South fault

(Fig. 3). The secondary faults cut vertical to overturned footwall strata and offset bedding shows that the faults have east-side-up offset. Fault slickensides have east-plunging slickenlines. These secondary faults strike northeast and dip from 44° to 73° southeast, in contrast to the north-striking, west dipping Rampart Range fault (Fig. 3). Their attitudes vary along strike. For example, slickensides along the Hidden Inn fault vary from a strike of 14° and a dip of 60° southeast to strike of 88° and a dip of 88° south, then back to 14° strike over a distance less than 40 ft. This relationship creates a step-like map pattern (Fig. 3) and suggests that segments of the faults are curviplanar, possibly due to the influence of alternating competent sandstones and incompetent siltstones. Indeed, the secondary faults developed at or near the stratigraphic boundary between competent Paleozoic sandstones (Fountain Formation plus Lyons Sandstone) and incompetent, thinly-bedded Mesozoic siltstone and shale units.

Using offset bedding as a marker and slickenlines for the fault slipline, the offsets on the faults measures tens to hundreds of feet of displacement across slickensided fault surfaces. Among the secondary faults, the amount of fault displacement decreases from east to west. The easternmost fault ("South fault" on Fig. 3) cuts out the Dakota-Purgatoire units, juxtaposing the Carlisle-Graneros-Greenhorn map unit, against the Morrison Formation. The Kindergarten Rock fault juxtaposes upper Lyons against lower Lyons. The westernmost fault (Hidden Inn fault (Wilcox, 1952) or Tower of Babel[2] fault) juxtaposes vertical lower Lyons Formation against overturned beds of the upper Fountain Formation. A decrease in fault offset from east to west suggests that the faults propagated toward the west (e.g. Twiss and Moores, 1992, p. 106-108). The secondary faults do not cross the trace of the Rampart Range fault zone and are confined to its footwall.

The observation that the secondary reverse faults juxtapose younger upon older stratigraphic units contrasts with the expected, older-upon-younger relationship for reverse faults (Twiss and Moores, 1992, p. 96). Because bedding has vertical dips and the faults dip east to southeast, the east-side-up motion created an older-on-younger relationship.

Brittle deformation at yet smaller scale than the three secondary faults affected the Fountain, Lyons, and Dakota Formations in the Garden of the Gods Park and Glen Eyrie. Joints, veins, and fractures pervade the rock, closely spaced at 0.5 to 5 inches. Veins contain calcite and accommodated opening perpendicular or oblique to the vein margins. Veins are best developed in the Lyons and Dakota Sandstones and are rare in the Fountain Formation. Shear fractures are small-scale faults marked by robust to delicate slickenside surfaces, best developed in the Lyons and Fountain Formations. The shear fractures dip moderately to west and east (forming a conjugate array in some outcrops), and accommodated reverse offset of a few inches or less (Siddoway and others, 1999; Moore, 1996). Kinematic analysis of the fault (Fig. 4A) and shear-fracture arrays indicates that the structures formed in response to east-west shortening (Siddoway and others, 1999), consistent with Laramide contraction along the Front Range and in southern Colorado during Late Cretaceous time (Erslev, in press). The involvement of Cretaceous rock units in the deformation indicates that the timing of deformation is Cretaceous or younger.

Evidence of plastic deformation and ductile behavior exists in incompetent units in Garden of the Gods Park and Glen Eyrie. The map units include the middle Lyons, Lykins, Morrison, and Carlisle-Graneros-Greenhorn Formations. Variations in map thickness along strike suggest ductile flow of material in response to deformation (e.g., Morrison Formation). Outcrop-scale observations of ductile behavior include:

[2] "Tower of Babel" is the Park terminology for the rock spire at the north end of the Garden of the Gods Park, in the hanging wall of the fault. "Kindergarten Rock" is another informal placename in the Park.

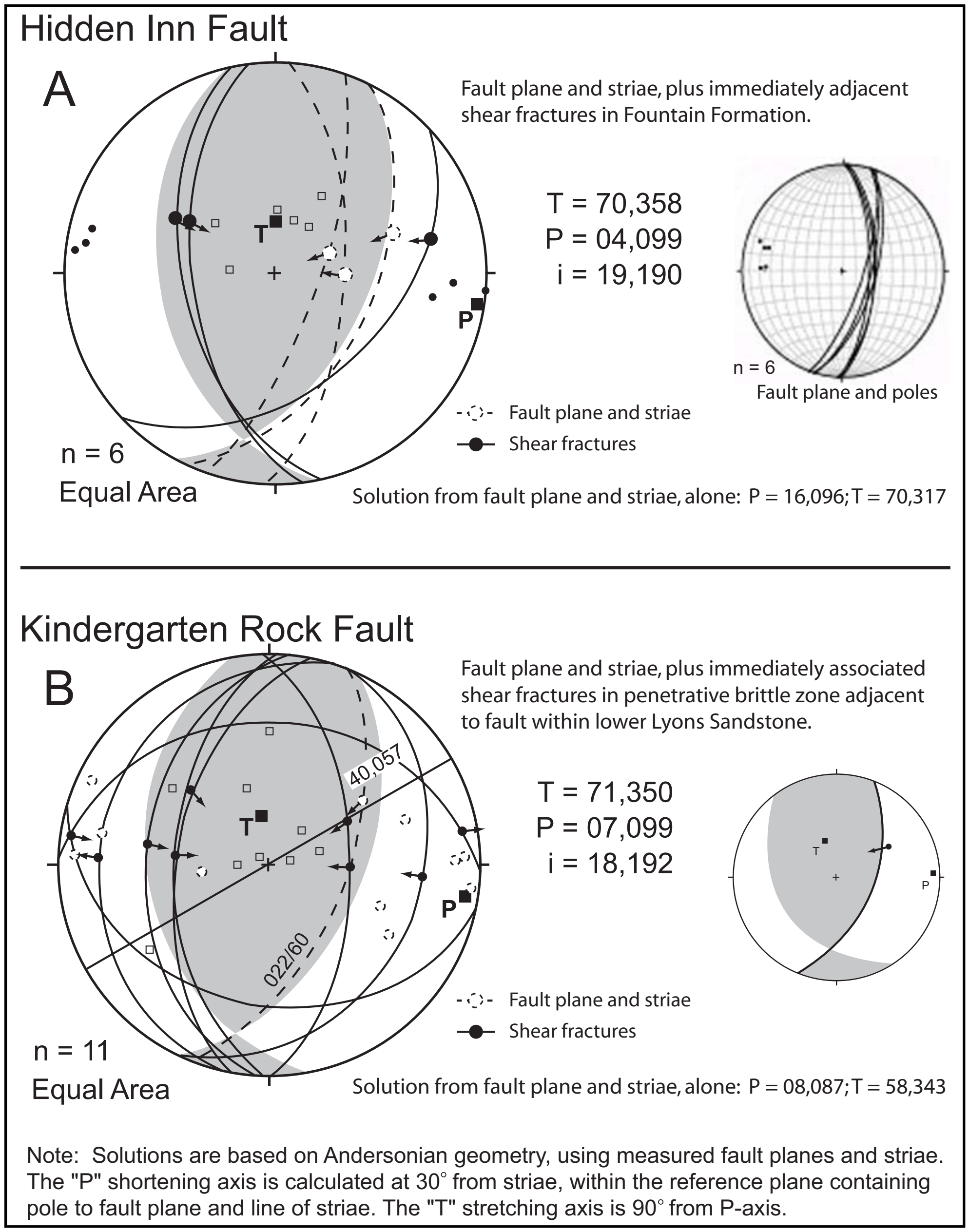


Figure 4. Kinematic solutions for the Hidden Inn and Kindergarten Rock faults in Garden of the Gods Park.

pinching and thickening of shale beds, boudinage of interstratified thin sandstone layers, facoidal-shaped lozenges suggestive of bedding-parallel shear, and tight intraformational folds at the scale of 5 to 15 ft wavelength. Poor exposures of the soft-weathering units in well-vegetated strike valleys, however, prevented detailed analysis of this deformation style.

INTERPRETATION

The primary structural relationship in Garden of the Gods Park is the older-upon-younger juxtaposition along the Rampart Range fault of gently to moderately steeply southeast-dipping Fountain Formation in the upthrown western fault block upon vertical to overturned younger units in the eastern footwall block. The fault does not crop out in Garden of the Gods Park and Glen Eyrie, however, the fault plane exposed at the McCullough Water Treatment Center strikes 170° and dips 74° to the west. Footwall strata adjacent to the Rampart Range fault have overturned dips to the west, consistent with a moderately steep westward dip of the Rampart Range fault, as illustrated on cross sections A-A' and B-B'. The rotation of footwall strata through an angle of greater than 90° likely occurred as a result of bedding flexure induced by faulting of underlying Proterozoic basement. The steeply inclined strata form the middle limb of a generally monoclinal fold structure formed through forced fold or fold-thrust processes (Stearns, 1978; Johnson and Johnson, 2002). The Rampart Range fault represents a master fault that initiated within Proterozoic basement and propagated up into and through folded overlying Phanerozoic sedimentary cover rocks (e.g. Mitra and Mount, 1998). Above the tip of a master fault in crystalline basement rock, folded sedimentary cover rocks undergo distributed deformation within a triangle-shaped zone that corresponds to the steeply inclined intermediate fold limb of the monoclinal fold (Mitra and Mount, 1998). The distributed deformation is expressed in Garden of the Gods Park by the brittle shear fractures and secondary faults formed in competent sandstone units in the footwall of the Rampart Range fault. The structures in the footwall served to dissipate the displacement that, within basement rocks, was focused upon the master fault. The succeeding paragraphs provide an interpretation for the development of the fault relationships that now exist in the footwall to the Rampart Range fault along cross section B-B' (see also figs. 3 and 5) through Garden of the Gods Park.

During movement on the Rampart Range fault, cover rocks in the middle limb of the monocline rotated to steep or vertical dips during flexural folding. Once bedding rotated out of a favorable orientation for bedding-plane slip, a splay fault (concealed at depth), the secondary faults, and small-scale structures formed to accommodate the ongoing deformation due to upward-propagation of the tip of the master fault. The brittle structures developed along the boundary between structurally competent Paleozoic units and incompetent Mesozoic rock units. Brittle deformation affected the former, while the latter underwent more plastic deformation, an indication that large mechanical contrasts existed at this interface.

The fault at depth (see B-B' and Fig. 5; labeled “floor fault” on Fig. 5) is interpreted to have formed as a splay off the Rampart Range fault that localized at or near the hinge region between the intermediate and lower fold limbs. Consistent with relationships further north (cross section A-A'), the splay fault accommodated a component of the reverse fault motion and bedding rotation. Upon the splay fault, competent sandstones (Dakota Sandstone and older units) were translated eastward, overriding incompetent Mesozoic units dominated by thin-bedded siltstone and shale. Within the competent sandstone units, shear fractures and secondary faults formed, while ductile behavior affected fine-grained Mesozoic strata. The faults and shear fractures accommodated east-west contraction as determined from brittle kinematic analysis (Fig. 4; Marrett and Allmendinger, 1990).

Within the block bounded below by the “floor” fault splay and above by the Rampart Range fault (Fig. 5), the southeast-side-up secondary faults verge toward the basement block. They are inferred to have formed when the eastward-translated Rampart Range and splay faults encountered resistance to their eastward propagation, causing some of the slip to be transferred to the secondary faults verging in the opposite direction (Erslev, 1993). The resistance may be attributable to the shallow dip of the splay fault and the substantial thickness of overlying rocks in its hanging wall (Davis and others, 1984). Noting that the secondary faults localized at the interface between sandstone-dominated and shale-dominated units, the faults are interpreted to project down to the east to the upper contact of Dakota Sandstone (the stratigraphically highest, reasonably thick, competent sandstone) where it is truncated against the splay fault (Fig. 5). The splay fault constitutes a “floor” fault in that it marks the lower structural boundary of the distributed zone of penetrative brittle deformation.

To the east of that point, or “tip,” due to the tendency of Cretaceous shale to fail parallel to bedding, it is probable that bedding-plane slip within weak shale units translated material back to the northwest (to the left in B-B' and Fig. 5), up the dip of bedding. This created an upper or “roof” fault (outside the limits of the Cascade quadrangle) as the first back-verging fault in the

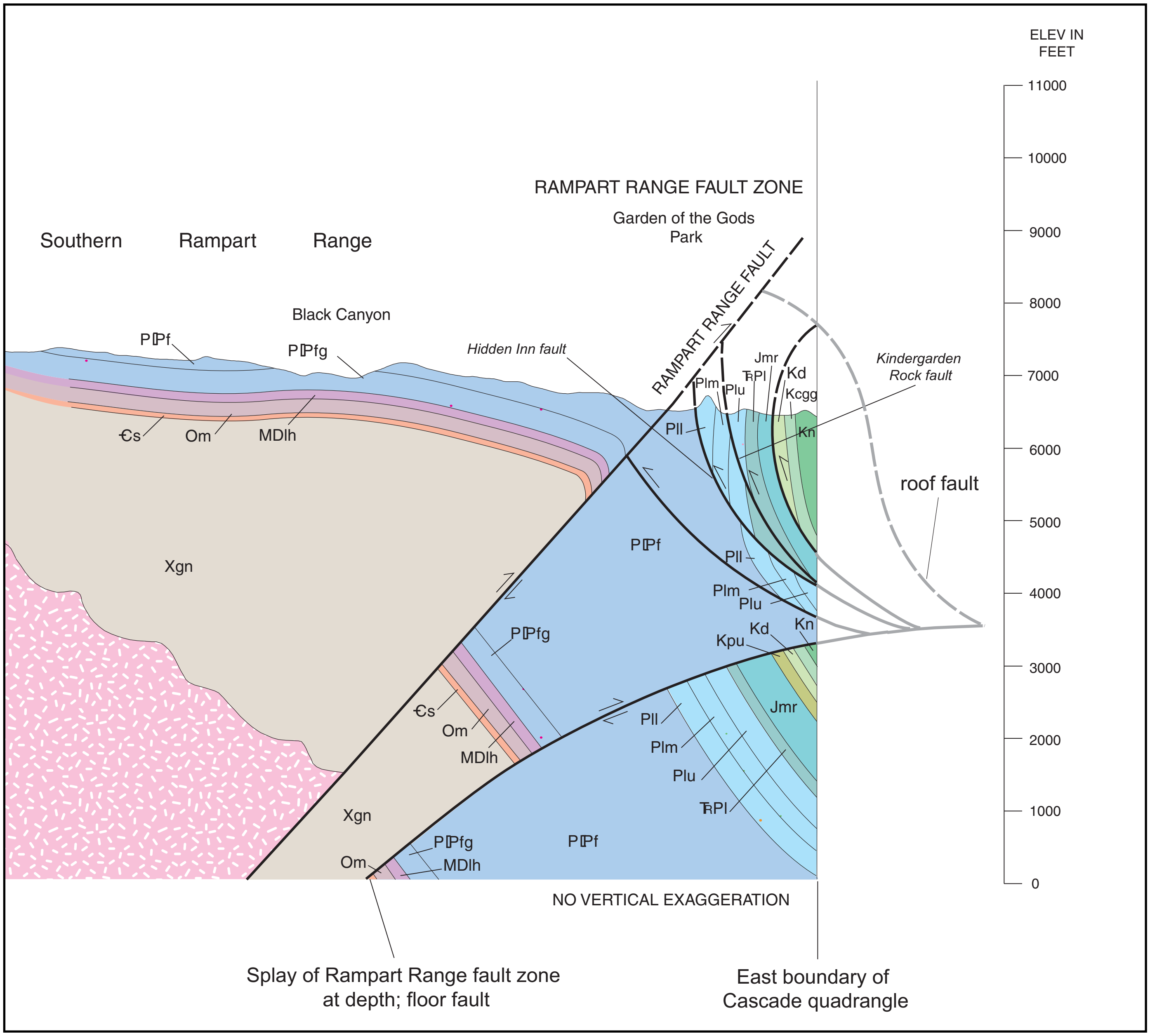


Figure 5. Interpretive cross section of the Rampart Range fault zone near the Garden of the Gods Park showing the prominent structures related to the "triangle zone". The diagram corresponds to the east end of cross section B-B'. In this analysis, the presence of an array of closely spaced, south-east-side-up (in figure, right-side-up) secondary faults with vergence counter to that of the master fault is explained by internal deformation within a fault block bounded above by the Rampart Range master fault and floored below by a moderately low angle fault splay. A roof fault is interpreted to exist to the east, outside the area of the Cascade quadrangle and cross section B-B'. When east-ward translation of the fault block upon the floor fault became mechanically unfeasible (e.g. Davis and others, 1984), motion was transferred to the roof fault and secondary faults internal to the fault block. The secondary faults accommodate only a small amount of displacement compared to the Rampart Range fault and they are truncated by the Rampart Range fault, so it is evident that the secondary faults were abandoned and overridden by the Rampart Range fault block during dominant west-side-up fault movement on the Rampart Range fault.

system. Successive faults at close spacing (Fig. 5, cross section B-B') formed in sequence from east to west, as indicated by the progressive decrease in displacement on the faults from east to west. These secondary, southeast-side-up faults can be considered as elements of the Rampart Range fault zone, since they are subsidiary structures that helped accommodate a small component of the overall east-west-oriented contraction. However, since the Rampart Range master fault truncates the secondary fault array, it is evident that the secondary faults were abandoned and overridden by the Rampart Range block during continued west-side-up translation on the Rampart Range fault. This assessment of distributed deformation within the footwall to the Rampart Range fault offers a resolution to contradictory relationships involving east-and west-vergent reverse fault structures. The interpretations here draw upon concepts advanced in triangle zone models (Jones, 1996; Mackay and others, 1996; Mitra and Mount, 1998; Sterne and others, 2002).

Because not all of the structural relationships fall within the boundaries of the Cascade quadrangle, some further points deserve mention. Notably, the roof fault is not exposed but the strike of its trace is interpreted to coincide with the valley of Camp Creek (the drainage flowing out of Queens Canyon). A rough north-striking fault is required there to separate strata overturned 52° to 25° west from steeply east-dipping Pierre Shale (attitudes shown on the Pikeview and Colorado Springs quadrangles; Thorson and others, 2002; Carroll and Crawford, 2000). The roof fault is predicted to truncate bedding in its footwall and to be parallel to east-dipping bedding in its hanging wall. Thus, the fault dip probably is on the order of 65° to 80° east. Furthermore, the west-dipping Rampart Range fault zone merges with the floor thrust at depth. It truncates the imbricate backthrusts acting as a piercement fault. This relationship suggests that the triangle zone was abandoned once it could no longer accommodate regional shortening in an efficient way.

Alternative interpretations for the complex structural relationships within footwall strata of the southernmost Rampart Range fault zone may involve basement fault propagation (e.g. Berg, 1962; Stone, 1984; Erslev, 1993) into forced folds (Johnson and Johnson, 2002), or faulting induced by overtightening in a footwall syncline. The successful model must account for seemingly contradictory east- and west-vergent reverse structures within a single structural system. In this analysis, the presence of southeast-side-up secondary faults with vergence counter to that of the master fault is explained by internal deformation within a fault block bounded above by the Rampart Range master fault and a roof fault to the east, and floored below by a moderately low angle fault splay.

Timing of Fault Movement

The most recent age of movement on the Rampart Range fault zone in the mapped area is best dated by mapped relationships of the Laramie and Dawson Formations near Mount St. Francis (sec. 3, T. 13 S., R. 67 W.). The steep to vertical beds of the Laramie Formation are in sharp contrast to the more gentle, easterly dipping beds of the Dawson Formation immediately to the north. A 50 ft thick sequence of beds within the Dawson Formation in the southwest part of the U.S. Air Force Academy shows progressively greater dips from higher to lower beds due to bedding rotation during deposition (Kluth and Nelson, 1988). This would suggest Late Cretaceous to early Tertiary movement of the Rampart Range fault zone. The syntectonic sediments are arkosic conglomerates derived from Pikes Peak Granite of the Rampart Range (Raynolds, 2002; Thorson, 2002). Thus, the Dawson Formation age brackets the timing (Laramide) of fault movement as Late Cretaceous to early Tertiary.

The significant relief along the abrupt, linear mountain front of the Rampart Range might be taken as signs of renewed faulting in middle Cenozoic or younger time, Leonard and Langford (1994) estimated the maximum offset across the Rampart Range fault to be on the order of 155 m on the basis of structural separation across the Rocky Mountain erosion surface and overlying rock units (Wall Mountain Tuff/Castle Rock Conglomerate). These units can be projected from the top of the Rampart Range to the tops of mesas and buttes near Castle Rock. The Rocky Mountain erosion surface (Kelley and Chapin, in press; Leonard and others, 2002; Chapin and Kelley, 1997) is a post-Laramide low-relief surface developed by erosion and basin infilling between Eocene and Miocene time. An extensive portion of the surface is preserved on the crest of the Rampart Range (Epis and others, 1980; Scott and Taylor, 1986). Tertiary volcanic rocks capped the surface, beginning with the widespread Wall Mountain Tuff at 36.6 Ma (Epis and others, 1980; Gregory and Chase, 1994). Erosional development of the Rampart surface continued into the Miocene, on the basis of gravels deposited on the surface that are probably lateral equivalents of the Ogallala Formation (latest Miocene) of the Great Plains (Steven and others, 1997; Dickson and others, 1986). Evidence of post-Miocene faulting does exist in the southwestern Rampart Range, where Miocene gravels are cut and displaced on the east margin of the Manitou graben (Steven and others, 1997; Leonard and others, 2002; Epis and others, 1980), downdropped along the Ute Pass fault zone. The Rocky Mountain erosion surface and capping gravels are displaced by at least 1,100 ft across the graben-margin fault (Steven and others, 1997).

More recent movement on faults associated with the Rampart Range fault zone is evidenced in photographs taken during the excavation of the McCullough Water Treatment Center located on the southern boundary of the Air Force Academy in sec. 28 of T. 12 S., R. 67 W. These photographs show that late Tertiary and Quaternary fill is faulted; however, the outcrops are no longer visible due to the artificial fill resulting from this massive engineering project. During this and other excavations, several faults were mapped and described at the U.S. Air Force Academy by Scott (1970) and Dickson (1986). In addition, recent seismic activity in the region together with the above evidence for young faulting suggests that Holocene movements of the Rampart Range fault zone should be considered. Seismic events of magnitude 2.8, 3.6, and 4.0 were recorded in the southern and western Rampart Range in the Woodland Park area in 1994 and 1995 (NEIC, *http://neic.usgs.gov/current_seismicity.shtml*). Other local evidence for recent faulting (Wong, 1986; Warner, 1986) includes Quaternary fault displacement of pediment gravels (Qg_2) (Rowley and others, 2002) and potentially young rockfall deposits (Kirkham and Rogers, 1981, 2000) along the Ute Pass fault zone. Thus, there may be potential for Neogene to Holocene fault movements along the Rampart Range fault zone, due to reactivation of the profound, preexisting structure. Thick mantling deposits of unconsolidated granite grus and colluvium produced by deep chemical weathering of granite along the Rampart Range conceal much of the bedrock along the rangefront, making it unlikely that fault scarps or surface breaks are expressed in the landscape.

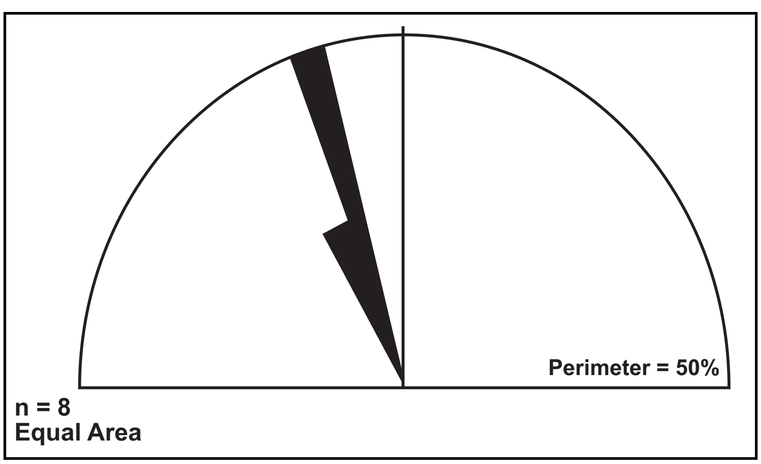


Figure 6. Rose diagram summarizing orientations of basement faults corresponding with lineaments and sheeted fractures in the Cascade quadrangle, southern Rampart Range.

HIGH ANGLE FAULTS WITHIN PRECAMBRIAN ROCKS

Previous reconnaissance geologic mapping of the Cascade quadrangle (Scott and Wobus, 1973; Wobus and Scott, 1977; Trimble and Machette, 1979) showed few faults other than the Ute Pass and Rampart Range fault zones. New mapping in 2002 revealed abundant steeply dipping, north-northwest to north-northeast faults within Precambrian crystalline rocks. The steeply dipping faults are exposed in most freshly excavated roadcuts, many borrow pits, and locally in stream cuts and steep canyons. In addition, strong north-northwest to north-northeast lineaments are evident on topographic maps, DEMs, and aerial photography. Most stream drainages follow the lineaments. Their direction is strongly coincident with the dominant joint attitude of strikes from northeast to east-northeast, although a secondary joint direction strikes north-northwest (Fig. 6).

Field examination of outcrops along the northerly striking lineaments revealed a relatively high proportion of sheared rock compared to rock in other parts of the mapped area. The outcrops contain sheeted fractures, slickensides (shear fractures), clay gouge, propylitic alteration, and rare quartz veins or breccia. Most individual fractures are open and expose weathered rock rather than annealed or mineralized zones. In addition, closed shear fractures occur locally in the Pikes Peak Granite, but cannot be traced laterally; they exhibit a black color due to presence of manganese oxides or oxidation of iron. The features are not developed in Windy Point Granite. The width of sheared rock along lineaments or in outcrops of sheeted fractures ranges from less than 5 in. to over 40 in. The fractures are oriented between 60º and 80º, parallel with the dominant joint direction (Fig. 7).

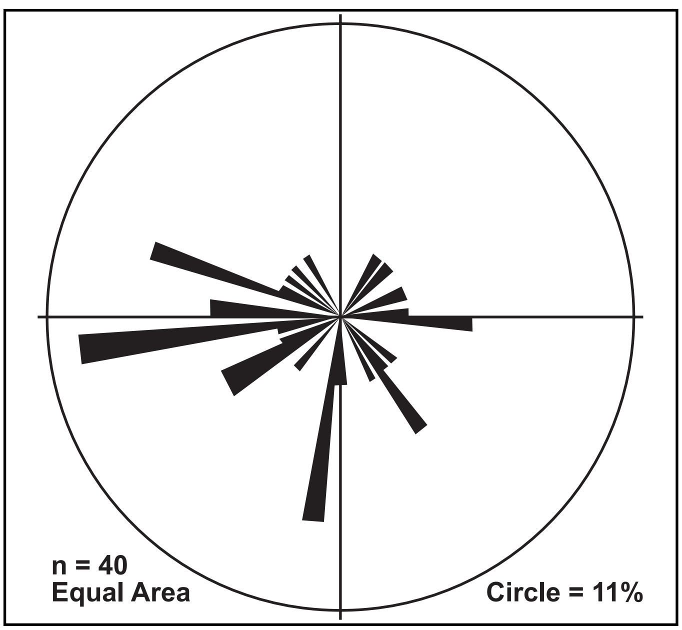


Figure 7. Rose diagram summarizing orientations of sheet fractures, shear fractures, and joints in Pikes Peak Granite within the Cascade quadrangle.

Criteria used to distinguish mappable faults from joints, shear fractures, and minor faults include the following: (1) presence of slickenside zones exceeding one inch in width, evident in roadcuts, cliff faces, or other "clean" exposures; (2) zones of parallel fractured and/or propylitically altered rock; (3) mineralization, alteration, veining, or brittle cataclasis; and (4) correspondence with lineaments expressed on maps, air photos, and DEMs. Faults containing gouge zones less than one inch thick or limited to isolated shear planes were deemed minor faults, too small to represent at 1:24,000 scale. Evidently, the correspondence of stream drainages with lineaments and faults reflects the greater erodability of cataclasized and chemically weathered rock along shears.

Studies of faults in outcrop show that virtually all are high angle, with dips of 60º or greater. Most strike between 325º and 30º, with the dominant strike orientation between 350º and 10º. In the western part of the Cascade quadrangle, this orientation is subparallel to that of the Ute Pass fault zone. Orientations of fault slickenlines are variable, from low rake to high rake on slickenside surfaces.

Piercing points and surface-kinematic criteria (e.g. Petit, 1987) are usually lacking in the homogeneous, porphyritic plutonic phases comprising the Precambrian bedrock of the Rampart Range. Phanerozoic sedimentary units have been eroded from most of the Rampart Range. Crosscutting relationships between fault arrays are generally unclear, due to the deep chemical weathering along the fault planes. Brittle shear criteria (Petit,

1987) showed conflicting shear sense (as both left-lateral and right-lateral oblique movement on similarly oriented faults); and the total number of observations was too small to allow a confident interpretation. Advanced chemical weathering of surface outcrops means poor preservation of such delicate surface features or preferential preservation that may introduce a sampling bias. Along the eastern side of the Rampart Range, low-angle slickenlines on steep north northwest-striking faults and shears suggest a component of lateral translation along the Rampart Range fault zone. However, within the interior part of the range block, direct determination of fault slip and relative timing between fault arrays is generally not possible.

In the southern Rampart Range where Paleozoic strata are preserved, however, steeply dipping east-northeast-striking faults show down-to-the-south offset. The sense of separation is consistent with, and probably helped accomplish, the increase in structural separation across the range-bounding Rampart Range fault zone, from south to north. Thus, an interpretation of south-side-down displacement across the approximate east-west, high-angle faults in the southern Rampart Range may be justified. Laramide timing for at least a component of the deformation accommodated by the faults is likely, in this case. No high-angle faults in the basement were observed to cut the Rampart Range fault zone, so the structures must have initiated prior to or during the Laramide event.

Potentially, the kinematics of north northwest- to north northeast-striking faults can be interpreted on the basis of geometrical compatibility with the Rampart Range fault zone. Faults in that orientation are subparallel to the range-bounding structure, and they formed pre-existing weaknesses at the onset of Laramide deformation (see below), and they likely accommodated down-to-the-east movements in response to approximate east-west shortening during the Laramide. Down-to-the-east movement is observed on the north edge of Queens Canyon, where moderately steeply dipping, north-striking faults cut the basal Sawatch Sandstone along its nonconformable contact with Pikes Peak Granite. Although these faults are too small to portray at 1:24,000 scale, they have 3 to 10 ft of east-side-down offset. Elsewhere, where Phanerozoic cover rocks have been eroded from the crystalline basement, sense of offset cannot be observed and magnitude of separation cannot be estimated.

Interpretation of faults and joints within the Precambrian crystalline rocks is difficult because the structures may have initiated during, and participated in, any of several deformational events during Colorado's protracted tectonic history, following the emplacement of the Pikes Peak Granite at 1.05 Ga. Major events include (1) Regional northeast-southwest extension in the foreland or continental interior (intracratonic deformation) during the Grenville orogeny at about 1 Ga (Marshak and others, 2000; Timmons and others, 2001); (2) regional east-west extension during supercontinent breakup at 0.80 to 0.74 Ga; (3) east-northeast/west-southwest convergent tectonics of the Ancestral Rockies event in Pennsylvanian time (e.g. Kluth, 1997); (4) east to west shortening during the Laramide orogeny during Late Cretaceous-early Tertiary time (e.g. Erslev and others, in press, and references therein); and (5) Miocene to Holocene epeirogeny (Leonard, 2002; McMillan and others, 2002; Leonard and others, 2002; Steven and others, 1997). Regional geological studies elsewhere in the southwestern United States show that Laramide contraction reactivated Proterozoic faults (Marshak and others, 2000; Timmons and others, 2001; Heizler, 2002). With new recognition of the extent and geometry of brittle faults from mapping, the Rampart Range presents rich ground for further investigation of Precambrian faults and evidence for reactivation.

With respect to Laramide kinematics, conflicting observations come from hanging wall versus footwall structures in the Rampart Range, with implications for the hypothesis of Chapin and Cather (1983) for dextral transpression upon Laramide structures in the southern Rocky Mountains. Within the upthrown basement block proximal to the Rampart Range fault zone, low-angle slickensides on steep north-northwest-striking faults and shears suggest a component of lateral translation along the Rampart Range fault zone. The abrupt increase in structural deformation northward along the Rampart Range fault zone suggests a sinistral rather than dextral component of transcurrent movement across the fault zone. Southward on the Ute Pass fault zone, northwest-plunging fault slickenlines associated with the west-side-up movement of the fault zone also indicate left-oblique slip, together with apparent left-lateral offset of a fault-bounded panel of Early Proterozoic gneiss and granitoids (Keller and others, 2003).

JOINTS

Blair (1976) noted that, regionally within the Pikes Peak batholith, an orthogonal set of extension joints and microjoints formed at 350º and 80º during cooling and resurging of the batholith. During the course of the field mapping of the Cascade quadrangle, we completed a cursory analysis of joints cutting the Pikes Peak and Windy Point Granites. Our study showed that the predominant strike direction of joints is between 40º and 70º, with a secondary trend about 60 degrees away, between 340º and 10º. Aplites, small Windy Point dikes, and closed shears in the Pikes Peak Granite tend to have the same trends, suggesting that most joints of these trends are Precambrian and that they were formed after shearing and emplacement of the late-stage dikes. Quartz veins trend between 15º and 60º, so most of them may reflect the same extension direction as most joints.

FOLIATION IN PRECAMBRIAN GNEISSES

Migmatite gneiss forms the Precambrian bedrock in the southern Rampart Range, from Queens Canyon on the east to Williams Canyon on the west. Layering in the stromatic migmatite is defined by alternation of biotite-rich (melanosome) and K-feldspar-rich layers (leucosome). Some horizons consist of fine-grained quartz-rich gneiss, or amphibolitic gneiss. The melanosome contains rare garnet and sillimanite, an indication that metamorphism occurred in the middle amphibolite facies. Foliation is slightly folded into open folds. Average foliation dips west at a moderate to shallow angle.

Discordant dikes of pegmatite, aplite and fine-grained granite cut the metamorphic foliation at a shallow to high angle (Fig. 8). Contacts of Pikes Peak Granite are discordant to the foliation, and the granite contains large xenoliths of gneiss (Xgn) in Queens Canyon.

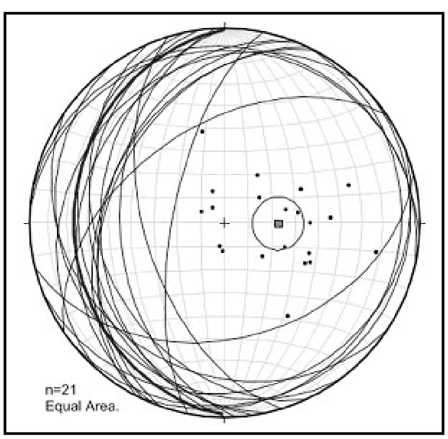


Figure 8. Foliation in gneiss (Xgn). The average plane is oriented 180º and plunges 23º west.

GEOLOGIC HAZARDS

Many different types of geologic hazards, such as landslides, debris flows, swelling soils and rockfall, are present within the Cascade quadrangle. Landslides and swelling soils are the most common and most costly hazards in the eastern urbanized area, potentially accounting for millions of dollars in property loss and damage (Noe and others, 1997; Himmelreich and Noe, 1999; Himmelreich, 1996; and City of Colorado Springs Office of Emergency Management Homepage, 2003). Not surprisingly, they are also the most-studied geologic hazards in the area, primarily due to their effects on urban development. However, evidence for less well-known hazards such as rockfall, debris flows, erosion/siltation, radon gas, earthquakes, and hydrocompactive soils make the quadrangle an interesting study in geologic hazards. Other geologic hazards constraints such as corrosive soils, settlement, high groundwater, springs, and flooding are not discussed here.

Bedrock structure, hydrogeology, topography, surface drainage, and lithology are very important controls on the development of geologically hazardous areas within the mapped area. Along the eastern margin of the quadrangle, these five factors combine to produce a complex geologic environment. Some of the rock types, in particular the Cretaceous bedrock formations and Glen Eryie Shale, are weak and prone to landslides, swelling soils, and heaving bedrock (White and Wait, in press; Himmelreich and Noe, 1999).

LANDSLIDES

Many landslides are located in the Cascade quadrangle. The largest one lies along Highway 24, about 0.25 mi southeast of the town of Cascade along the eastern margin of French Creek (SE¼ sec. 26, T. 13 S., R. 68 W.). This large, complex pre-historic slide-flow deposit covers an area of at least 0.42 mi. The basal 20 ft of the deposit is poorly sorted, weakly stratified, and contains subangular to subrounded cobble-sized clasts of Windy Point Granite and Pikes Peak Granite set in a silty-sand matrix. The upper 60 ft of the deposit is poorly sorted, unstratified, and contains cobbles and boulders (some 20 ft in diameter) of predominantly Windy Point Granite. Localized organic-rich layers are present. Hummocky topography and small, less than four feet high, pressure ridges are visible on the surface. The basal 20 ft of this deposit may represent several debris fan events that occurred in short succession. With increased rainfall or steady rainfall over a short period, increased pore pressure in fractured crystalline bedrock caused a slope failure resulting in a large debris avalanche and landslide event that is preserved in the top 60 ft of the deposit. Some of the material crossed Fountain Creek and moved a short distance up slope on the other side of the valley. Volume calculations using a GIS estimate 564,000,000 ft of material was moved and deposited during this single event.

Numerous other landslides are located in the eastern part of the quadrangle, mostly associated with the weak sedimentary rocks. Landslides that have damaged property have historically occurred along the eastern margin of the Front Range (Hansen, 1973) and in the Colorado Springs area (Johnson and Himmelreich, 1998). Since at least the mid-1960s, landslides have damaged property in various areas in or near Colorado Springs (Himmelreich, 2003a). Some landslides, particularly those derived from the Pierre Shale, have moved in historic time. In 1999, after heavy spring flooding reactivated old landslides and triggered several new ones, the area received a presidential disaster area designation. In 1999, the City of Colorado Springs estimated 75 million dollars in property damage and mitigation costs due to landslides (City of Colorado Springs Office of Emergency Management Homepage, 2003). The Federal Emergency Management Administration (FEMA) designated funds to buy out distressed properties due to the 1999 landslides. This program has spent nearly 6 million dollars on property loss and damage as of 2002 (White and Wait, in press).

Both prior to and as a result of the 1999 storms, landslide damage has occurred in the

Cedar Heights subdivision, west of Garden of the Gods Park (secs. 28, 29, 32, 33, T. 13 S., R. 67 W), where the Glen Eyrie Shale Member of the Fountain Formation is accountable for both old and active landslides. Some of these landslides have clear signs of active movement such as deposition of material on sidewalks and roadways as well as disruption of curbs, driveways, and foundations. Translational landslides like those in the Cedar Heights subdivision form where jointed and fractured, east-dipping beds of Fountain Formation are undercut by the downward erosion of Black Canyon and its tributaries (Himmelreich and others, 1980; Myers, 1981; White and Wait, in press).

The Mountain Shadows subdivision (sec. 22, T. 13 S., R. 67 W) is built upon shale, limestone, and sandstone overturned by Laramide movement on splays of the Rampart Range fault zone that pass beneath the neighborhood. This area was previously mapped as earthflow, colluvium, and landslide deposits (Trimble and Machette, 1979; Scott and Wobus, 1973; Himmelreich and Essigmann, 1980). Deposits in the area consist of large blocks of Dakota Sandstone intermixed with black to yellow sandy clay matrix. The landslide covering much of the area appears to be largely inactive, although some disruption of curbs and sidewalks was noted during our field work. This area contains probable active landslides, surface creep, expansive soils/bedrock, and hydrocompaction problems (Garrabrant and Frank, 1980; Himmelreich and Essigmann, 1980).

North of the Mountain Shadows subdivision, landslides in the Pierre Shale locally affect Qg_2 gravels. Numerous landslides have occurred in the Pikeview Quarry (sec. 9, T. 13 S., R. 67 W.) as a result of mining operations exposing dipping carbonate layers of the Manitou Limestone (Himmelreich, oral communic. to Pikes Peak Ranger District, 2001). Although it contains no evidence of historic movement, the landslide in Lofland Gulch (S½ sec. 4 and N½ sec. 9, T. 13 S., R. 68 W.) exhibits hummocky topography, disturbed drainage, and localized ponding—all indicative of young mass movement.

Most of the landslides mapped in the Peregrine subdivision (secs. 3 and 4, T. 13 S., R. 68 W) are derived from the Pierre Shale and other Cretaceous rocks (Himmelreich, unpublished maps). They affect roads and sidewalks, and hummocky topography with closed depressions is observed in some of the deposits. In addition, other small (not mapped) landslides occur in the quadrangle, and soil slumps have developed on road cuts along Woodmen Road near Dry Creek in the Peregrine subdivision (J. White, oral comm., 2003).

Two landslides (sec. 21, 28 T. 12 S., R. 67 W.) located along the westernmost boundary of the U.S. Air Force Academy are also derived from the Pierre Shale. They contain cobbles and boulders of Qg_2 gravels, subrounded fragments of Pikes Peak Granite, and buff-colored fragments of Dawson Formation. These landslides themselves, contain localized debris flows and slumps. Furthermore, they cover and in some cases cut out unit Qa_2, indicating movement during the Holocene.

DEBRIS FLOWS

Debris flows are heterogeneous mixtures of mud, rock fragments, and plant materials that commonly form in the lower parts of tributary streams as they enter a large valley (Rogers and others, 1974). As the debris flow moves down its valley, unconsolidated surficial material is incorporated into the flow until the suspended sediment is no longer confined and is released as a fan-shaped deposit at the mouth of the tributary stream. 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 (FEMA, 1999; White, 1999). Such conditions may exist in areas mapped as alluvial fans (Qf), colluvium and sheetwash (Qcs), and landslides (Qls), or in areas where crystalline bedrock units are weathered to grus.

Deposits formed by debris-flow activity have been recognized and reported within the quadrangle in the Mountain Shadows and Peregrine subdivisions (Bass and Himmelreich, 1987; Himmelreich and Essigmann, 1983; Himmelreich, 2000). Several techniques are available for the mitigation of debris flows. These include construction of debris basins (to be cleaned after each flow event), channelization and/or diversion of runoff, protective structures, debris-catching devices, and structures with significant clearance.

ROCKFALL

Rockfall deposits are grouped into the colluvium and sheetwash deposits (Qcs) on the accompanying geologic map. While rockfall deposits were not very extensive or of great thickness, they represent a significant hazard in the map area where hogbacks are located near urban development. The Dakota Sandstone is heavily jointed at some locations, forming large boulders commonly exceeding eight feet in diameter. Some boulders appear to have spalled sporadically while others have come down as debris avalanches, probably during times of high precipitation and runoff. Sections of U.S. Highway 24, where Fountain Creek passes through Precambrian Pikes Peak Granite and forms steep-walled cliffs, are in an area of significant rockfall hazard. These slopes carry a "high" rating in the Colorado Department of Transportation Rockfall Rating System (J. White, personal communic., 2003). Very large granite boulders, some exceeding 15 ft in diameter, are found along the highway, along with smaller boulders, cobbles, and fan deposits. Rockfall hazards can also occur from weathered exposure of granitic rocks that are exposed on the steep slopes of the Rampart Range north of Pikeview Quarry within the northwest corner of the Colorado Springs city limits that extend into the mapped area.

EARTHQUAKES

Minor seismic activity has been recorded near Colorado Springs, possibly from movement along the Rampart Range and Ute Pass fault zones. In April of 1991, MicroGeophysics Corporation (1991) located an earthquake swarm with magnitudes 2.6 to 2.8 on the southern end of the Rampart Range fault zone. A magnitude 4.0 earthquake occurred near Manitou Springs on December 25, 1994 (U.S. Geological Survey, 2002). Epicentral coordinates in the National Earthquake Information Center (NEIC) database (*http://neic.usgs.gov/neis/epic/epic.html*) suggest a location near the eastern flank of the Rampart Range about 21 mi north of Manitou Springs. The earthquake was felt at intensity IV at Victor, Cripple Creek, and Manitou Springs (Kirkham and Rogers, 2000). Felt reports along the southern Front Range (from newspaper articles) have been recorded in 1994, 1995, 1997, 1998, and 2001 (Himmelreich, 2003b). Additional information on faulting and earthquakes in this area can be found in the Colorado Late Cenozoic Fault and Fold Database and Internet Map Server (Widmann and others, 2002), available at no cost on-line at *http://geosurvey.state.co.us/pubs/ceno/*. Widmann and others (1998) presented a database of faults and folds potentially active in the Quaternary.

The Rampart Range and Ute Pass fault zones are considered to be potentially active by the Colorado Geological Survey. This area, like most of central Colorado, is subject to a degree of seismic risk. The Colorado Geological Survey considers this area of Colorado to be in Seismic Risk Zone 2 (Kirkham and Rogers, 1981). If a sizable seismic event did occur, it may trigger slope failures. Seismic forces should be considered in the analysis and design of essential/critical facilities and critical slopes (Essigmann and Himmelreich, 1986; Himmelreich and Hoffmann, 1997a and 1997b).

SWELLING SOILS AND HEAVING BEDROCK

Expansive or swelling soils and heaving bedrock are one of the most costly geologic hazards along the Front Range Urban Corridor, accounting 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. The expansive minerals are commonly derived from layers of bentonitic clay found within the Pierre Shale and other Cretaceous bedrock units. Heaving bedrock occurs where in-situ shale and claystone layers with high expansive clay content within upturned bedrock are found at shallow depth below the ground surface. When wetted, these clay layers may heave at markedly different rates of expansion over small lateral distances. Such differential ground movements can cause significant and damaging deformation to houses, roads, sidewalks, and other constructed media (Noe and others, 1997; Noe, 1997).

In the Cascade quadrangle, areas along the mountain front where the Pierre Shale and other Cretaceous formations are upturned, and where soils are derived from these units, are most susceptible to damage caused by expansive clays, mostly within the city limits of Colorado Springs. Past studies along the Front Range Urban Corridor of potentially swelling soils (Hart, 1974) and heaving bedrock (Himmelreich and Noe, 1999) place a moderate to high potential for expansive clays along the far eastern margin of the Cascade quadrangle. Areas particularly susceptible are east of the Rampart Range fault zone, north to the McCullough Water Treatment Center (sec. 28, T. 12 S., R. 67 W.), here the Pierre Shale and other shale units are near-vertical to overturned. The surficial soils in this area, derived from these claystone formations, may also be susceptible. 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) and colluvium and sheetwash (Qcs). Particularly susceptible are the soils derived from the Colorado Group (Niobrara, Carlile, and Greenhorn Formations). Severe hydrocompaction has been attributed as the primary contributing cause to much property damage in the Mountain Shadows subdivision on Stoneridge Drive (Himmelreich, unpublished data), although some of the damage may also be the result of landslide movement.

RADIOACTIVITY

No occurrences of radioactive minerals have been reported from the Cascade quadrangle (Nelson-Moore, 1978). Gamma ray logs from water wells in facies units three and four of the upper Dawson Formation in the Monument quadrangle to the north, occasionally have elevated responses (2 to 4 times background) that may indicate small low-grade uranium occurrences (Thorson and Madole, 2002). Radon gas is a hazard if one is subject to long-term exposure to high levels. This is a potential problem in structures if they are not well ventilated. The Pikes Peak Granite, and Quaternary deposits derived from it, typically generate “above average” levels of radon gas (Smith and others, 1987). There also appears to be a zone of low-grade uranium occurrence at the base of the Glen Eyrie Member (Himmelreich and Essigmann, 1996). The potential for radon-gas accumulation should be addressed in building design and construction.

CARBONATE KARST

Solution features and clay alteration in Paleozoic carbonates (Manitou Limestone and Hardscrabble Limestone) range from narrow openings along joints to extensive solution caves. A large feature is the Cave of the Winds, a tourist attraction situated in the Manitou Limestone in the west wall of Williams Canyon. Sites of solution are prone to collapse and block fall. High permeability of bedrock allows penetration of surface waters derived from snow melt or torrential summer rains; these can rapidly mobilize the alteration clays that accumulate in solution caves, according to anecdotal observations from Cave of the Winds staff. Luiszer (1999) investigated the paleohydrology of the karst systems surrounding Cave of the Winds, finding interface between cells of geothermal fluid circulation along fault systems and meteoric waters associated with the paleo-Fountain Creek drainage.

MINERAL RESOURCES

Limestone that is mined and crushed and used for construction aggregate and riprap is, by far, the most important mineral resource in the Cascade quadrangle. Over one million tons of limestone is mined annually from quarries within the quadrangle. In addition to limestone resources, a minor potential exists for small and probably uneconomic coal resources in the extreme northeastern part of the quadrangle. There is one historically productive copper mine, and a few other metal prospects that apparently never achieved commercial production. There are no oil or gas wells in the quadrangle, and no productive wells exist within a radius of 30 mi. Additionally, sand and gravel have been mined from the sand and gravel pediments within the quadrangle. Figure 9 shows the locations of the mines and potential resource areas within the quadrangle.

CONSTRUCTION AGGREGATES (CRUSHED ROCK AND SAND AND GRAVEL)

Two currently active crushed rock operations, the Pikeview Quarry and the Snyder Quarry, are located in the quadrangle. Another very large quarry, the Queens Canyon, is no longer active and is under reclamation. These limestone quarries produce material mainly from the Manitou Limestone of Ordovician age.

The large and highly visible Pikeview Quarry is on the eastern slope of the Rampart Range in sec. 9, T. 13 S., R. 67 W. Limestone from the Ordovician Manitou Limestone is mined, crushed, and used as construction aggregate. The Pikeview Quarry is operated by the Castle Concrete Company of Colorado Springs. It produces an estimated 1.0 million tons per year of crushed rock aggregate. The smaller Snyder Quarry is also operated by the Castle Concrete Company and is located in the extreme southern part of the Cascade quadrangle in sec. 32, T. 13 S., R. 67 W. It produces approximately 80,000 tons per year of limestone for use as aggregate.

Gravel has been mined in significant quantities in the past near the eastern boundary of the Cascade quadrangle north of Mountain Shadows Park in sec. 15, T. 13 S., R. 67 W. The sand and gravel mine was known as the Wolf pit (Keller and others, 2002). Unit Qg_2 underlies that area. An older, smaller gravel pit is located in sec. 27, T. 12 S., R. 67 W. just south of Pine Drive in the Air Force Academy grounds. Gravel deposits along the eastern flank of the Front Range are shown as “potential resource deposits” in the Master Plan for the Extraction of Commercial Mineral Deposits in El Paso County (Lewis and Sundaram, 1975).

Sand, gravel, and decomposed granite are mined at the Houchin gravel pit near Chipita Park in sec. 15, T. 13 S., R. 68 W. Annual production is small and variable. The pit exploits alluvium and colluvium (Qac), alluvial fan deposits (Qf), and Pikes Peak Granite. Schwochow (1981) reported that grus was mined at this site.

The Cambrian Sawatch Sandstone also called “Manitou Green Stone” was quarried in small quantities in the past near Williams Canyon in the southeastern part of the quadrangle and in places west of Manitou Springs south of the Cascade quadrangle boundary (Schwochow, 1981). It was used as dimension stone or flagstone. Schwochow (1981) also shows that clay was mined in the past from a site near the eastern edge of the Cascade quadrangle (sec. 22, T. 13 S., R. 67 W.), probably from beds within the Dakota Sandstone. This mine consisted of both above ground and below ground mining in the Dakota (Himmelreich, 2000).

COAL

The northeastern part of the Cascade quadrangle is within the Denver coal region and close to the formerly productive Colorado Springs coal field (Carroll and Bauer, 2002). Although there were never any coal mines in the Cascade quadrangle, several historic underground mines once operated within a mile of the eastern quadrangle boundary in the Pikeview quadrangle. The largest of these historic mines was the Pikeview, which produced 8,738,174 tons of coal between 1900 and 1957 (Thorson and others, 2001).

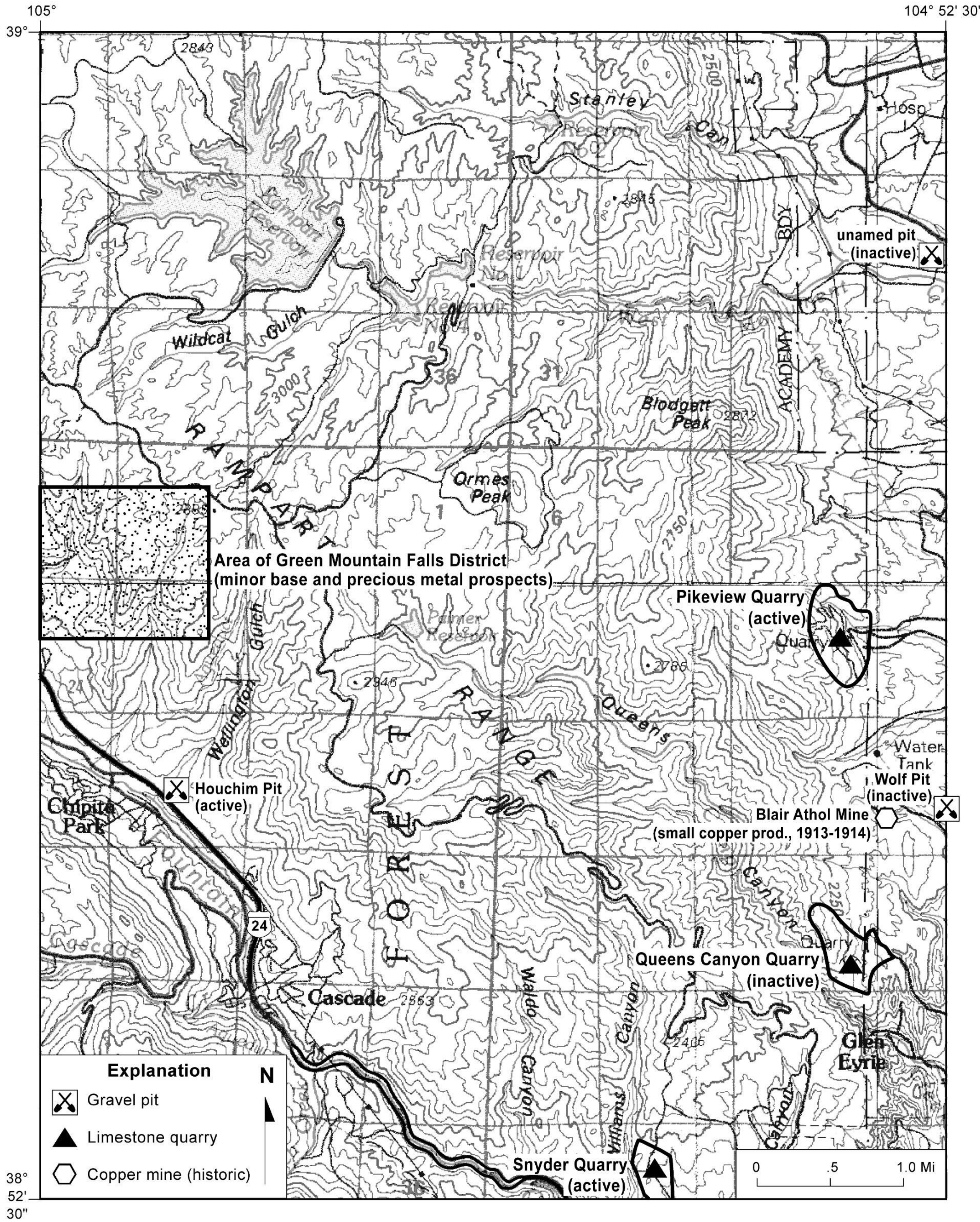


Figure 9. Location of mineral resource areas in the Cascade quadrangle, El Paso County, Colorado.

In the Pikeview quadrangle, coal was mined from two main seams within the lower part of the Laramie Formation of Late Cretaceous age. Where mined, the seams range in thickness from 3 to 20 ft (averaging between 5 and 10 ft) and are generally lenticular. The coal has heat values that range from 8,000 to 9,310 Btu per pound and ranks as subbituminous B to subbituminous C. Sulfur content ranges from about 0.3 to 0.7 percent, volatile matter ranges from 30.2 to 45.1 percent, ash content ranges from 5.4 to 20.8 percent, and moisture ranges from 18.2 to 26.9 percent (Thorson and others, 2001).

It is possible that coal seams are present within the Laramie Formation in the northeastern part of the Cascade quadrangle. By modern coal mine standards, however, the thin and lenticular seams in this region are small. The amount of residential and commercial development in the area would make development of any coal resources problematic. For these reasons, there is little potential for future development of coal resources on the Cascade quadrangle.

METALLIC MINERAL PROSPECTS

There are only a few small, abandoned metal mines and prospects in the Cascade quadrangle. None of these are known to have produced any ore material since 1914 when the Blair Athol copper mine closed after two years of operation. The Cascade quadrangle has low potential for hosting economically significant metal deposits.

Blair Athol Mine (Copper)

The Permian Lyons Sandstone, hosted at least one small copper deposit in the eastern part of the Cascade quadrangle. The Blair Athol Mine, located in the SW1/4 sec. 15, T. 13 S., R. 67 W., produced 323 tons of copper oxide ore that yielded 13,276 pounds of copper from 1913 to 1914 (Henderson, 1926). The deposit is characterized as a typical "redbed" copper deposit (Lovering and Goddard, 1950). Copper oxide minerals, primarily malachite, are irregularly disseminated in white to buff, fine-grained sandstone of the upper part of the Lyons Formation. The mineralized zone extends for approximately 200 ft along the strike of the sandstone beds. At the mine, the Lyons sandstone strikes about 20° and dips about 50° to the southeast. The copper ore at the Blair Athol Mine was taken from an open cut about 75 ft long, 50 ft wide, and 15 ft deep (Lovering and Goddard, 1950). The potential for additional copper resources of economic significance in the area is low.

Green Mountain Falls District (Lead, Gold, Zinc, and Manganese)

The Mineral Resource Data Set (MRDS) (Mason and Arndt, 1996) lists three small metal deposits in the western part of the Cascade quadrangle as part of the Green Mountain Falls district. There has been very little, if any, production from the district. Only one prospect pit is shown on the 7.5-minute topographic map of the Cascade quadrangle in the vicinity of one of the MRDS entries, in the NW1/4 of sec. 10, T. 13 S., R. 68 W. According to an unpublished 1936 Colorado State Planning Commission report, the Iron King Mine is located "3 mi north of Cascade." Galena, sphalerite, pyrite, and manganese oxides are said to exist within a vein in Proterozoic Pikes Peak Granite. There was no reported production. Furthermore, Green Mountain Falls resident Cecil Smisching (oral communic., September 2002), stated that the shaft at this mine was sunk 600 ft, with adits off it, in order to look for gold, but none was found. The mine dump contains sparse epidote, quartz vein material, and sheared granite.

Many dozens of prospect pits are sprinkled across the landscape of Precambrian rocks in the quadrangle. Nearly all of these were originally less than 10 ft deep and 20 ft in diameter. Most exploited visible quartz in the Pikes Peak Granite for either quartz veins-some clearly related to fault zones-and for pegmatite bodies. Residents indicate that the objective was gold, although apparently it was rarely found. Quartz crystals from pegmatite veins also were exploited. In one place (SW1/4 sec. 20, T. 12 S., R. 67 W.), a prospect pit tested pyrite from a lamprophyre dike cutting the Pikes Peak Granite. In some places, the pits were deepened into vertical shafts or significant adits. One occurrence, which is the stuff of legends, generated a Colorado Springs newspaper article (Sunday Gazette and Telegraph for Sunday, April 21, 1929) provided by Lynn Engle, Director of Operations of Eagle Lake Camp (oral commun., October, 2002). According to the article, prospector William Lincicum tunneled 1,200 ft into a secret location in the wall of Queens Canyon, following a vein that contained 115 oz of gold to the ton, as well as native copper. Although he started his adit in 1894, there is no indication that any ore was shipped.

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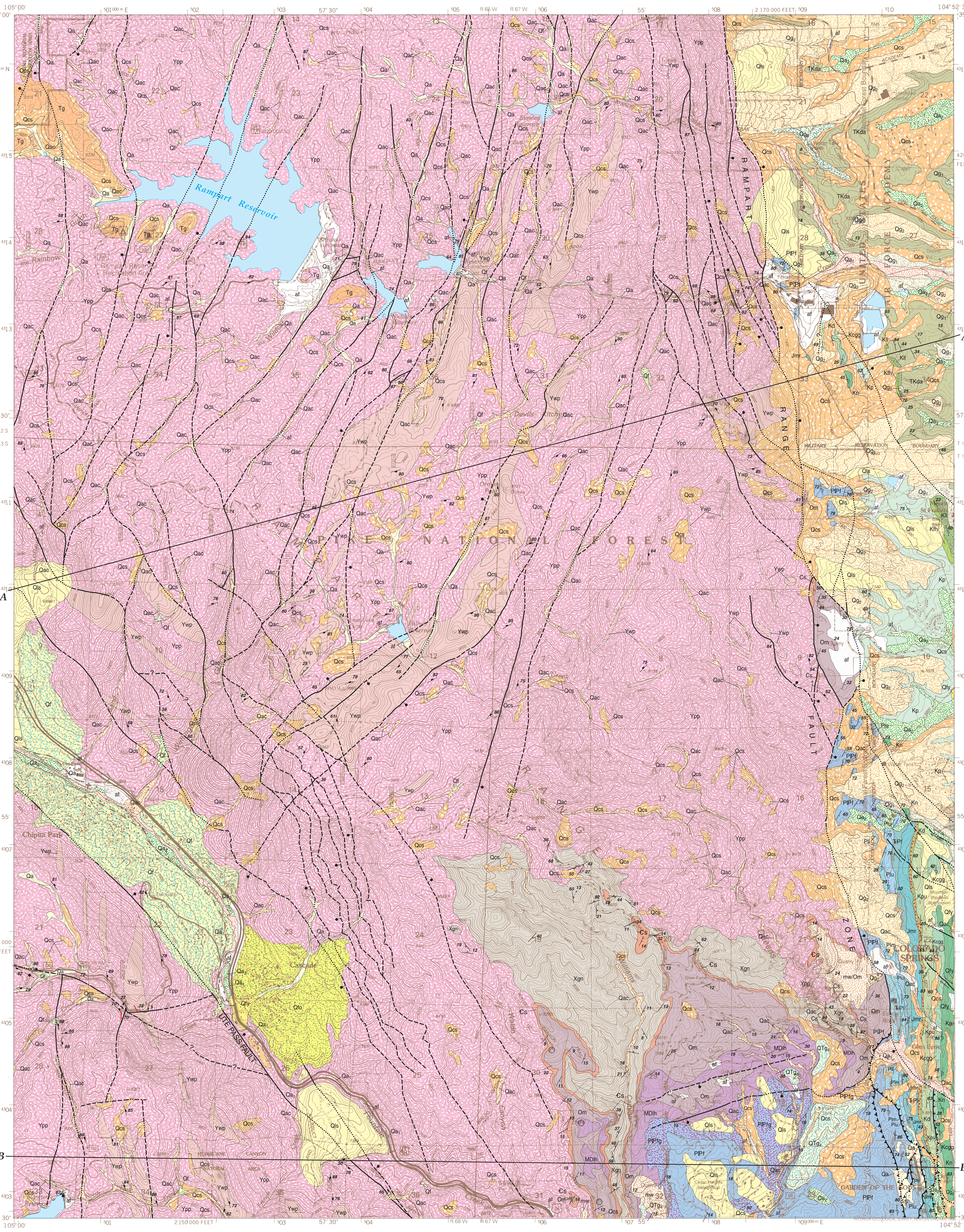
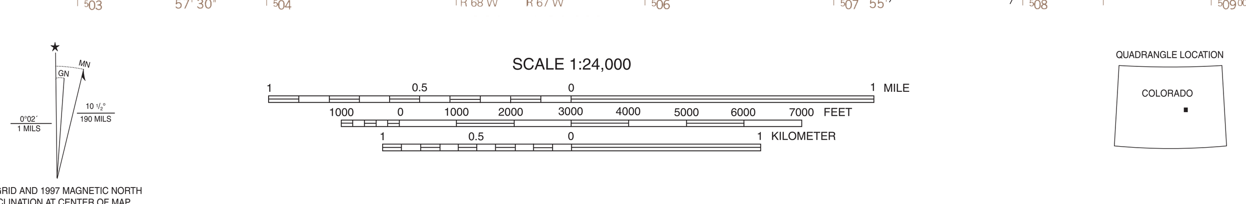
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN-FILE MAP 03-18
GEOLOGIC MAP OF THE CASCADE QUADRANGLE
EL PASO COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1994
Lambert Conformal Conic projection, 1927 North American Datum
10,000-foot grid based on Colorado coordinate system, central zone
1,000-meter Universal Transverse Mercator grid ticks, zone 13



Geology mapped in 2002
GIS and cartography by Karen Morgan

LIST OF MAP UNITS

The complete description of map units and references are in the accompanying booklet. Units shown as fractions (mw/Om) indicate areas where unit shown second has been removed or covered by first unit.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af	**Artificial fill (late Holocene)**
mw	**Mine waste (late Holocene)**

ALLUVIAL DEPOSITS

Qa	**Stream-channel, flood-plain, and terrace alluvium, undivided (Holocene to late Pleistocene)**
Qa_1	**Alluvium one (late Holocene)**
Qa_2	**Alluvium two (late to early Holocene)**
Qg_1	**Pediment gravel one (middle Pleistocene)**
Qg_2	**Pediment gravel two (middle Pleistocene)**
Qg_3	**Pediment gravel three (middle? to early Pleistocene)**
QTg_4	**Pediment gravel four (early Pleistocene to late Pliocene)**
Tg	**Gravel (Upper Tertiary)**

ALLUVIAL AND COLLUVIAL DEPOSITS

Qac	**Alluvium and colluvium, undivided (Holocene to late Pleistocene)**
Qcs	**Colluvium and sheetwash deposits, undivided (Holocene to late Pleistocene)**
Qf	**Alluvial fan deposits (Holocene to late Pleistocene)**
Qfy	**Young alluvial fan deposits (Holocene)**
Qfo	**Old alluvial fan deposits (late to middle? Pleistocene)**

MASS-WASTING DEPOSITS

Qls	**Landslide deposits (Holocene to late Pleistocene)**

BEDROCK

TKda	**Upper part of the Dawson Formation (Paleocene and Upper Cretaceous)**
Kll	**Lower member of the Laramie Formation (Upper Cret-aceous)**
Kfh	**Fox Hills Sandstone (Upper Cretaceous)**
Kp	**Pierre Shale (Upper Cretaceous)**
Kn	**Niobrara Formation (Upper Cretaceous)**
Kcgg	**Carlile Shale, Greenhorn Limestone, and Graneros Shale, undivided (Upper Cretaceous)**
Kd	**Dakota Sandstone (Lower Cretaceous)**
Kpu	**Purgatoire Formation (Lower Cretaceous)**
Jmr	**Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic)**
ȒPl	**Lykins Formation (Lower Triassic? and Upper Permian)**
Plu	**Upper unit of the Lyons Sandstone (Permian)**
Plm	**Middle unit of the Lyons Sandstone (Permian)**
Pll	**Lower unit of the Lyons Sandstone (Permian)**
PPf	**Fountain Formation (Lower Permian and Pennsylvanian)**
PPfg	**Glen Eyrie Member of the Fountain Formation (Lower Pennsylvanian)**
MDlh	**Hardscrabble Limestone Member of the Leadville Limestone and the Williams Canyon Formation, un-divided (Devonian and Mississippian)**
Om	**Manitou Limestone (Lower Ordovician)**
€s	**Sawatch Sandstone, undivided (Upper Cambrian)**
Ym	**Mafic dikes (Middle Proterozoic)**
Ywp	**Windy Point Granite (Middle Proterozoic)**
Ypp	**Pikes Peak Granite (Middle Proterozoic)**
Xgn	**Migmatitic gneiss (Early Proterozoic)**

MAP SYMBOLS

Contact—Dashed where approximately located

Fault—Dashed where approximately located and dotted where covered by younger deposits. Ball and bar on downthrown block. Arrows show sense of movement. Tick shows dip of fault plane. **Thrust fault**—Sawteeth on upper plate. Dotted where concealed

Strike and dip of inclined beds—Angle of dip shown in degrees

Strike of vertical beds

Strike and dip of overturned beds—Angle of dip shown in degrees

Strike and dip of inclined foliation—Angle of dip shown in degrees. Arrow shows direction and plunge of linear feature if present

Strike and dip of joints—Angle of dip shown in degrees

Inclined

Vertical

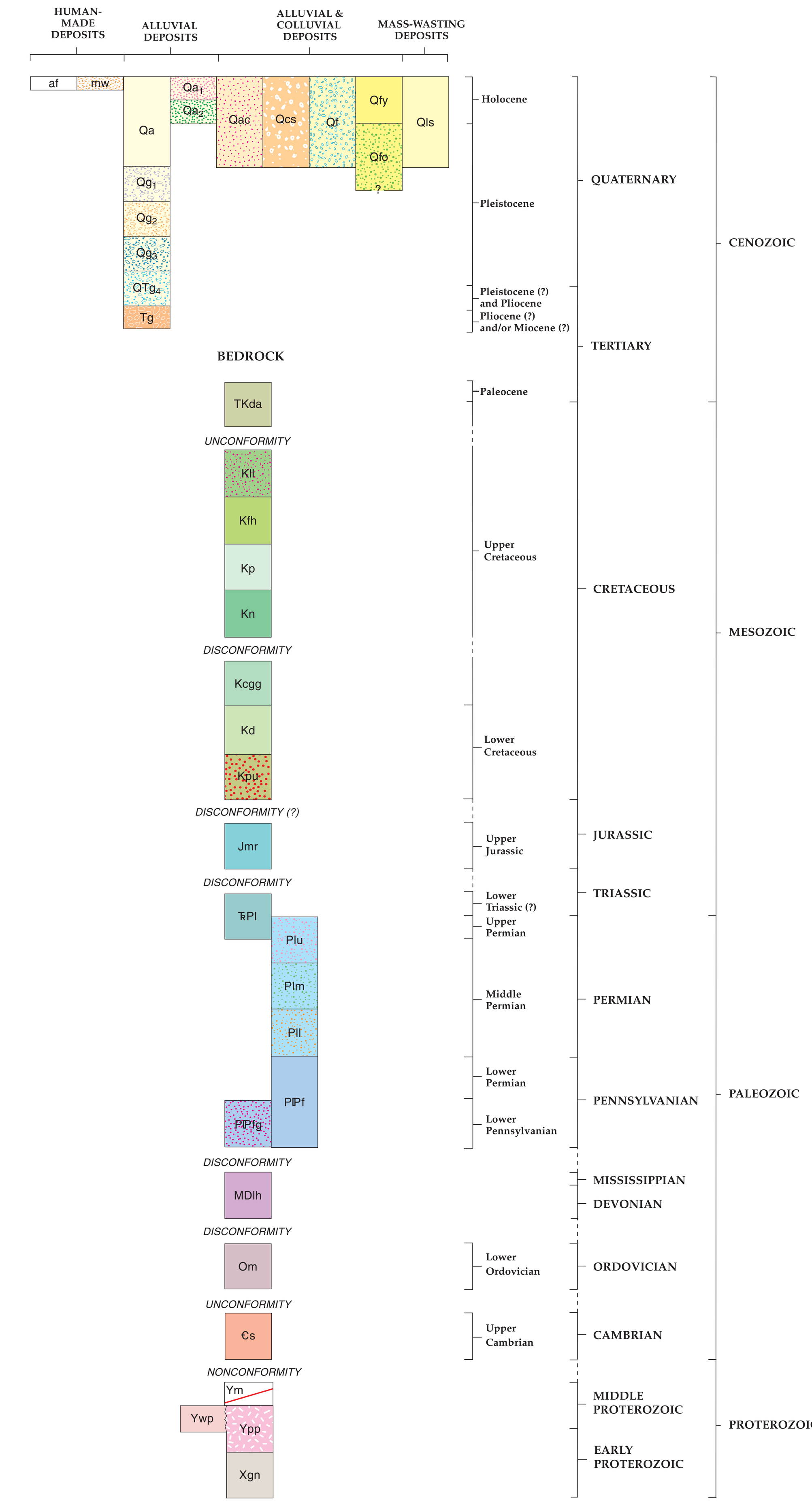
Direction and plunge of slickenline—Angle of dip shown in degrees

Karst feature

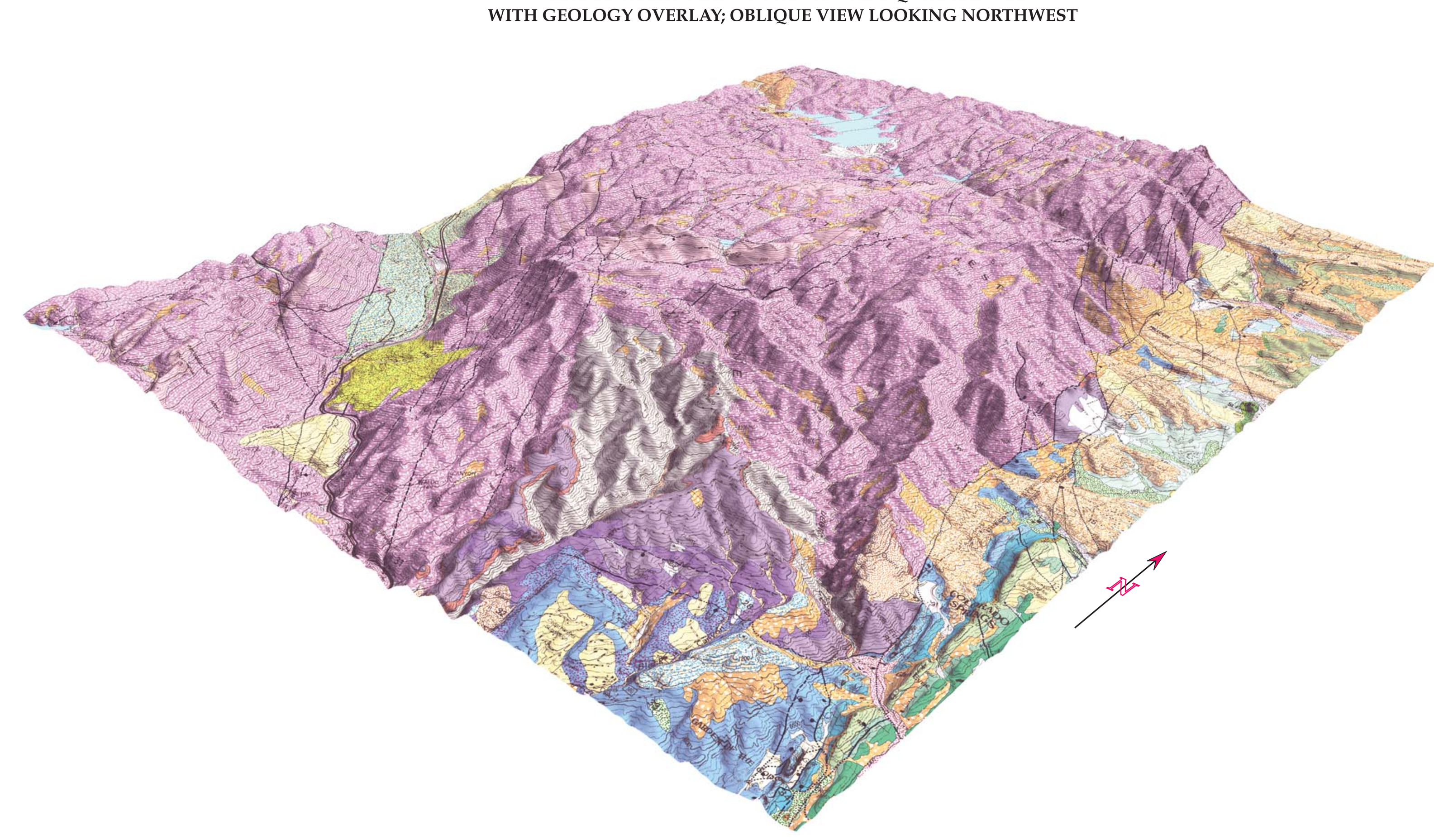
A T **Relative movement of blocks on either side of fault with strike-slip component.** "A" signifies 'away', "T" signifies 'towards'. Shown only in cross section A— A'

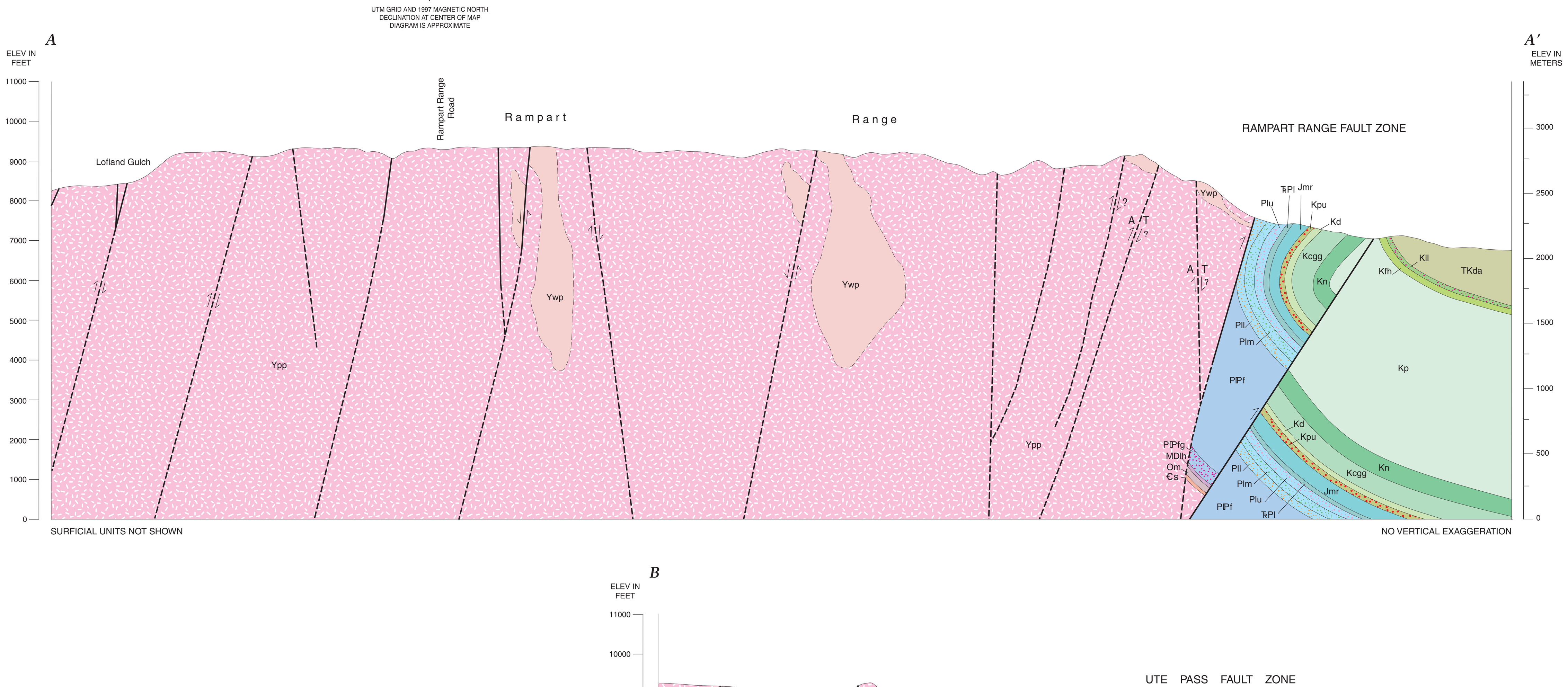
A———A′ **Alignment of cross sections**

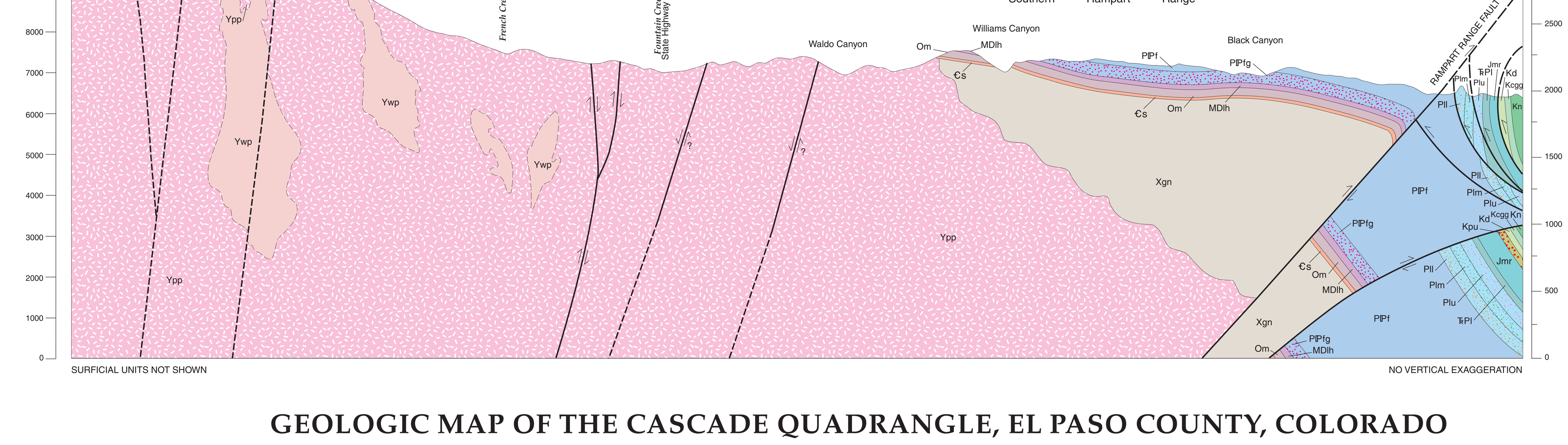
CORRELATION OF MAP UNITS



SHADED RELIEF MAP OF THE CASCADE QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTHWEST







Bill Owens, Governor
State of Colorado

Greg Walcher, Executive Director,
Department of Natural Resources

Ronald W. Cattany, Director,
Division of Minerals and Geology

GEOLOGIC MAP OF THE CASCADE QUADRANGLE, EL PASO COUNTY, COLORADO

By Matthew L. Morgan, Christine S. Siddoway, Peter D. Rowley, Jay Temple, John W. Keller, Bonny Hawkins Archuleta, and John W. Himmelreich Jr.

2003