Map Series 37

Geologic Map of the Cottonwood pass Quadrangle, Eagle and Garfield Counties, Colorado

By Randall K. Streufert, Robert M. Kirkham,
Beth L. Widmann, and Timothy J. Schroeder II

1876

Bill Ritter Jr., Governor
State of Colorado

COLORADO
DEPARTMENT OF
NATURAL
RESOURCES

Harris D. Sherman, Executive Director
Department of Natural Resources

Vincent Matthews
State Geologist and Director
Colorado Geological Survey

Colorado Geological Survey
Denver, Colorado
2008

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Map Series 37, *Geologic Map of the Cottonwood Pass Quadrangle, Eagle and Garfield Counties, Colorado*. Its purpose is to describe the geologic setting of this 7.5-minute quadrangle, which is located east of the city of Glenwood Springs.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds are competitively awarded through the STATEMAP component of the National Cooperative Geologic Mapping Program (Agreement No. 1434-96-HQ-AG-1477 and 01HQAG0094). The program is authorized by the National Mapping Act of 1992. 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.

Vince Matthews,
State Geologist and Director,
Colorado Geological Survey

ACKNOWLEDGMENTS

This geologic map was funded in part by the USGS. The project was also supported by the State of Colorado General Funds and the Colorado Department of Natural Resources Severance Tax Operational Funds. The Severance Tax Funds are paid on the production of natural gas, oil, coal, and metals.

We appreciate the many landowners and property managers who gave permission to enter their property. Craig Bair, Roger Lawrence, Jim Neislanic, Bill Joy, Bob Joy, Lois Walker, and Sue Rodgers were especially helpful. The first geologic map of the Cottonwood Pass quadrangle by the CGS (Streufert and others, 1997b) benefited from reviews by Jim Soule and Bruce Bryant. Jim Cappa, Eric Nelson, Ken Hon, Karl Kellogg, Bruce Bryant, Pat Rogers, Mick Kunk, Jim Budahn, Mark Hudson, Bob Scott, Bill Perry, Dan Unruh, Jim Soule, Bruce Stover, Dick Moore, Chris Carroll, Jon White, Roger Pihl, Dave Noe, Bob Thompson, and Tony Svatos contributed data or advice to us. Jim Messerich set photogrammetric models of our annotated aerial photographs on a Kern PG-2 plotter. Jane Ciener served as the technical editor of the earlier map. In 2002 Vince Matthews collected additional structural attitudes in the Paleozoic rocks in Glenwood Canyon.

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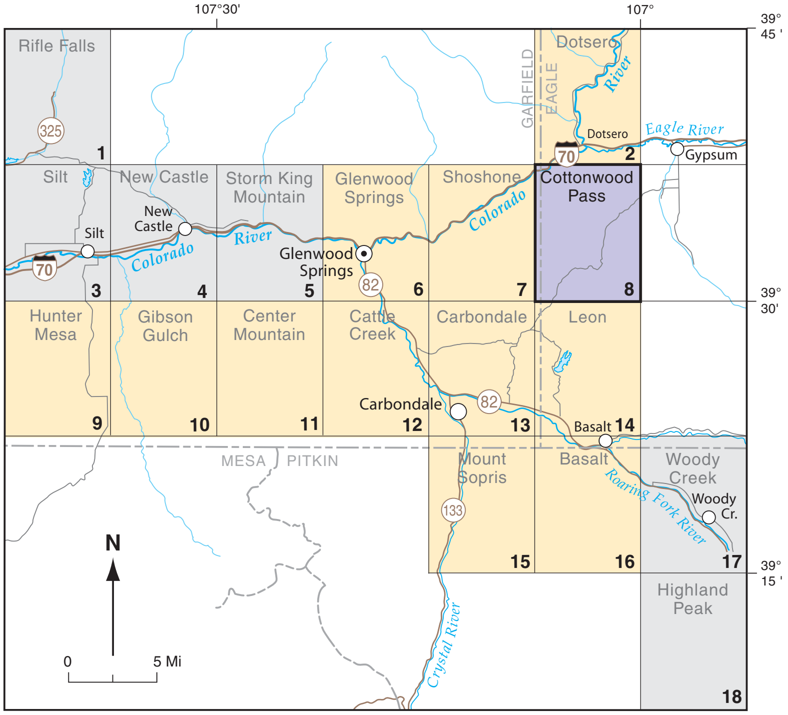
INTRODUCTION

OVERVIEW

Between 1993 and 2001 the Colorado Geological Survey (CGS) mapped the geology of twelve 7.5-minute quadrangles in the Glenwood Springs area in west-central Colorado (**Figure 1**). These maps were released to the public in varying formats, but many were "old-fashioned," hard-to-read, black-and-white diazo prints of hand-drafted, non-digital maps. During this same time period, map production involving computer-aided drafting and geographic information systems evolved rapidly.

This publication includes the digitally produced, full-color geologic map of the Cottonwood Pass 7.5-minute quadrangle. The digital map and accompanying booklet are slightly modified from an earlier publication released by the CGS as Open-File Report 97-4. The digital update was undertaken as part of the STATEMAP component of the National Cooperative Geologic Mapping Program, which is administered by the United States Geological Survey (USGS). In addition to the Cottonwood Pass quadrangle, six other quadrangles in the Glenwood Springs area are being digitally updated. They include the Glenwood Springs, Shoshone, Carbondale, Leon, Basalt, and Mount Sopris quadrangles (Fig. 1).

Most of the modifications to this updated digital geologic map of the Cottonwood Pass quadrangle relate to the discovery of widespread late Cenozoic evaporite collapse in the region (e.g. Kirkham, Streufert, and others, 2001; Kirkham, Scott, and Judkins, 2002) and to a collaborative investigation of that phenomenon by the CGS and USGS subsequent to the release of the CGS Open-



Index Map No.	Quadrangle Name and Reference
1	Rifle Falls quadrangle (Scott and others, 2001)
2	Dotsero quadrangle (Streufert and others, 1997)
3	Silt quadrangle (Shroba and Scott, 2001)
4	New Castle quadrangle (Scott and Shroba, 1997)
5	Storm King Mountain quadrangle (Bryant and others, 2002)
6	Glenwood Springs quadrangle (Kirkham, Streufert, Cappa and others, 2008)
7	Shoshone quadrangle (Kirkham, Streufert, and Cappa, 2008)
8	**Cottonwood Pass quadrangle (this publication)**
9	Hunter Mesa quadrangle (Madole, 1999)
10	Gibson Gulch quadrangle (Madole, 2003)
11	Center Mountain quadrangle (Carroll and others, 1996)
12	Cattle Creek quadrangle (Kirkham and others, 1996)
13	Carbondale quadrangle (Kirkham and Widmann, 2008)
14	Leon quadrangle (Kirkham, Widmann, and Streufert, 2008)
15	Mount Sopris quadrangle (Streufert, 2008)
16	Basalt quadrangle (Streufert, Widmann, and Kirkham, 2008)
17	Woody Creek quadrangle (Freeman, 1972)
18	Highland Peak quadrangle (Bryant, 1972)

Explanation

▨	This publication
▨	CGS 7.5-minute map
▨	USGS 7.5-minute map

Figure 1. Geologic maps of 7.5-minute quadrangles in the vicinity of the Cottonwood Pass quadrangle.

File Report 97-4. The initial discovery of regional evaporite collapse was made during the middle years of the mapping program, and new evidence of the collapse was found as additional quadrangles were mapped and as the data from the collaborative CGS–USGS investigation were interpreted. The conceptual model of the collapse process also evolved considerably during this time, which caused us to re-evaluate some of the structures and mapped units within the quadrangle.

A key part of the collaborative CGS–USGS investigation involved the correlation of Neogene basaltic rocks. Numerous samples of these igneous rocks were collected in the region subsequent to the publication of CGS Open-File Report 97-4. They were analyzed and correlated using geochemistry, $^{40}Ar/^{39}Ar$ geochronology, magnetostratigraphy, paleomagnetism, and petrography (Unruh and others, 2001; Budahn and others, 2002; Kunk and others, 2002; Hudson and others, 2002). Sixteen samples of volcanic rocks from Cottonwood Pass quadrangle were studied during the collaborative CGS–USGS investigation; the correlation and age of these basaltic samples are briefly discussed in a later section.

Most other modifications to the map and booklet are a result of (1) edge matching the geology shown on the Cottonwood Pass quadrangle with adjacent quadrangles; (2) interpretation of the geology of the mapped area with respect to the regional knowledge acquired by mapping contiguous quadrangles; (3) expansion of the booklet to develop a consistent format for all digitally updated maps; and (4) editorial corrections. In addition to producing a block of full-color geologic maps in uniform digital format, the seven edge-matched quadrangles have compatible stratigraphic nomenclature and consistently use formation colors, patterns, and symbols.

Geologic maps produced by the CGS through the STATEMAP program are useful for many purposes, including land-use planning, geotechnical engineering, geologic-hazards assessment, analysis and mitigation of environmental problems, and mineral-resource and ground-water exploration and development. The maps describe the geology of the quadrangle at a scale of 1:24,000 and serve as a good basis for more detailed research and for regional and broad-scale studies.

The Cottonwood Pass quadrangle covers about 58 sq mi in Eagle and Garfield Counties, which are in west-central Colorado. Interstate Highway 70 crosses the northwest corner of the quadrangle. The highway is within Glenwood Canyon, a deep and steep-walled canyon carved by the Colorado River. Most of the land in the northern half of the quadrangle is public land administered by the Bureau of Land Management; the southeast part of the quadrangle is within the White River National Forest; and the remainder of the quadrangle is private land that historically was used mainly for ranching. The 1:24,000-scale topographic base map of the quadrangle was first published in 1961 and later updated in 1987 using aerial photographs taken in 1983.

Mapping responsibilities for the geologic map of Cottonwood Pass quadrangle were as follows: R.K. Streufert mapped the Precambrian and Paleozoic rocks and sedimentary rocks, and R.M. Kirkham the mapped the surficial deposits and the Mesozoic and Cenozoic rocks. B.L. Widmann and T.J. Schroeder served as field assistants. R.M. Kirkham is responsible for the current modifications to the original geologic map and booklet and for preparation of the updated digital product, which was edited by Ms. Widmann.

PRIOR GEOLOGIC MAPS

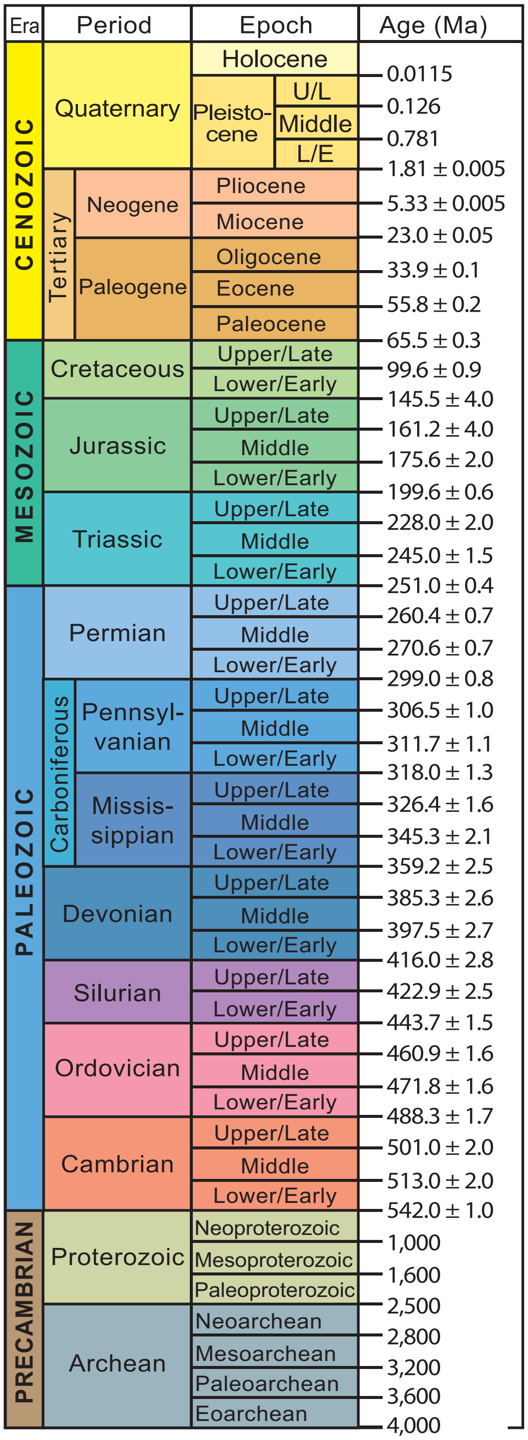
Previously published small-scale geologic maps of the Cottonwood Pass quadrangle include 1:500,000-scale maps by Burbank and others (1935) and Tweto (1979), and the 1:250,000-scale map of Tweto and others (1978). Bass and Northrop (1963) focused on the bedrock in their 1:31,680-scale map of the Glenwood Springs 30-minute quadrangle. F.M. Fox and Associates (1974) mapped the southwest part of the quadrangle at a scale of 1:48,000. CGS originally mapped the north half of the Cottonwood Pass quadrangle at a scale of 1:24,000 (Streufert and Kirkham, 1996). The 1:24,000-scale map of the entire Cottonwood Pass quadrangle was released as Open-File Report 97-4 (Streufert and others, 1997b).

MAPPING METHODS AND TERMINOLOGY

Most field work in Cottonwood Pass quadrangle was conducted by the authors during the 1996 and 1997. The authors occasionally spent short periods of time in the field during ensuing years; most of this work related to the collaborative CGS-USGS investigation of basaltic rocks and evaporite collapse. Traverses were made along all public roads and many of the private roads in the quadrangle. Numerous foot traverses were needed to access remote parts of the quadrangle. Aerial photography was used extensively during the project. Geologic information collected in the field was plotted on 1:24,000-scale or larger-scale photography using a pocket stereoscope. Geologic information drawn on the aerial photographs was transferred to a mylar base map using a Kern PG-2 plotter at the U.S. Geological Survey's photogrammetric facility in Denver.

Volcanic rocks are classified on the basis of the total alkali-silica diagram of Le Bas and others (1986). Grain-size terminology used herein for the sedimentary deposits follows the modified Wentworth scale (Ingram, 1989). This classification system describes pebbles, cobbles, and boulders as differing sizes of gravel. Terms used for sorting are those of Folk and Ward (1957). Sedimentary clasts are defined in this study as rock fragments larger than 2 mm in diameter, whereas matrix refers to surrounding material that is 2 mm or less in diameter (sand, silt, and clay). In clast-supported deposits, the majority of the material consists of clasts that are in point-to-point contact. In matrix-supported deposits most clasts are separated by or embedded in matrix.

The divisions of geologic time and the age estimates of their boundaries are shown in **Figure 2.**



Era	Period	Epoch	Age (Ma)
CENOZOIC	Quaternary	Holocene	0.0115
		Pleistocene U/L	0.126
		Pleistocene Middle	0.781
		Pleistocene L/E	1.81 ± 0.005
	Tertiary Neogene	Pliocene	5.33 ± 0.005
		Miocene	23.0 ± 0.05
	Paleogene	Oligocene	33.9 ± 0.1
		Eocene	55.8 ± 0.2
		Paleocene	65.5 ± 0.3
MESOZOIC	Cretaceous	Upper/Late	99.6 ± 0.9
		Lower/Early	145.5 ± 4.0
	Jurassic	Upper/Late	161.2 ± 4.0
		Middle	175.6 ± 2.0
		Lower/Early	199.6 ± 0.6
	Triassic	Upper/Late	228.0 ± 2.0
		Middle	245.0 ± 1.5
		Lower/Early	251.0 ± 0.4
PALEOZOIC	Permian	Upper/Late	260.4 ± 0.7
		Middle	270.6 ± 0.7
		Lower/Early	299.0 ± 0.8
	Carboniferous Pennsylvanian	Upper/Late	306.5 ± 1.0
		Middle	311.7 ± 1.1
		Lower/Early	318.0 ± 1.3
	Mississippian	Upper/Late	326.4 ± 1.6
		Middle	345.3 ± 2.1
		Lower/Early	359.2 ± 2.5
	Devonian	Upper/Late	385.3 ± 2.6
		Middle	397.5 ± 2.7
		Lower/Early	416.0 ± 2.8
	Silurian	Upper/Late	422.9 ± 2.5
		Lower/Early	443.7 ± 1.5
	Ordovician	Upper/Late	460.9 ± 1.6
		Middle	471.8 ± 1.6
		Lower/Early	488.3 ± 1.7
	Cambrian	Upper/Late	501.0 ± 2.0
		Middle	513.0 ± 2.0
		Lower/Early	542.0 ± 1.0
PRECAMBRIAN	Proterozoic	Neoproterozoic	1,000
		Mesoproterozoic	1,600
		Paleoproterozoic	2,500
	Archean	Neoarchean	2,800
		Mesoarchean	3,200
		Paleoarchean	3,600
		Eoarchean	4,000

U. S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time - major chronostratigraphic and geochronologic units: U. S. Geological Survey Fact 2007-3015, March 2007.

Pleistocene internal ages from International Commision on Stratigraphy, 2007, International stratigraphic chart: downloaded December 2007 from www.stratigraphy.org/cheu.pdf

Figure 2. Geologic time scale.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits in the quadrangle are subdivided into map units on the basis of either genesis or landform and also relative age. Surficial units shown on the map are generally more than about 5 ft thick. Deposits associated with distinct landforms locally may be thinner than 5 ft. Surficial deposits with a width of about 25 ft or less are not shown on the map because they cannot be depicted on a 1:24,000-scale map. Artificial fill of limited areal extent and residuum were not mapped. Contacts between many surficial units may be gradational and therefore should be considered as approximate boundaries.

Most of the surficial deposits in the Cottonwood Pass quadrangle are not well exposed. Therefore, the attributes of these units, such as thickness, texture, stratification, and composition, are based on observations made at only a few locations and on geomorphic characteristics. Since some of the intended users of this map will be interested in unconsolidated surficial materials and active surficial processes, the surficial deposits are subdivided into a relatively large number of map units compared to traditional bedrock-oriented geologic maps.

Characteristics such as the position in the landscape, degree of erosional modification of original surface morphology, clast weathering, and soil development were used to estimate the relative ages of the surficial deposits. Soil-horizon names used here are those of the Soil Survey Staff (1975) and Guthrie and Witty (1982), and the stages of secondary carbonate morphology are from Gile and others (1966), with the modifications of Machette (1985).

HUMAN-MADE DEPOSITS—Materials placed by humans

af **Artificial fill (latest Holocene)—**Fill and waste rock placed by humans during the construction of small dams. Artificial fill is composed mostly of unsorted silt, sand, and rock fragments. Maximum thickness about 25 ft.

ALLUVIAL DEPOSITS—Silt, sand, and gravel deposited in stream channels, flood plains, terraces, and sheetwash areas along the Colorado River and in tributaries. Locally includes minor lacustrine deposits.

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)—**Includes modern alluvium and other deposits underlying the Colorado River, adjacent flood-plain deposits, and low-terrace alluvium that is as much as about 15 ft above modern stream level. Mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel sometimes interbedded with and often overlain by sandy silt and silty sand. Unit is poorly to moderately well sorted and moderately well to well bedded. Clasts are subangular to well rounded, and their varied lithology reflects the diverse types of bedrock in their provenance. Unit Qa includes organic-rich deposits and lacustrine clay or silt that were deposited upstream of a rockfall dam that formed during the early Holocene in the vicinity of modern Shoshone dam about 4 mi downstream of the quadrangle (White and Kirkham, 1997). The lacustrine deposits are well sorted and well bedded. Maximum thickness of unit Qa may exceed 200 ft in Glenwood Canyon (White and Kirkham, 1997). Carbon 14 dates on organic material within the thick section of lacustrine sediments deposited upstream of the rockfall dam ranged from 9,820 ± 130 to 3,890 ± 120 radiocarbon years B.P. (J.B. Gilmore, 1984, personal commun., cited in White and Kirkham, 1997).

Qsw **Sheetwash deposits (Holocene and late Pleistocene)—**Includes deposits locally derived from weathered bedrock and surficial materials which are transported predominantly by sheetwash and accumulate in ephemeral stream valleys, on gentle hillslopes, or in basinal areas. Sheetwash deposits typically consist of pebbly, silty sand and sandy silt. Unit is common on gentle to moderate slopes underlain by shale, basalt, and landslide deposits. Sheetwash deposits frequently fill the floor of sinkholes. Locally the deposits are gradational and interfingered with colluvium on steeper hillslopes and with lacustrine or slackwater deposits in closed depressions. Maximum thickness is probably about 30 ft.

Qty **Younger terrace alluvium (late Pleistocene)—** Chiefly stream alluvium in a terrace about 45 ft above the Colorado River. Consists of poorly sorted, clast-supported, silty, sandy, occasionally bouldery, cobble and pebble gravel that is overlain by 3 to 5 ft of fine-grained overbank deposits. Clasts are subround to round and are composed mainly of coarse-grained plutonic rocks, red sandstone, and basalt with lesser amounts of other lithologies, including hypabyssal rocks. Clasts generally unweathered or only very slightly weathered. Exposed thickness about 35 ft, but likely is thicker.

West of the quadrangle, at the rest area on Highway I-70 in West Glenwood Springs, peat interbedded with tufa that overlies a younger terrace deposit only 19 ft above the Colorado River yielded a conventional radiocarbon ^{14}C date of 12,410 ± 60 years B.P. (Kirkham, Streufert, Cappa and others, 2008). This dated terrace may in part correlate with or be slightly younger than younger terrace alluvium in the Cottonwood Pass quadrangle. Unit Qty was probably deposited during the Pinedale glaciation.

Qgo **Older gravel deposits (Pleistocene)—**Older gravel deposits cap the eastern end of the ridge between Spring Gulch and the Cottonwood Pass road along the eastern edge of the quadrangle. Although the deposit is very poorly exposed, it appears to vary from poorly sorted, clast-supported, silty, pebble and cobble gravel to poorly sorted, matrix-supported, sandy, pebbly silt. The clasts are moderately weathered, rounded to subangular, and composed chiefly of red sandstone with lesser amounts of quartzite, quartz, plutonic rocks, limestone, and light-brown sandstone. The older gravel deposits range from 160 to 280 ft above adjacent drainages. The age of unit Qgo is poorly constrained. Maximum thickness is around 30 ft.

QTg **High-level gravel (early Pleistocene and late Tertiary)—**A single deposit of high-level gravel caps the ridge south of Spring Gulch along the eastern edge of the quadrangle. The deposit is very poorly exposed. It probably is a clast-supported, sandy, silty, pebble and cobble gravel that locally is slightly bouldery. Clasts are rounded to subangular and are composed almost entirely of red sandstone and quartzite with minor amounts of quartz, limestone, and plutonic rocks. Clasts are moderately to very weathered. The deposit is as much as 80 ft thick in Cottonwood Pass quadrangle and is about 110 ft thick immediately east of quadrangle. It lies about 400 to 450 ft above the floor of Spring Gulch, which suggests the deposit is early Pleistocene or late Tertiary in age.

MASS-WASTING DEPOSITS—Silt, sand, gravel, and clay on valley sides, valley floors, and hill slopes that were transported and deposited primarily by gravity, although water can play an important role in triggering the movement.

Qlsr **Recent landslide deposits (latest Holocene)-** Includes a single, narrow, elongate earthflow in upper Tom Creek that occurred during the spring of 1995. The deposit consists of unsorted, unstratified clay, silt, sand, gravel, and rock debris derived from landslide deposits (unit Qls). Clasts are mainly angular to subangular basalt and rounded to subangular red sandstone. In the fall of 1995 the deposit was water saturated, and water was seeping from the base of the head scarp. The maximum thickness of the deposit is about 20 ft.

Qc **Colluvium (Holocene and late Pleistocene)—** Ranges from unstratified, unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Colluvium is typically coarser grained in the upper reaches of colluvium-covered slope and finer grained in distal areas. Clasts within colluvium usually are angular to subangular. Areas mapped as colluvium locally include talus, landslides, sheetwash, and debris flows that are too small or too indistinct on aerial photography to be mapped separately. Maximum thickness is estimated at about 50 ft.

Qt **Talus (Holocene and late Pleistocene)—** Angular, cobbly and bouldery rubble on and at the base of steep slopes that was transported downslope principally by gravity as rockfalls, rockslides, rock avalanches, and rock topples. Talus frequently lacks matrix material. Much of the talus in the quandrangle is derived from cliffs of volcanic rock on Dock Flats, Cottonwood Divide, Buck Point, and Gobbler Knob and from lower Paleozoic rocks in Glenwood Canyon. Talus is locally underlain by or incorporated into landslides around the margin of Dock Flats, Cottonwood Divide, and Buck Point. Maximum thickness of talus is estimated at about 50 ft.

Qls **Landslide deposits (Holocene and Pleistocene)—**Highly variable deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Landslide deposits are associated with landforms that have recognizable, but sometimes subdued, geomorphic features such as hummocky ground, lobate form, headscarps, and closed depressions. The unit includes rotational landslides, translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Maximum thickness of landslide deposits is estimated at 200 ft. The upper end of the large landslide on the north side of Dock Flats and east side of Cottonwood Divide includes long, linear toreva blocks of intact but displaced and rotated volcanic bedrock. Two landslides mapped in the NE¼ Sec. 34, T. 5 S., R. 86 W., one of which is northeast of Blue Hill and a second one in Mary Jane Gulch, may actually be regional subsidence features related to large-scale collapse of the ground surface into voids or caves in the underlying Eagle Valley Evaporite.

Qco **Older colluvium (Pleistocene)—**Includes erosional remnants of formerly more extensive colluvial deposits on ridges, drainage divides, and dissected slopes on valley. Older colluvium also locally occurs as collapse debris or fill in sinkholes formed by dissolution of evaporite beds. Deposits of older colluvium are similar in genesis, texture, and bedding to deposits of colluvium (unit Qc). Areas mapped as older colluvium locally may include small, unmapped, older landslide deposits (unit Qlso). Unit Qco averages 10 to 25 ft thick and has a maximum thickness about 60 ft.

Qlso **Older landslide deposits (Pleistocene and late Tertiary?)—**Older landslide deposits have subdued morphologic features or are deeply dissected by erosion, which suggests the deposits are middle Pleistocene or older. Older landslide deposits are similar in texture, bedding, sorting, and clast lithology to landslide deposits (unit Qls). The type of landslide movement generally is not identifiable due to the eroded character of the deposits. Maximum thickness of older landslide deposits is probably around 100 ft.

ALLUVIAL AND MASS-WASTING DEPOSITS—
These deposits include alluvial and colluvial material that is mapped as a single unit because they are juxtaposed and are too small to show individually, or they have contacts that are not clearly defined. Fan deposits also are classified as mixed alluvial and mass-wasting deposits because in addition to alluvium, they also include significant volumes of sediment from debris flows, which are generally considered to be a form of mass wasting (e.g. Cruden and Varnes, 1996; Hungr and others, 2001).

Qdfy **Younger debris-flow deposits (Holocene)—**Sediments deposited by debris flows, hyperconcentrated flows, streams, and sheetwash on active fans and in stream channels. Younger debris-flow deposits range from poorly sorted to moderately well-sorted, matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble and cobble gravel in a sandy, clayey silt or silty sand matrix. The unit commonly is very bouldery, particularly near fan heads. Distal parts of some fans are characterized by mudflow and sheetwash and tend to be finer grained. Younger debris-flow deposits are locally interfingered or interbedded with modern alluvium adjacent to perennial stream channels. Clasts are mostly angular to subround sedimentary rock and basalt fragments up to about 6 ft in diameter. Original depositional surfaces are usually preserved, except where they have been disturbed by human activities. Maximum thickness of the unit is about 50 ft.

Qac **Alluvium and colluvium, undivided (Holocene and latest Pleistocene)—**This unit chiefly consists of stream-channel, low-terrace, and flood-plain deposits along the valley floors of ephemeral, intermittent, and small perennial streams, with colluvium and sheetwash common on valley sides. Locally, areas mapped as unit Qac may include younger debris-flow deposits, or they may grade to debris-flow deposits in some drainages. The alluvial fraction typically is composed of poorly sorted to well-sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel. Colluvial beds are commonly unsorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt. Thickness of unit Qac usually ranges from 5 to 20 ft, and its maximum thickness is estimated at about 40 ft.

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)—**Composed of colluvium (see unit Qc) on steeper slopes and sheetwash deposits on flatter slopes. Sheetwash consists of sorted and stratified pebbly, silty sand and sandy silt. Thickness of unit Qcs averages 10 to 30 ft.

Qdfo **Older debris-flow deposits (early Holocene and Pleistocene)—**Older debris-flow deposits fill a tributary valley to the Colorado River along the north edge of the quadrangle. The deposits are genetically, texturally, and lithologically similar to younger debris-flow deposits (unit Qdfy), and locally are cemented with tufa. The channels of modern drainages are incised 20 to 60 ft below the original depositional surface of the older debris-flow deposits. Thickness of unit Qdfo is generally about 10 to 60 ft, but it locally exceeds 80 ft.

Qaco **Older alluvium and colluvium, undivided (Pleistocene)—**Includes deposits of alluvium and colluvium that underlie terraces and hillslopes 10 to 50 ft above adjacent ephemeral, intermittent, and small perennial streams. Texture, bedding, sorting, and genesis of unit Qaco are similar to unit Qac. Locally, unit Qaco includes debris-flow and sheetwash deposits. Maximum thickness of unit Qaco is about 20 ft.

QTbg **High-level basaltic gravel (early Pleistocene or late Tertiary?)—**Deposits of high-level basaltic gravel cap the ridge west of Spruce Creek, and a small deposit of high-level basaltic gravel lies on the north end of Spruce Ridge. The unit consists of slightly indurated, matrix-supported, gravelly and clayey sandy silt that probably was deposited as debris flows, earthflows, colluvium, or landslides. Clasts vary from pebble to boulder sizes and are primarily composed of very weathered, rounded to subangular basalt with minor amounts of red sandstone and conglomerate, quartzite, quartz, pink granite, and chert. The deposits are 400 to 600 ft above Spruce Creek. Maximum thickness is about 60 ft.

QTc **Sediments of Cottonwood Bowl (early Pleistocene and late Tertiary?)—**Locally derived gravel, sand, silt, and clay in unit QTc lies in and near the topographic bowl in the headwaters of East Coulter Creek. The unit is poorly exposed, but it appears to vary from sandy and silty pebble, granule, or cobble gravel to gravelly, sandy silt. Gravel clasts are predominantly subangular or subrounded and are moderately to highly weathered. Basalt, red, pink, and tan sandstone and siltstone, gray limestone, and quartz are the primary clast lithologies. The sediments of Cottonwood Bowl probably were deposited in fluvial, sheetwash, and colluvial environments in a large collapse bowl that formed in response to subsidence caused by dissolution or flowage of underlying evaporitic rocks. The maximum preserved thickness of the sediments is estimated at 100 ft; however they likely were much thicker prior to incision by East Coulter Creek.

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q **Surficial deposits, undifferentiated (Quaternary)—**Shown only on cross section.

BEDROCK

Tag **Basaltic trachyandesite of Gobbler Knob (Pliocene)—**Unit Tag includes two erosional remnants of gray, dark-gray, and black, dense to vesicular flows of basaltic trachyandesite on and south of Gobbler Knob. The flows contain phenocrysts of olivine and xenocrysts of quartz with reaction rims of clinopyroxene. Budahn and others (2002) included a sample from the flow on Gobbler Knob (KH95-26) in their compositional group 7a. This sample yielded an ^{40}Ar/^{39}Ar age of 3.03 ± 0.02 Ma (Kunk and others 2002). The eroded Gobbler cone is probably the eruptive center for the flows in unit Tag.

Tagc **Cinder deposits of Gobbler Cone (Pliocene)—**Red and red-brown scoriaceous, ashy cinder beds, agglutinated cinder beds, flow breccias, and thin lava flows associated with an eroded eruptive center on Dock Flats that we call Gobble Cone. Petrographically the unit is olivine basalt with quartz xenocrysts; chemically it is classified as basaltic trachyandesite and is included in compositional group 7a (Budahn and others, 2002). These cindery deposits overlie and hence are younger than the 7.7–7.8 Ma basaltic flows of unit Tb that cap most of Dock Flats.

Tbpc

Cinder deposits of Buck Point (Pliocene)—Red to brownish-red and black, loose to well-cemented cinder beds, minor flow breccias with clasts ranging from 1 to 20 inches in diameter, and thin flows. Highly vesicular clasts are typically red and very oxidized. The less vesicular clasts and flows are petrographically similar to the basaltic trachyandesite flows in unit Tbp. A sample from a thin flow interbedded with cinder deposits on the east side of Buck Point (sample CPV-3) is basaltic trachyandesite (Appendix A) and is included in compositional group 6b", as are all flows in unit Tbp (Budahn and others, 2002). The cinder deposits of Buck Point are probably the result of a late stage, high gas content, explosive eruption which probably eminated from the Buck Point vent. This explosive eruption may post-date the eruption or series of eruptions that produced the flat-lying flows of unit Tbp on the north and northwest sides of Buck Point, because the columnar-jointed flows of unit Tbp exposed at the base of the south flank of Buck Point appear to underlie and grade upward into the cinder deposits of unit Tbpc.

Tbp

Basaltic trachyandesite of Buck Point (Pliocene)—Medium- to dark-gray, dense to slightly vesicular flows of basaltic trachyandesite on Buck Point. The flows contain phenocrysts of pyroxene and abundant olivine. Quartz and feldspar xenocrysts are partially resorbed and sometimes recrystallized. The quartz xenocrysts have reaction rims of pyroxene, carbonate, and biotite. The holocrystalline to glassy groundmass is fine grained and contains plagioclase microlites and 1 to 5 percent opaque minerals. Budahn and others (2002) included samples from unit Tbp (CP86, CPV-2, CPV-4) in their compositional group 6b". The unit includes a sequence of flat-bedded lava flows, with an approximate total thickness of 50 to 100 ft, and an outcrop of massive columnar-jointed lava approximately 100 to 150 ft thick. The flows of unit Tbp were erupted from a vent at Buck Point. The columnar-jointed lava is interpreted as the near-vent facies of the unit, while the flat-bedded lavas may have flowed farther from the vent. Sample CP86 yielded an ^{40}Ar/^{39}Ar plateau age of 3.17 ± 0.02 Ma (Kunk and others, 2002).

Tta

Trachyandesite (Pliocene)—Includes a single, small outcrop of dense to vesicular medium-gray flows and flow breccias. These rocks are contiguous with a sequence of volcanic rocks in Leon quadrangle for which petrographic and chemical data are available (Kirkham, Widmann, and Streufert, 2008). Petrographically these flows consist of olivine basalt with xenocrysts of quartz, sanidine, and plagioclase; chemically they are basaltic trachyandesite (sample L-6 of Kirkham, Widmann, and Streufert, 2004). These rocks probably are ~3 to 4 Ma, as are the other trachyandesitic rocks in Cottonwood Pass quadrangle, in Shoshone quadrangle (Kirkham, Streufert, and Cappa, 2008), and in Leon quadrangle (Kirkham, Widmann, and Streufert, 2008).

Tb

Basalt (Miocene)—Multiple stacked flows and minor flow breccias of trachybasalt that are widespread across the west-central and south-central parts of the quadrangle. The trachybasalt flows range from massive to highly vesicular, with sparse amygdules of calcite. The groundmass is predominantly plagioclase and pyroxene, with minor amounts of olivine, glass, pigeonite, augite, and magnetite. Phenocrysts are euhedral to subhedral olivine that weathers to iddingsite along the crystal edges and fractures. Unit Tb is well exposed in the headscarps of two large landslides on the north and east sides of Dock Flats, where it consists of multiple, stacked flows with a maximum exposed thickness of around 180 ft. Eight chemically analyzed flows from unit Tb are included in compositional group 5a of Budahn and others (2002), and one is in compositional group 5a' (Table 1). Three of the group 5a samples were dated using whole-rock ^{40}Ar/^{39}Ar methods. The ages ranged from 7.72 ± 0.04 Ma to 7.80 ± 0.04 Ma (Kunk and others, 2002).

Ts

Sedimentary deposits (Miocene)—Includes widespread deposits that underlie basalt flows near and south of Cottonwood Pass, and a thin, localized deposit associated with the basalt (unit Tb)on Spruce Ridge. Deposits of unit Ts near and south of Cottonwood Pass are poorly exposed. Here the unit contains abundant round to subangular pebbles of red sandstone, quartz, and coarse-grained plutonic rocks, with minor amounts of metamorphic and hypabyssal lithologies. The hypabyssal clasts are similiar to ones in late Pleistocene Colorado River deposits upstream of Dotsero. Float mapping was the primary field technique used to map the extent of unit Ts. Due to the lack of exposures, it is uncertain whether the strata in unit Ts are clast supported or matrix supported. East of Cottonwood Pass the unit includes finer-grained sandy and clayey silt that is exposed in roadcuts along the Cottonwood Pass road.

Pebbly strata in unit Ts also underlies a basaltic flow (unit Tb) on Spruce Ridge. A channel filled with clast-supported sandy pebble and cobble gravel included in unit Ts partially cuts out the basaltic flow on Spruce Ridge (Kirkham, Kunk, and others, 2001). These channel deposits also are included in unit Ts. The clasts in the channel gravel are moderately to very weathered, well rounded to subrounded, and chiefly composed of various types of plutonic granitic rocks, red sandstone, quartzite, quartz, and conglomeratic sandstone. These lithologies are typical of a Colorado River provenance. Cross-cutting relationships between the channel and basaltic flow on Spruce Ridge indicates unit Ts both pre-dates and post-dates the eruption of unit Tb lavas around 7.7–7.8 Ma. The thickness of the channel deposit on Spruce Ridge may be as much as about 50 ft. Deposits of unit Ts near and south of Cottonwood Pass may attain thicknesses in excess of 200 ft.

TRPcs

Chinle and State Bridge Formations, undivided (Upper Triassic and Permian)—The Chinle Formation consists of thin, even-bedded, and massive red beds of dark-reddish-brown, orangish-red, and purplish-red, calcareous siltstone and mudstone with occasional thin lenses of light-purplish-red and gray limestone and limestone-pebble conglomerate. The underlying State Bridge Formation consists of pale red, grayish-red, reddish-brown, and greenish-gray, micaceous siltstone, clayey siltstone, and minor sandstone. Unit TRPcs occurs in the southeast corner of the quadrangle where it is exposed in a large footwall syncline on the east and downthrown side of the Laramide Basalt Mountain Fault. The Chinle and State Bridge Formations are poorly exposed, which prevents recognition of the contact between the formations. Total estimated thickness of the combined unit is 385 ft. Environments of deposition for the combined unit include shallow marine and fluvial-lacustrine.

PIPm

Maroon Formation (Lower Permian and Upper Pennsylvanian)—Red beds of sandstone, conglomerate, siltstone, mudstone, and shale with minor thin beds of gray limestone comprise the Maroon Formation. Most Maroon strata are arkosic and micaceous. Only parts of the formation are preserved in the quadrangle. The lower part of the formation crops out in the northeast corner of the quadrangle. Only the uppermost part of the formation is present in the southeast corner of the quadrangle; the balance of the formation is cut out by a fault. Total thickness of the formation in adjacent areas is 3,000 to 5,000 ft (Kirkham, Streufert, and Cappa, 2008; Kirkham, Bryant and others, 1996). The Maroon Formation was deposited in the Central Colorado Trough between the Ancestral Front Range and Uncompahgre Highlands in fluvial and perhaps eolian environments (Johnson and others, 1988).

IPe

Eagle Valley Formation (Middle Pennsylvanian)—The Eagle Valley Formation consists of interbedded reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks. The formation represents a stratigraphic interval in which the red beds of the Maroon Formation grade into and intertongue with the predominantly evaporitic rocks of the Eagle Valley Evaporite. It includes rock types of both formations. Strata in the lower part of the Eagle Valley Formation frequently are deformed by dissolution and flowage of underlying evaporite rocks. The Eagle Valley Formation is both conformable and intertonguing with the overlying Maroon Formation and underlying Eagle Valley Evaporite. Contact with the Maroon Formation is placed at the top of the uppermost evaporite bed or light-colored clastic bed. The intertonguing relationship with the underlying Eagle Valley Evaporite is well exposed on the east side of Cottonwood Creek. Thickness is variable, ranging from about 500 to 1,000 ft. The formation was deposited in the Eagle Basin in fluvial, eolian, and marine environments on the margin of an evaporite basin.

IPee

Eagle Valley Evaporite (Middle Pennsylvanian)—A sequence of evaporitic rocks consisting mainly of massive to laminated gypsum, anhydrite, and halite, interbedded with light-colored mudstone and fine-grained sandstone, thin carbonate beds, and black shale comprises the Eagle Valley Evaporite. Strata in the formation commonly are intensely folded, faulted, and ductily deformed by diapirism, flowage, load metamorphism, dissolution, hydration of anhydrite, and regional tectonism. The Eagle Valley Evaporite generally is poorly exposed; however, there are excellent exposures along east side of Cottonwood Creek. The contact with overlying Eagle Valley Formation is both conformable and intertonguing and is defined as the base of the lowest red bed within the Eagle Valley Formation. Thickness of the formation averages about 1,800 ft, but it varies due to flowage and diapirism. The Eagle Valley Evaporite was deposited in the Eagle Basin after the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1989) recognized multiple transgressive-regressive sedimentary cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment rather than in a sabkha. The formation may include eolian deposits similar to those reported by Schenk (1987).

ℙeu

Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian)—Includes the Eagle Valley Formation and Eagle Valley Evaporite on the west side of upper Cottonwood Creek where thick vegetation precludes recognition of the contact between the units.

ℙb

Belden Formation (Lower Pennsylvanian)—The Belden Formation consists of medium-gray to black shale, dark-brown, calcareous and locally micaceous shale, and coarse-grained, gray, fossiliferous limestone. Thin interbeds and lenses of fine-grained, micaceous, greenish-tan sandstone are locally present. The upper 100 ft of the formation includes four or five prominent beds of conglomeratic, very coarse-grained, lithic-rich wackes and subarkoses that probably are equivalent to the Minturn Formation that crops out in the Dotsero quadrangle (Streufert, Kirkham, and others, 1997a). Discontinuous gypsum beds may occur anywhere in the Belden Formation, but they tend to be more common near the top of the formation. Belden strata locally are rich in fossils (Bass and Northrup, 1963). The entire formation, including the basal and upper contacts, is well exposed along the east wall of lower Cottonwood Creek valley. A massive bed of gypsum at the base of the overlying Eagle Valley Evaporite conformably overlies the Belden Formation (Mallory, 1971). Thickness of the Belden ranges from 1,150 to 1,270 ft thick in the quadrangle. The formation was deposited in the Central Colorado Trough over a widespread area between the Ancestral Uncompahgre and Front Range Highlands. Shale-limestone sequences in the lower part of the formation record low-energy sedimentation distal from source areas. Conglomeratic beds near the top of the Belden may have been eroded from nearby uplifts formed by Pennsylvanian mountain building (Streufert and others, 1997a).

Ml

Leadville Limestone (Mississippian)—Light- to medium-gray, bluish-gray, massive, coarse to finely crystalline, fossiliferous, micritic limestone and dolomite. Lenses and nodules of dark-gray to black chert as much as 0.3 ft thick are present in the lower one-third of the formation. The upper half of the formation locally contains coarse-grained oolites. Carbonate veinlets with disseminated silt-sized quartz grains are common. Collapse breccias, filled solution cavities, and a locally preserved thin reddish-purple claystone regolith called the Molas Formation formed on a paleokarst surface at the top of the formation. The Leadville Limestone is very fossiliferous and contains abundant crinoid and brachiopod fragments. The upper contact of the Leadville Limestone is irregular and unconformable with the overlying Belden Formation. Thickness of the Leadville Limestone averages 180 to 200 ft. Leadville sediments formed in a marine environment in the sub-littoral zone by the accumulation of biogenic and oolitic sediment.

Dc

Chaffee Group (Upper Devonian)—Three formations are included in the Chaffee Group. In descending order they are the Gilman Sandstone, Dyer Dolomite, and the Parting Formation. The **Gilman Sandstone** consists of tan to yellow, laminated, fine to very fine-grained calcareous sandstone. Laminae are generally less than 1 inch in thickness and consist of beds of fine sand that locally have weak planar-tabular cross-bedding and minor load structures. Some laminae contain discontinuous lenses of quartz arenite with relict casts of carbonate rhombohedron. The contact between the Gilman Sandstone and overlying Leadville Limestone is unconformable. Tweto and Lovering (1977) suggested a water-reworked, eolian origin for the Gilman Sandstone near Gilman. Most likely it was deposited in a changing environment of very shallow water and periodic subaerial exposure in the supratidal (tidal flat) zone.

The **Dyer Dolomite** is divided into two members. The upper or Coffee Pot Member, consists of crystalline, micritic dolomite, dolomitic gray shale, and micritic limestone that is somewhat sandy, especially near the top of the member. The Coffee Pot Member was deposited predominantly in the uppermost intertidal to supratidal (tidal flat) zones in a changing environment of periodic subaerial exposure with influxes of shallow marine conditions The lower or Broken Rib Member consists of gray, nodular, crystalline limestone that is characterized by abundant rip-up clasts, intraformational breccia, and bioturbated bedding (Soule, 1992). The Dyer Dolomite formed in a shallow marine environment in the sub-littoral zone.

The **Parting Formation**, which is the lowest formation in the Chaffee Group, consists of interbedded white to buff, massive orthoquartzite containing feldspar and rock fragments, micaceous green shale with discontinuous lenses of quartzite, and gray, sandy micritic dolomite. The orthoquartzite beds range in thickness from 0.5 to 1.0 ft and give the formation its popular name, "Parting quartzite." The Parting Formation formed in a shallow marine environment Total thickness of the Chaffee Group in Glenwood Canyon is 252 ft (Soule, 1992).

Om

Manitou Formation (Lower Ordovician)— Consists predominantly of medium-bedded, brown dolomite, limestone, sandstone, and thin beds of gray, flat-pebble limestone conglomerate interbedded with greenish-gray calcareous shale. In Glenwood Canyon the Manitou Formation is 156 ft thick according to Bass and Northrop (1963) and 167 ft thick as measured by Soule (1992). The Manitou Formation is divided into two members, the Tie Gulch Member and the underlying Dead Horse Conglomerate Member.

The upper or **Tie Gulch Member** consists of massive, micritic, brown- and orange-weathering, crystalline, somewhat siliceous dolomite and minor limestone that becomes somewhat sandy near the top. Some beds are glauconitic although considerably less so than the underlying beds of the Dead Horse Conglomerate Member. Contact with the overlying Devonian Chaffee Group is unconformable, occurring at a thin shale bed that may be a paleosol (Soule, 1992). The Tie Gulch Member is 50 to 90 ft thick. Strong dolomitization and a lack of marine fossils suggest that sediments of the Tie Gulch Member accumulated in the upper intertidal and/or lowermost supratidal (tidal flat) environments.

The lower or **Dead Horse Conglomerate Member** consists mostly of thin-bedded, gray, flat-pebble limestone conglomerate, thin-bedded limestone, shaly limestone, and two beds of massive, dolomitic orthoquartzite. This member is glauconitic, especially in its lower part. A diverse Lower Ordovician fossil fauna was collected from the member by Bass and Northrop (1963) in Glenwood Canyon. The Dead Horse Conglomerate Member most likely was deposited under fluctuating conditions and varying water depths in the intertidal and shallow marine environments.

Єd

Dotsero Formation (Upper Cambrian)— Includes four units which in descending order are the Clinetop Bed, Glenwood Canyon Member, Red Cliff Member, and Sheep Mountain Member (Myrow and others, 2003). The uppermost unit is a 5-ft thick sequence of matrix-supported limestone-pebble conglomerate with abundant rip-up clasts and an overlying bed of stromatolitic limestone with well-preserved algal-head crinkle structure that is now called the **Clinetop Bed** (Myrow and others, 2003).

The Glenwood Canyon Member consists of approximately 50 ft of thin-bedded dolostone, dolomitic sandstone, conglomeratic limestone, coarse-grained fossiliferous limestone, and dolomitic shale. Dolomitic beds in the Glenwood Canyon Member are glauconitic, giving the beds a greenish hue. Worm tracks and worm burrow (fucoids) are common, especially in the middle third of the member.

The **Red Cliff Member** is composed of approximately 20 ft of sandy dolostone, flat-pebble conglomerate, and dolomitic shale. It is locally glauconitic and/or bioturbated. Although it is a distinct member east of the quadrangle, the contact between the Red Cliff Member and overlying Glenwood Canyon Member is much less distinct within the quadrangle (Myrow and others, 2003). The basal unit of the Dotsero Formation is the **Sheep Mountain Member**, which rests on the white quartz-rich Sawatch Formation. The member consists of 5-6 ft of light-brown, very fine- to medium-grained, glauconitic, well-sorted sandstone and local dolomitic flat-pebble conglomerate.

The Dotsero Formation generally forms a vegetated slope above the prominent cliffs of the Sawatch Formation. The formation is about 80 ft thick. Variation in lithologies and sedimentary structures in the formation indicate a period of widely fluctuating depositional patterns ranging from near-shore shallow marine through intertidal to supratidal (tidal flat) environments.

€s

Sawatch Formation (Upper Cambrian)—The Sawatch Formation consists of white and buff to gray-orange, brown-weathering, vitreous quartz arenite in beds from 1 to 3 ft thick. The middle part of the formation includes beds of sandy dolomite. The Sawatch Formation probably was deposited in a beach environment or in shallow water of the littoral zone. The unnamed beds above the Sawatch may have formed in the intertidal or lowermost supratidal (tidal flat) environment. Total thickness of this unit is about 500 ft.

p€

Precambrian rocks, undivided (Proterozoic)—Igneous and metamorphic rocks. Shown only on cross section.

GEOLOGIC SETTING

The rocks and surficial deposits of the Cottonwood Pass quadrangle record a long and diverse geologic history. The rocks are moderately to well exposed on the steep walls of Glenwood Canyon and on the northeast wall of Cottonwood Creek but are less well exposed in the rest of the mapped area. The oldest exposed rocks are the Cambrian Sawatch Formation (unit Ꞓs). A spectacular nonconformity that crops out in Glenwood Canyon a few miles downstream of the Cottonwood Pass quadrangle separates the Sawatch Formation from underlying Early Proterozoic igneous and metamorphic rocks, which are not exposed in the quadrangle. The Sawatch Formation is the basal formation in a sequence of Cambrian through Mississippian sediments that were episodically deposited in a shelf environment. In addition to the Sawatch Formation, this sequence includes in ascending order the Dotsero Formation, Manitou Formation, Chaffee Group, and Leadville Limestone. Disconformities within the Cambrian through Mississippian sequence represent more geologic time than do the preserved strata (Ross and Tweto, 1980).

A long period of extended subaerial exposure occurred between deposition of the Leadville Limestone and the overlying Lower Pennsylvanian Belden Formation. An extensive karst topography that included sinkholes, caverns, and limestone towers developed on the top of the Leadville Limestone during this time interval. A brightly colored regolith, the Molas Formation, formed on the karst topography and filled many of the sinkholes. The Molas Formation is too thin and discontinuous in the quadrangle to be mapped at a scale of 1:24,000, therefore it is included in the Leadville Limestone.

Major elongate, northwest-trending uplifts began to form in Early or Middle Pennsylvanian time. These uplifts, commonly referred to as the Ancestral Rocky Mountains, developed both to the east of the quadrangle (Ancestral Front Range Highland) and to the west (Ancestral Uncompahgre Highland). As the uplifts rose, lower Paleozoic strata were stripped off the uplifts, exposing the underlying Precambrian rocks. During the Pennsylvanian and Permian, clastic sediments eroded from the uplifts and accumulated in flanking basins such as the Central Colorado Trough (Brill, 1944; De Voto, 1980). The Cottonwood Pass quadrangle, which lies within the Eagle Basin part of the Central Colorado Trough, received several thousand feet of sediment stripped from the uplifts.

Carbonaceous marine shales, thin limestones, and minor gypsum within the Belden Shale were the initial fill deposited in the Eagle Basin in the quadrangle. Conglomeratic beds in the upper part of the Belden may have been eroded off small nearby uplifts. Evaporitic sediments of the Eagle Valley Evaporite, including halite and gypsum, accumulated over the Belden. Highly soluable evaporite minerals like halite were not observed in outcrop in the quadrangle, but they have been encountered in oil test holes drilled in nearby areas. Lower Permian and Upper Pennsylvanian red beds of sandstone, conglomerate, and siltstone of the Maroon Formation were deposited in fluvial and fan environments that prograded into and over the evaporitic sequence. An interval of interbedded red beds and evaporitic strata that separates the Eagle Valley Evaporite from the Maroon Formation is mapped as the Eagle Valley Formation. Thick sequences of Permian to Eocene sedimentary rocks overlie the Maroon Formation in adjacent areas, but of these rocks only the Triassic and Permian Statebridge Formation and Triassic Chinle Formation are preserved in the quadrangle.

Tectonism and igneous activity associated with the Laramide orogeny initiated near the end of the Cretaceous. The White River Uplift, a broad domal structure whose southern flank extends into the northwestern part of the quadrangle, formed during the late Cretaceous-Eocene Laramide orogeny (Tweto, 1975). Evidence reported by

Donnell (1961) and Tweto (1975) indicate the White River Uplift was active chiefly in the Eocene.

Sometime after the Laramide orogeny, perhaps initially during late Eocene time (Scott, 1975) and possibly later modified by one or more subsequent periods of erosion (Kirkham, Kunk, and others, 2001; Steven, 2002), a broad erosion surface was cut across the region. Fluvial gravels of probable Miocene age (unit Ts) were deposited locally on this unconformity. Remnants of these deposits are preserved near and south of Cottonwood Pass and on Spruce Ridge. Miocene basaltic rocks, including the 7.7–7.8 Ma flows in unit Tb, also were episodically erupted onto low-relief erosion surfaces in the quadrangle. These volcanic flows cover much of the southwestern part of the quadrangle, where they locally overlie the Miocene sediments. Volcanism continued episodically into the Pliocene, as evidenced by the ~ 3 Ma eruptive centers at Buck Point and Gobbler cone and their associated flows.

The lithologies of clasts contained in the Miocene sediments suggest unit Ts was deposited by an ancestral Colorado River. The Miocene sediments locally include fine-grained silts and clays, which have been interpreted as evidence that the volcanic flows of unit Tb dammed the ancestral river. Relationships between the Miocene sediments and volcanic flows on Spruce Ridge, including the cobble gravel that cuts through the volcanic flows, support a conclusion that the ancestral river was diverted into Glenwood Canyon as the flows were erupted or shortly thereafter (Kirkham, Kunk, and others, 2001).

During the Miocene, the Colorado River and its tributaries began to downcut through the low-relief erosion surface, creating younger and topographically lower erosion surfaces inset into the regional late Eocene-early Miocene erosion surface (Larson and others, 1975; Kirkham, Kunk, and others, 2001; Kunk and others, 2002). This incision triggered flow and dissolution of halite and gypsum in the Eagle Valley Evaporite, which in turn led to widespread collapse of the ground surface in the region (Kirkham, Streufert, and others, 2001, 2002; Lidke and others, 2002; Scott and others, 2002). The southwestern part of the quadrangle lies within the Carbondale Collapse Center, one of two large evaporite collapse centers that formed in the region. The northeastern margin of the Carbondale Collapse Center crosses the quadrangle. From the west edge of the quadrangle to near Cottonwood Pass, the collapse margin coincides with Cottonwood Monocline, along which the late Miocene volcanic flows of unit Tb are downwarped about 600 ft. The sediments of Cottonwood Bowl (unit QTc) were deposited in a basin that formed at the foot of the monocline. The Laramide Basalt Mountain Fault constrains the margin of the Carbondale Collapse Center from the east end of the Cottonwood Monocline to the south edge of the quadrangle. On the west (upthrown) side of this Laramide fault, the evaporitic rocks are shallow and prone to dissolution, whereas on the east (downthrown) side of the fault, the evaporitic strata are generally buried deep in the subsurface and are less prone to dissolution and collapse.

The 3.17 Ma eruptive center at Buck Point provides critical control on the timing of evaporite collapse (Kirkham, Streufert, and others, 2002). The top of the Buck Point eruptive center lies at an elevation of nearly 8900 ft, which is only about 100 ft lower than the 7.75 Ma flows on Little Grand Mesa, yet the margin of the collapse center lies between these two locations. This elevation difference (100 ft) represents the maximum vertical collapse that could have happened at Buck Point during the ~4.5 million year time span separating the late Miocene flows on Little Grand Mesa and the eruption of the Pliocene volcano at Buck Point. Most of the evaporite collapse must have occurred after the eruption of the 3.17 Ma Buck Point volcano.

The dissolved halite and gypsum from the collapse areas eventually end up in the Colorado River. Chafin and Butler (2002) estimate that about 880,000 tons of salt are dissolved from the Eagle Valley Evaporite in the Carbondale and Eagle Collapse Centers every year. Yampa hot spring, which provides the water for the hot springs pool in the town of Glenwood Springs, discharges about 260 tons of dissolved halite and gypsum to the Colorado River daily (Barrett and Pearl, 1976). Many other hot springs in the area also discharge water that is enriched in dissolved evaporite minerals. These high salt concentrations are strong evidence that the evaporite dissolution and collapse is active.

CORRELATION AND AGE OF LATE CENOZOIC BASALTIC ROCKS

Early during the collaborative CGS–USGS investigation of evaporite tectonism in the region, it was recognized that a thorough understanding of the late Cenozoic volcanic stratigraphy was needed to better characterize evaporite-related deformation. By tracing dated and correlated volcanic flows across the region, the lateral extent, amount of vertical deformation, and timing and rates of collapse could be assessed. To accomplish this goal, an extensive effort involving ^{40}Ar/^{39}Ar age dating and geochemical correlation of the volcanic rocks in the region was undertaken. 133 dates were obtained from 84 samples of late Cenozoic volcanic rocks (Kunk and others, 2002). Major-, minor-, and trace-element data was determined for 220 samples, and 65 of these samples were analyzed for lead, strontium, and neodymium (Unruh and others, 2001). Budahn and others (2002) used the chemical analyses and age dates, along with petrographic data, to identify 46 distinct compositional groups of volcanic rocks. These compositional groups were erupted during signicant pulses of volcanic activity spread across the region during the time intervals from 24 to 22 Ma, 16 to 13 Ma, and 11 to 9 Ma. Smaller, more widely spaced eruptions occurred in the region about 7.8–7.7 Ma, 4 Ma, 3 Ma, 1.3 Ma, and 4 ka (Kunk and others, 2002).

Sixteen samples of volcanic rocks from the Cottonwood Pass quadrangle were chemically analyzed, and ^{40}Ar/^{39}Ar ages were obtained on five volcanic rock samples as part of the collaborative CGS–USGS investigation. Locations of these samples are shown on the accompanying geologic map. The chemical analyses are listed in Appendix A, as well as the latitude and longitude of the sample locations. Five of the compositional groups identified by Budahn and others (2002) were identified in the Cottonwood Pass quadrangle (**Table 1**).

The unit Tb flows in the southwest part of the mapped area are the oldest and most widespread volcanic rocks in the quadrangle. Three samples of flows in unit Tb were dated, yielding ages of 7.72 ± 0.04 Ma (CP89), 7.74 ± 0.06 Ma (CP8), and 7.80 ± 0.04 Ma (KH95-32). One dated sample was from the subhorizontal unit Tb flows that cap Little Grand Mesa, one was from south-tilted flows in Cottonwood Monocline west of Cottonwood Pass, and one was from the flow remnant on Spruce Ridge. Budahn and others (2002) correlated eight of the chemically analyzed samples, including the three dated samples, with compositional group 5a. Samples from compositional groups 5a' and 5b also were collected in the quadrangle (Table 1). Samples from compositional

Table 1. Compositional geochemical groups and preferred ^{40}Ar/^{39}Ar ages of volcanic rocks in the Cottonwood Pass quadrangle (from Budahn and others, 2002; Kunk and others, 2002). Sample locations are shown on the accompanying geologic map and are described in Appendix A.

Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)
CP8	Tb	5a	7.74 ± 0.06 Ma
CP76	Tb	5a	
CP77	Tb	5a	
CP83	Tb	5a	
CP89	Tb	5a	7.72 ± 0.04 Ma
KH95-28	Tb	5a	
KH95-30	Tb	5a	
KH95-32	Tb	5a	7.80 ± 0.04 Ma
KH95-29	Tb	5a'	
CP88	Tb	5b	
CP86	Tbp	6b"	3.17 ± 0.02 Ma
CPV-2	Tbp	6b"	
CPV-3	Tbpc	6b"	
CPV-4	Tbp	6b"	
KH95-26	Tag	7a	3.03 ± 0.02 Ma
KH95-27B	Tagc	7a	

group 5b collected in nearby areas yielded ages of 7.71 ± 0.04 Ma and 7.77 ± 0.05 Ma, very similar to the age of group 5a rocks. No samples from compositional group 5a' were dated. Larson and others (1975) reported a K-Ar age of 11.1 ± 1.0 Ma for a sample of basalt collected near Cottonwood Pass. His latitude and longitude for this sample plots on the east side of Cottonwood Pass in an area that we map as Tertiary sediments (unit Ts). His descriptive sample location of the sample is "south of Cottonwood Pass road just west of summit." Basaltic flows are present at his descriptive location, but the flows are so altered that we chose not to sample these rocks for chemical analysis or age dating. Our sample CP89 was collected from less altered flows that were on the north side of the Cottonwood Pass road near the descriptive sample location of Larson and others. Sample CP89 yielded an age of 7.72 ± 0.04 Ma.

All four samples from the Buck Point flows and cinders of units Tbp and Tbpc are included in composition group 6b''. An ^{40}Ar/^{39}Ar age of 3.17 ± 0.02 Ma was obtained on a sample from unit Tbp on the south side of Buck Point (CP86). Samples of the cinder deposits in Gobbler cone (unit Tgac; sample KH95-27B) and the flow on Gobbler Knob (unit Tga; sample KH95-26) are included in compositional group 7a. The flow on Gobbler Knob yielded an ^{40}Ar/^{39}Ar age of 3.03 ± 0.02 Ma.

GEOLOGIC HAZARDS AND CONSTRAINTS

Several types of geologic hazards and constraints exist in the Cottonwood Pass quadrangle. Areas mapped as younger debris-flow deposits (unit Qdfy) are prone to future debris flows, mudflows, and flooding. Low-lying areas mapped as stream-channel, flood-plain, and low-terrace deposits (unit Qa) and as alluvium and colluvium, undivided (unit Qac) are subject to flooding. Sheet flooding may affect areas mapped as sheetwash (unit Qsw).

White (2002) developed a geologic hazard map that characterized collapsible soils in the nearby Roaring Fork River valley. The derivative approach used by White (2002) can be applied to the units in the Cottonwood Pass quadrangle. The hydrocompaction potential of sheetwash deposits (unit Qsw), fine-grained colluvium (unit Qc) and alluvium and colluvium, undivided (unit Qac) is moderate to high. These deposits, along with the older debris-flow deposits (unit Qdfo), also have moderate to high potential for settlement and piping. Areas mapped as colluvium (unit Qc) are susceptible to future colluvial deposition, and locally they are subject to landslides, sheetwash, rockfall, small debris flows, and mudflows.

The recent earthflow in upper Tom Creek (unit Qlsr) demonstrates that future landslides may occur in the quadrangle. This recent slope failure involved remobilization of existing landslide deposits (unit Qls), which are widespread in the quadrangle. Existing landslide deposits encompass Buck Point, border the north and east sides of Little Grand Mesa, and are scattered across other parts of the quadrangle. Spectacular slump blocks of nearly intact but broken and dislocated blocks of basalt occur in the landslides along the north of edge of Little Grand Mesa in the headwaters of Spruce Creek. An incipient tension crack in the basalt cap on the northeast corner of Little Grand Mesa forebodes future slope stability problems in that area.

Sinkholes, which pose significant hazards to humans, buildings, and irrigation systems, may occur in areas where the Eagle Valley Evaporite is present at or near the surface (Mock, 2002; White, 2002). Numerous sinkholes and a large area of hummocky ground interpreted to be the result of collapse over evaporite beds were detected during this project and are shown on the geologic map. Modern rates of ground movement related to regional evaporite collapse and diapirism are poorly constrained. If these rates are sufficiently high to pose hazards, then these types of deformation should be considered in engineering design, particularly where differential movement is possible, such as within Cottonwood Monocline. In addition to causing collapse hazards, the Eagle Valley Evaporite and surficial deposits eroded from it can be corrosive.

There is moderate to high potential for rockfall below cliffs of well-indurated bedrock throughout the quadrangle, especially in areas mapped as talus (unit Qt). Proterozoic crystalline rocks and lower and middle Paleozoic rocks in Glenwood Canyon and in steep-walled tributary valleys pose severe rockfall hazards. The volcanic cliffs on the north margin of Little Grand Mesa and around Buck Point also generate rockfall debris. Large gravel clasts and boulders contained within surficial deposits can be hazardous when exposed in the walls of excavations and in roadcuts.

Historic earthquakes have shaken the region on numerous occasions (Kirkham and Rogers, 2000), and future earthquakes, some possibly strong enough to cause damage and trigger landslides and rockfall, may affect the mapped area.

ECONOMIC GEOLOGY

Mineral commodities with possible economic potential in the quadrangle include sand and gravel, gypsum, scoria, riprap, and to a lesser degree, high-calcium limestone and base metals. Many of the surficial deposits have sand and gravel potential. Units Qa and Qty have high potential for sand and gravel resources. The sand and gravel potential of units Qgo, QTg, Qac, Qdfy, Qaco, Qdfo, and QTc is moderate to low, because either the clasts within these units are decomposed or the deposits contain undesirable amounts of matrix.

The Eagle Gypsum Company produces gypsum from an open pit developed in the Eagle Valley Evaporite at their Eagle Gypsum Mine, located 4 mi northeast of the Cottonwood Pass quadrangle. The gypsum is manufactured into wallboard and other products at a calcining and production facility located at Gypsum, Colorado. The Eagle Valley Evaporite may contain economic deposits of gypsum within the quadrangle. A short adit was driven into a gypsum bed on the north side of Brewster Gulch.

Scoriaceous basalt mined from the 4,000-year-old Dotsero crater by Mayne Block Company northeast of the quadrangle is crushed and used as light-weight filler in the manufacture of cinder blocks. This material is also marketed as landscaping aggregate and road cinders. The cinder deposits of unit Tgac at Gobbler cone and unit Tbpc at Buck Point contain similar scoriaceous material.

High-quality riprap or landscaping boulders may be obtained from deposits of talus (unit Qt), the hard and indurated sedimentary beds in the middle and lower Paleozoic Leadville Limestone, Manitou Formation, and Sawatch Formation, and the volcanic flows in units Tb, Tag, and Tbp. Boulder and cobbles of basaltic rock in unit QTbg also may be sources of riprap or landscaping boulders.

The Mississippian Leadville Limestone has been suggested as a source of high-calcium limestone. There are quarries near the city of Glenwood Springs where the Leadville Limestone was produced for aggregate and high-calcium limestone. Areas in the northwest part of the quadrangle where the Leadville Limestone lacks appreciable overburden may be a target area for limestone development, but these areas are small in size and generally have poor access. It is also possible that zones of high-calcium limestone exist in the Devonian Chaffee Group, but this is less likely.

A small lead-zinc mine and prospects occur in the Paleozoic rocks on the north side of the Colorado River west of the Cottonwood Pass quadrangle (Heyl, 1964; Kirkham, Streufert, Cappa, and others, 2008, Kirkham, Streufert, and Cappa, 2008). Similar base-metal occurrences may exist in the quadrangle.

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APPENDIX A

Major element, whole-rock XRF analyses of the volcanic rocks in Cottonwood Pass quadrangle. Sample locations are given in the lower table and also are shown on the accompanying geologic map.

	Weight Percent											
Sample ID	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**Fe_2O_3**	**MnO**	**P_2O_5**	**TiO_2**	**LOI***	**Total**
CP8	49.3	14.5	7.31	7.21	2.98	2.24	11.1	0.15	0.60	1.69	0.20	97.2
CP39	51.3	15.1	7.37	5.47	3.27	3.23	8.91	0.14	0.66	1.41	0.95	98.2
CP76	50.3	15.1	7.81	7.15	3.10	2.10	10.8	0.15	0.63	1.73	0.40	99.41
CP77	50.3	15.1	7.82	7.51	3.15	2.17	10.9	0.16	0.66	1.77	0.16	99.65
CP83	49.9	15.3	8.01	6.86	3.21	2.19	11.2	0.16	0.70	1.79	0.33	99.58
CP86	50.8	15.8	7.57	6.52	3.20	3.24	10.1	0.16	0.65	1.63	0.11	99.57
CP88	51.2	15.3	7.34	6.64	3.23	2.49	10.8	0.16	0.72	1.81	0.09	99.63
CP89	47.8	14.7	8.27	8.14	2.94	2.21	11.5	0.16	0.74	1.82	1.59	99.78
CPV-2	49.9	15.6	8.15	6.65	3.33	2.54	10.1	0.16	0.68	1.64	0.94	99.76
CPV-3	50.9	16.0	7.28	6.11	3.16	3.27	10.1	0.16	0.66	1.62	0.25	99.52
CPV-4	50.4	16.0	7.16	6.28	3.09	3.19	10.1	0.15	0.55	1.64	0.50	99.02
KH95-26	52.5	15.9	7.40	5.46	3.45	3.42	8.70	0.15	0.69	1.50	0.26	99.41
KH95-27B	52.2	15.8	7.35	5.64	3.39	3.44	8.71	0.14	0.72	1.51	0.49	99.42
KH95-28	49.8	15.5	7.99	6.98	3.20	2.19	11.2	0.16	0.72	1.82	0.06	99.59
KH95-29	49.9	15.1	7.92	7.29	3.18	2.29	11.2	0.16	0.69	1.78	0.06	99.65
KH95-30	50.8	15.3	7.56	6.87	3.26	2.30	10.6	0.15	0.68	1.77	0.12	99.45
KH95-32	50.3	15.1	7.79	7.48	3.21	2.28	10.7	0.15	0.69	1.76	0.01	99.46

*LOI = loss on ignition

Samples CP8 and CP39 analyzed by XRAL Laboratories, Denver, Colo.
Sample CP86 analyzed by Chemex Lab, Inc., Sparks, Nev.
All other samples analyzed by USGS (Unruh and others, 2001)

Sample Locations (NAD27)

Sample ID	Map Unit	Latitude	Longitude
CP8	Tb	39.5736° N	107.1055° W
CP39	Tag	39.5806° N	107.0764° W
CP76	Tb	39.5411° N	107.0668° W
CP77	Tb	39.5411° N	107.0667° W
CP83	Tb	39.5585° N	107.0632° W
CP86	Tbp	39.5112° N	107.1152° W
CP88	Tb	39.5265° N	107.1176° W
CP89	Tb	39.5308° N	107.0688° W
CPV-2	Tbp	39.5177° N	107.1053° W
CPV-3	Tbpc	39.5166° N	107.1119° W
CPV-4	Tbp	39.5212° N	107.1138° W
KH95-26	Tag	39.5803° N	107.0762° W
KH95-27B	Tagc	39.5624° N	107.0797° W
KH95-28	Tb	39.5622° N	107.0862° W
KH95-29	Tb	39.5726° N	107.1114° W
KH95-30	Tb	39.5723° N	107.1115° W
KH95-32	Tb	39.5844° N	107.0967° W

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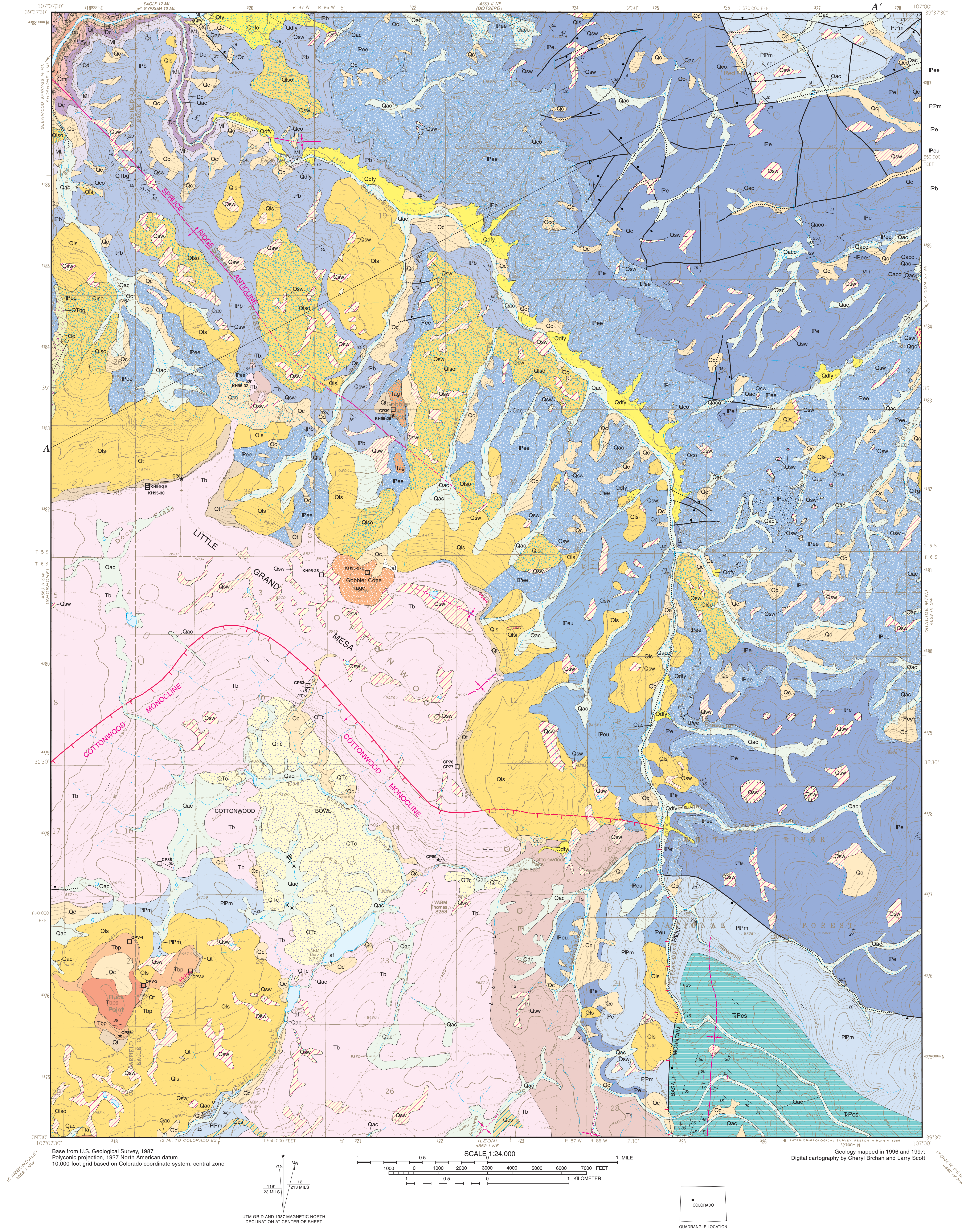
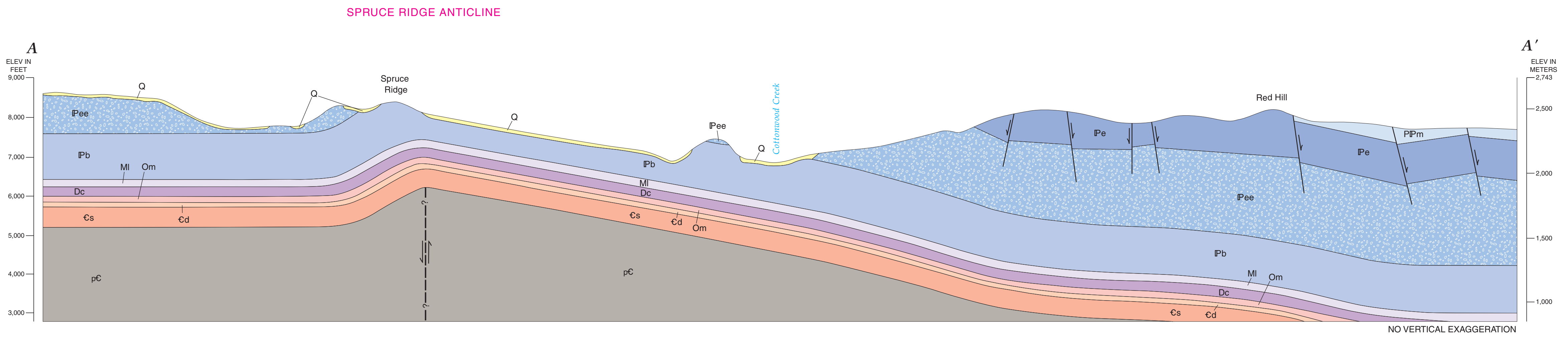
MAP SERIES 37
GEOLOGIC MAP OF THE COTTONWOOD PASS
QUADRANGLE, GARFIELD COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1987
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

Geology mapped in 1996 and 1997;
Digital cartography by Cheryl Brchan and Larry Scott



GEOLOGIC MAP OF THE COTTONWOOD PASS QUADRANGLE, EAGLE AND GARFIELD COUNTIES, COLORADO

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CONDENSED DESCRIPTION OF MAP UNITS

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

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**

ALLUVIAL DEPOSITS

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel. Poorly to moderately well sorted. Includes modern alluvium and other deposits underlying the Colorado River, adjacent flood-plain deposits, and low-terrace alluvium. Unit includes a thick sequence of organic-rich, gray, silty clay of probable lacustrine origin

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly, silty sand and sandy silt. Occurs on gentle to moderate slopes underlain by shale, basalt, red beds, and landslide deposits. Frequently fills the floor of sinkholes. Gradational and interfingering with colluvium on steeper hillslopes and with lacustrine and slackwater deposits in closed depressions

Qty — **Younger terrace alluvium (late Pleistocene)**—Consists of poorly sorted, clast-supported, silty, sandy, occasionally bouldery, cobble and pebble gravel. Chiefly stream alluvium in a terrace about 45 ft above the Colorado River. Overlain by 3 to 5 ft of fine-grained overbank deposits. Clasts are generally unweathered or only very slightly weathered

Qgo — **Older gravel deposits (Pleistocene)**—Varies from poorly sorted, clast-supported, silty, pebble and cobble gravel to poorly sorted, matrix-supported sandy, pebbly silt. Caps the eastern end of the ridge between Spring Gulch and Cottonwood Pass road. Deposits range from about 160 to 280 ft above adjacent drainages

QTg — **High-level gravel (early Pleistocene and late Tertiary)**—Occurs as a single deposit of gravel along the eastern edge of the quadrangle. Poorly exposed. Most likely a clast-supported, sandy, silty, pebble and cobble gravel that is locally bouldery. Unit caps ridge south of and about 400 to 450 ft above the floor of Spring Gulch

MASS-WASTING DEPOSITS

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes a single, narrow, elongate, earthflow in upper Tom Creek that occurred during the spring of 1995. Consists of unsorted, unstratified, clay, silt, sand, gravel, and rock debris derived from landslide deposits. Clasts are mainly angular to subangular basalt and rounded to subangular red sandstone

Qc — **Colluvium (Holocene and late Pleistocene)**—Ranges from clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Deposits are typically coarser grained in upper reaches of a colluvial slope and finer grained in distal areas

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly, and bouldery rubble on steep slopes that was transported downslope by gravity as rockfalls, rockslides, and rock topples. Unit frequently lacks matrix material. Locally underlain by or incorporated into landslide deposits

Qls — **Landslide deposits (Holocene and Pleistocene)**—Highly variable deposits of unsorted, unstratified, rock debris, clay, silt, sand, and gravel. Deposits range in age from recently active, slowly creeping landslides to long-inactive, middle or perhaps early Pleistocene landslides. Unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes

Qco — **Older colluvium (Pleistocene)**—Occurs on ridge lines, drainage divides, and dissected slopes on valley walls as erosional remnants of formerly more extensive deposits. Genesis, texture, bedding, and clast lithologies are similiar to colluvium (Qc)

Qlso — **Older landslide deposits (Pleistocene and late Tertiary?)**—Landslide deposits dissected by erosion. Similiar in texture, bedding, sorting, and clast lithology to landslide deposits (Qls). Deposits lack distinctive landslide geomorphologic features

ALLUVIAL AND MASS-WASTING DEPOSITS

Qdfy — **Younger debris-flow deposits (Holocene)**—Unit ranges from poorly sorted, matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble, cobble, and boulder gravel with a sandy, clayey silt or silty sand matrix. Deposited by debris flows, hyperconcentrated flows, streams, and sheetwash on active debris fans and in stream channels. Occasionally very bouldery, particularly near fan heads

Qac — **Alluvium and colluvium, undivided (Holocene and latest Pleistocene)**—Alluvium is typically poorly to well-sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel. Colluvium may range to unsorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt. Occurs in tributary valleys of small perennial, intermittent, and ephemeral streams. Deposited by alluvial and colluvial processes

Qcs — **Colluvium and sheetwash deposits undivided (Holocene and late Pleistocene)**—Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on on flatter slopes. Unit is mapped where contacts between the two types of deposits are very gradational and difficult to locate

Qdfo — **Older debris-flow deposits (early Holocene and Pleistocene)**—Occur as valley-filling deposits in tributaries to the Colorado River. Unit is genetically, texturally, and lithologically similiar to younger debris-flow deposits (Qdfy). Elevation differences between original depositional surfaces and adjacent incised modern drainages range from 20 to 60 ft

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Underlies terraces and hillslopes about 10 to 50 ft above adjacent intermittent or ephemeral streams. Texture bedding, clast lithology, sorting, and genesis are similiar to alluvium and colluvium (Qac)

QTbg — **High-level basaltic gravel (early Pleistocene or late Tertiary?)**—Unit consists of slightly indurated, matrix-supported, cobbly, pebbly, and bouldery clayey, sandy silt. Occurs on ridge between Spruce Creek and Ike Creek on western edge of map area and on north end of Spruce Ridge. Probably deposited as debris flows, earthflows, colluvium, or landslides

QTc — **Sediments of Cottonwood Bowl (early Pleistocene and late Tertiary?)**—Locally derived gravel, sand, silt, and clay deposited in and near the topographic bowl in headwaters of East Coulter Creek. Deposits range from sandy and silty pebble, granule, or cobble gravel to gravelly, sandy silt. Deposited in fluvial, sheetwash, and colluvial environments in a large collapse bowl that developed after emplacement of the basalts of Dock Flats

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q — **Surficial deposits, undifferentiated (Quaternary)**—Shown only on cross-section

BEDROCK

Tag — **Basaltic trachyandesite of Gobbler Knob (Pliocene)**—Gray to dark-gray and black, dense to vesicular, basaltic trachyandesite. Contains phenocrysts of olivine and xenocrysts of quartz with reaction rims of clinopyroxene. Occurs as two elongate, narrow, flow remnants which cap Gobbler Knob and part of the ridgeline extending south. Flow was probably erupted from a small cinder cone located on Dock Flats about 1 mile to the south. Correlative with compositional group 7a of Budahn and others (2002). $^{40}Ar/^{39}Ar$ age of 3.03 ± 0.02 Ma (Kunk and others, 2002)

Tagc — **Cinder deposits of Gobbler Cone (Pliocene)**—Red and red-brown, scoriaceous, unconsolidated, vesicular, cindery lava in an eruptive vent on Dock Flats. Cindery deposits overlie and are younger than the basalt flows (Tb) that cap Dock Flats. Correlative with compositional group 7a of Budahn and others (2002)

Tbpc — **Cinder deposits of Buck Point (Pliocene)**—Red to brownish-red and black, loose to well-cemented, moderately well-bedded breccia consisting of clasts of slightly to highly vesicular basaltic trachyandesite (Tbp). Probably deposited during a late-stage, high gas content, explosive eruption which eminated from the Buck Point vent. Deposit overlies and appears to have a gradational contact with columnar jointed lava flow in unit Tbp exposed on south flank of Buck Point. Correlative with compositional group 6b'' of Budahn and others (2002)

Tbp — **Basaltic trachyandesite of Buck Point (Pliocene)**—Medium- to dark-gray flows of basaltic trachyandesite with phenocrysts of olivine and pyroxene and xenocrysts of resorbed quartz and feldspar. Occurs as lava flows and as columnar jointed lavas on and near Buck Point. Correlative with compositional group 6b of Budahn and others (2002). $^{40}Ar/^{39}Ar$ age of 3.17 ± 0.02 Ma (Kunk and others, 2002)

Tta — **Trachyandesite (Pliocene)**—Includes basaltic trachyandesite flows and flow breccias in southwest corner of quadrangle

Tb — **Basalt (Miocene)**—Multiple stacked flows of massive to highly vesicular trachybasalt that are widespread across the west-central and south-central parts of the quadrangle. Groundmass is plagioclase and pyroxene with minor olivine, glass, pigeonite, augite, and magnetite. Phenocrysts are euhedral to subhedral olivine. Unit is well exposed in the headscarps of two large landslides on the north and east sides of Dock Flats. Correlative with compositional groups 5a, 5a', and 5b of Budahn and others (2002). $^{40}Ar/^{39}Ar$ age dates range from 7.72 ± 0.04 Ma to 7.80 ± 0.04 Ma (Kunk and others, 2002)

Ts — **Sedimentary deposits (Miocene)**—Unit composed mostly of silty, pebbly gravel and pebbly silt but ranges to sandy and clayey silt. Includes extensive deposits that underlie basalt flows near and south of Cottonwood Pass, and a thin, areally limited deposit associated with basalt on Spruce Ridge. May be predominantly a matrix-supported deposit. Clasts are rounded to subangular and consist mostly of red sandstone, quartz, and coarse-grained plutonic rocks

TRPcs — **Chinle and State Bridge Formations, undivided (Upper Triassic and Permian)**—Chinle Formation consists of thin, even-bedded, and structureless red beds of dark-reddish-brown, orangish-red, and purplish-red siltstone and mudstone with a few beds of limestone. State Bridge Formation consists of pale red, grayish- red, reddish-brown, and greenish-gray siltstone, clayey siltstone, and minor sandstone

PIPm — **Maroon Formation (Lower Permian and Upper Pennsylvanian)**—Redbeds of sandstone, conglomerate, siltstone, mudstone, and shale with minor thin beds of gray limestone. Frequently arkosic and micaceous

IPe — **Eagle Valley Formation (Middle Pennsylvanian)**—Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, limestone, and carbonate rocks. Unit represents a stratigraphic interval in which red beds of the Maroon Formation grade into and intertongue with the predominantly evaporitic rocks of the Eagle Valley Evaporite. Unit includes rock types of both formations

IPee — **Eagle Valley Evaporite (Middle Pennsylvanian)**—Sequence of evaporitic rocks consisting mainly of massive to laminated gypsum, anhydrite, and halite, interbedded with light-colored mudstone and fine-grained sandstone, thin carbonate beds, and black shale. Beds commonly deformed by diapirism, flowage, load metamorphism, dissolution, hydration of anhydrite, and regional tectonism. Frequently contains cavernous voids and sinkholes caused by near-surface dissolution

IPeu — **Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian)**—Includes Eagle Valley Formation and Eagle Valley Evaporite where contact between the formations is not mappable

IPb — **Belden Formation (Lower Pennsylvanian)**—Medium-gray to black, and dark-brown, calcareous and locally micaceous shale and coarse-grained, gray, fossiliferous limestone. Upper 100 ft of unit contains four or five prominent beds of conglomeratic, very-coarse-grained, lithic-rich wackes and subarkoses that may be equivalent to the Minturn Formation mapped by Streufert and others (1997) in the Dotsero quadrangle. May contain discontinuous beds of gypsum at any interval in section

Ml — **Leadville Limestone (Mississippian)**—Light- to medium-gray, bluish-gray, massive, coarse to finely crystalline, fossiliferous limestone and dolomite. Unit contains lenses and nodules of dark-gray to black chert in lower one-third of formation. Top of unit contains collapse breccias, filled solution cavities, and a locally derived reddish claystone regolith, all of which formed on a paleokarst surface

Dc — **Chaffee Group (Upper Devonian)**—Includes in ascending order: Parting Formation—white to buff orthoquartzite, green shale, and gray dolomite; Dyer Dolomite—limestone and dolomite; and Gilman Sandstone—tan to yellow, fine-grained, dolomitic sandstone

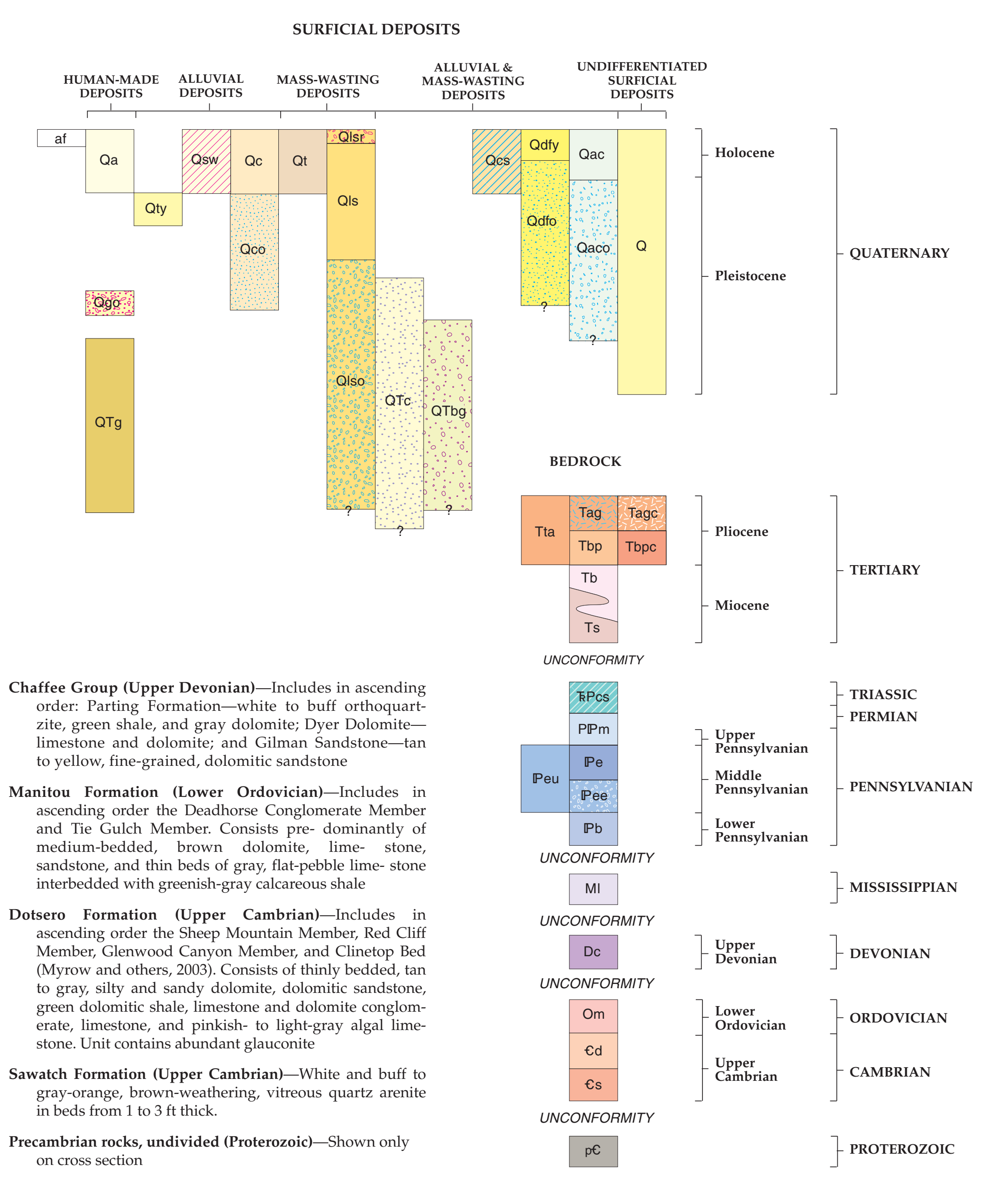
Om — **Manitou Formation (Lower Ordovician)**—Includes in ascending order the Deadhorse Conglomerate Member and Tie Gulch Member. Consists pre- dominantly of medium-bedded, brown dolomite, lime- stone, sandstone, and thin beds of gray, flat-pebble lime- stone interbedded with greenish-gray calcareous shale

€d — **Dotsero Formation (Upper Cambrian)**—Includes in ascending order the Sheep Mountain Member, Red Cliff Member, Glenwood Canyon Member, and Clinetop Bed (Myrow and others, 2003). Consists of thinly bedded, tan to gray, silty and sandy dolomite, dolomitic sandstone, green dolomitic shale, limestone and dolomite conglomerate, limestone, and pinkish- to light-gray algal limestone. Unit contains abundant glauconite

€s — **Sawatch Formation (Upper Cambrian)**—White and buff to gray-orange, brown-weathering, vitreous quartz arenite in beds from 1 to 3 ft thick.

p€ — **Precambrian rocks, undivided (Proterozoic)**—Shown only on cross section

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximately located; queried where uncertain

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; arrows on Basalt Mountain Fault indicate direction of Neogene collapse along the fault due to dissolution and/or flowage of evaporite

Anticline—Showing trace of crestline; dashed where approximately located; dotted where concealed

Syncline—Showing trace of trough line; dashed where approximately located; dotted where concealed; arrow indicates direction of plunge of axial trace

Synclinal sag—Showing approximate axial trace of syncline related to evaporite tectonism; dotted where concealed

Margin of late Cenozoic collapse area—Collapse caused by evaporite tectonism; blackline used where collapse margin coincides with a fault; dashed when approximately located; queried where uncertain (see Kirkham, Streufert, and others, 2001; and Kirkham, Scott, and Judkins, 2002, for description of collapse)

23 — **Strike and dip of beds**—Angle of dip shown in degrees; attitudes in basalt were measured on top of flow surfaces

Inclined beds—Showing approximate attitude of bedding in sedimentary rocks and the upper flow surface in volcanic rocks as determined from stereographic models set on a photogrammetric plotter

7 — **Strike and dip of foliation**—Angle of dip shown in degrees

□ CPV-2 — **Location and identification number of geochemical rock sample (see Table 1 and Appendix A in booklet; Unruh and others, 2001; Budahn and others, 2002)**

★ CP86 — **Location and identification number of rock sample with geochemical analysis and $^{40}Ar/^{39}Ar$ age data (see Table 1 and Appendix A in booklet; Unruh and others, 2001; Budahn and others, 2002; and Kunk and others, 2002)**

A ——— *A'* **Alignment of cross section**

X — **Sinkhole**—Created by subsidence over voids in the Eagle Valley Evaporite or by piping of surficial deposits into such voids; "X" indicates location of small sinkholes; floors of many sinkholes are filled with sheetwash deposits

Subsidence area—Large area of hummocky ground inferred to have resulted from regional subsidence into cavernous voids within the Eagle Valley Evaporite

Tension fracture—In basalt above headscarp of landslide

Adit—Small, 20-ft-long exploration tunnel into gypsum bed

ACKNOWLEDGEMENTS

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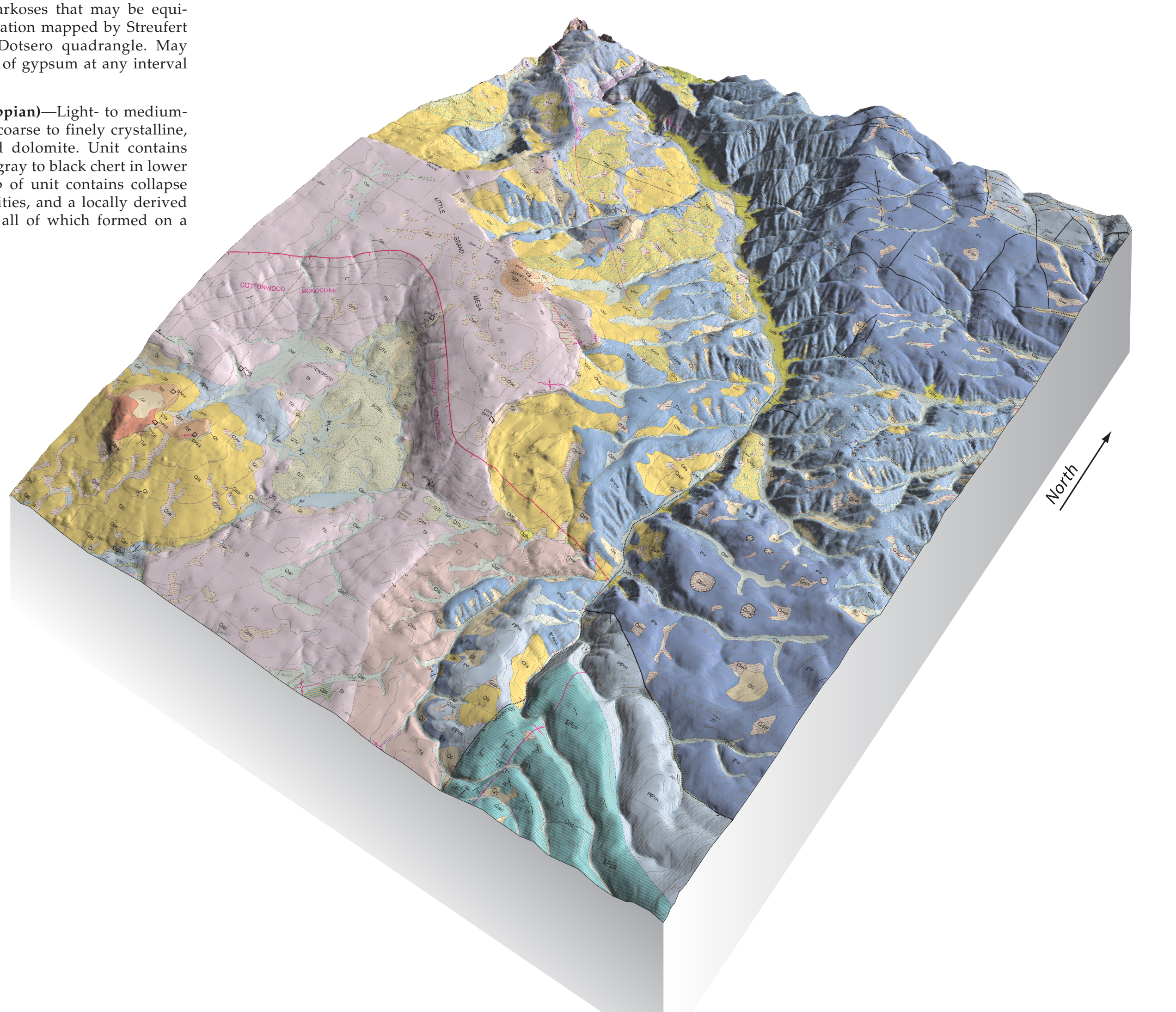

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