Map Series 36

GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE, GARFIELD COUNTY, COLORADO

By Robert M. Kirkham and Beth L. Widmann

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Colorado Geological Survey
Denver, Colorado
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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Map Series 36, *Geologic Map of the Carbondale Quadrangle, Garfield County, Colorado*. Its purpose is to describe the geologic setting of this 7.5-minute quadrangle, which is located in the Roaring Fork River Valley and includes the town of Carbondale.

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 numbers 1434-HQ-96-AG-01477 and 01HQAG0094). 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.

The original geologic map of the Carbondale quadrangle (Kirkham and Widmann, 1997) benefited from reviews by Bruce Bryant and Jim Soule. Jane Ciener was the technical editor of the earlier CGS open-file report. Beth Widmann edited this updated version. Photogrammetric models of annotated aerial photographs were set by Jim Messerich on a Kern PG-2 plotter. The following geologists provided helpful suggestions during the course of the study: Jon Lovekin, John White, Jim Cappa, Randy Streufert, Bob Scott, Dick Moore, Ralph Shroba, Paul Carrara, Ralph Mock, Steve Pawlak, Jim McCalpin, Bill Perry, and Tim Schroeder. Wayne Shelton provided valuable subsurface data from water wells. Jon White provided locations of new sinkholes that recently formed, as well as subsurface drill hole data and a re-interpretation of the surface geology in part of the Colorado Mountain College campus. We appreciate the many helpful landowners who gave permission to enter their properties and contributed information that only long-time residents would possess. Sue Rodgers, Dwayne Gilfrey, Sarah McNulty, Doug Davis, and Roger Lawrence were especially helpful.

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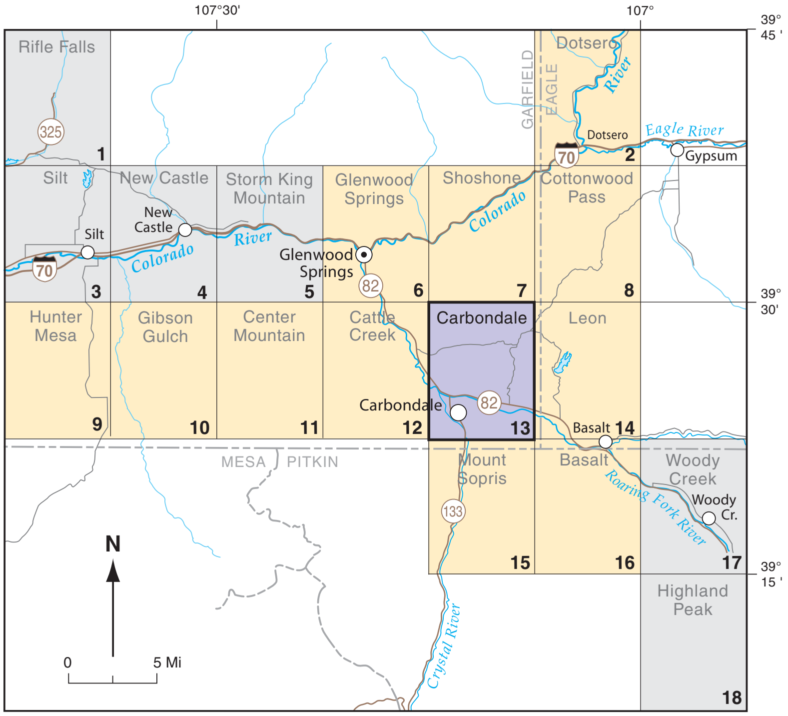
OVERVIEW

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 Carbondale 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 97-3 (Kirkham and Widmann, 1997). 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 Carbondale quadrangle, six other quadrangles in the Glenwood Springs area are being digitally updated. They include the Glenwood Springs, Shoshone, Cottonwood Pass, Leon, Basalt, and Mount Sopris quadrangles (Fig. 1).

Most of the modifications to this updated digital geologic map of the Carbondale 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 (Streufert and others, 2008)
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 (this publication)**
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 Carbondale quadrangle.

File Report 97-3. The initial discovery of regional evaporite collapse was made early during 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 98-3 and were analyzed and correlated using geochemistry, $^{40}Ar/^{39}Ar$ geochronology, magnetostratigraphy, paleomagnetism, and petrography subsequent to the publication of CGS Open-File Report 98-3 (Unruh and others, 2001; Budahn and others, 2002; Kunk and others, 2002; Hudson and others, 2002). Fifty-five samples of volcanic rocks from the Carbondale quadrangle were studied during the collaborative CGS-USGS investigation; the correlation and ages of these 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 Carbondale 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 Carbondale quadrangle includes about 58 square miles of Garfield County, which is in west-central Colorado. The town of Carbondale is in the southwest part of the quadrangle. Colorado Highway 82 parallels the Roaring Fork River and Colorado Highway 133 follows the Crystal River Valley through the southern part of the quadrangle. Most of the land in the quadrangle is private. All federal lands within the quadrangle are managed by the U.S. Bureau of Land Management. 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.

R.M. Kirkham was responsible for the geologic mapping of the quadrangle. B.L. Widmann served as his field assistant. Mr. Kirkham is responsible for the 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

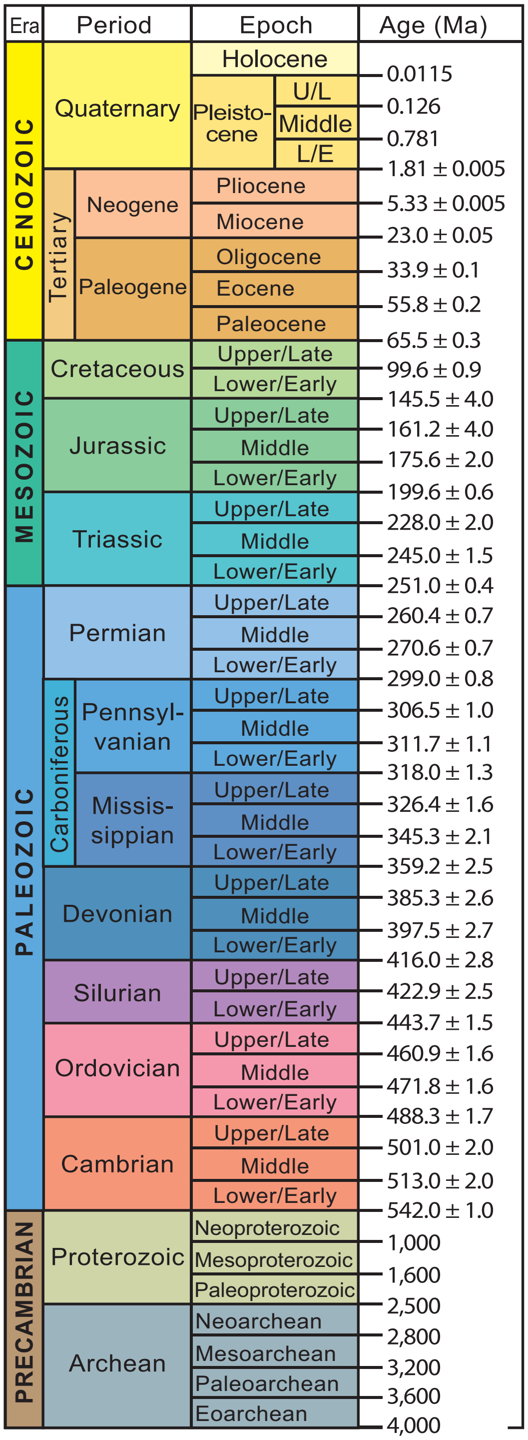
Previously published small-scale geologic maps of the Carbondale quadrangle include 1:500,000-scale maps by Burbank and others (1935) and Tweto (1979), and the 1:250,000-scale map of Tweto and others (1978). The quadrangle was included in a 1:100,000-scale map by Ellis and Freeman (1984). F.M. Fox and Associates (1974) mapped the quadrangle at a scale of 1:48,000. The 1:50,000-scale mapping of Soule and Stover (1985), which covered part of the quadrangle, emphasized surficial deposits. A small part of the quadrangle was mapped by Bass and Northrup (1963) at a scale of 1:31,680. The collapsible soils and evaporite karst hazards of the quadrangle were characterized at a scale of 1:50,000 by White (2002). The CGS originally mapped the Carbondale quadrangle at a scale of 1:24,000 and released it as Open-File Report 97-3 (Kirkham and Widmann, 1997).

MAPPING METHODS AND TERMINOLOGY

Most field work in the Carbondale quadrangle was conducted by the authors during the 1996 field season. 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
				Middle	0.781
				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

The surficial map units are classified by genesis and relative age. Surficial units shown on the map are generally more than about 5 ft thick. Deposits associated with distinct landforms may locally be thinner than 5 ft. Surficial deposits with a width less than about 25 ft 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 Carbondale 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, and relative degree of weathering and soil development were used to estimate the relative ages for the surficial deposits. Prior age estimations of the terrace deposits along the Roaring Fork River by Piety (1981) were used in this map. 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)—**Includes fill and waste rock placed by humans during the construction of dams, sewage treatment plants, and tunnels. The unit also includes trash placed in landfills. Maximum thickness is estimated at 50 ft.

ALLUVIAL DEPOSITS—Sediments deposited in stream channels, flood plains, glacial-outwash terraces, and sheetwash areas along the Roaring Fork and Crystal Rivers and their tributaries.

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)—**Includes modern alluvium and flood-plain deposits adjacent to the Roaring Fork and Crystal Rivers, and alluvium beneath low terraces that are as much as about 12 ft above modern stream level. Unit Qa consists mostly of clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel with a sandy or silty matrix. The unit is poorly to moderately well sorted and moderately well to well bedded. It is sometimes interbedded with and often overlain by sandy silt and silty sand. Clasts within the unit are subangular to well rounded, and their varied lithology reflects the diverse types of bedrock in their provenance. Deposits along the Roaring Fork River upstream of Carbondale are rich in clasts of Proterozoic plutonic rocks, whereas those along the Crystal River are rich in middle Tertiary hypabyssal rocks and contain distinctive clasts of green hornfels, probably derived from metamorphosed Morrison Formation. Fine-grained sediments, including silt and clay, are present in some of the subsidence troughs formed in unit Qa. The unit locally may include organic-rich deposits. The maximum estimated thickness is 50 ft. Flood-plain and terrace deposits included in this unit correlate with sediment in terrace T8 of Piety (1981) in the Carbondale-Glenwood Springs area.

Qsw **Sheetwash deposits (Holocene and late Pleistocene)—**Includes deposits locally derived from weathered bedrock and surficial materials that were transported predominantly by sheetwash and accumulated in ephemeral stream valleys, on gentle hillslopes, or in closed depressions. Sheetwash deposits typically consist of pebbly, silty sand and sandy or clayey silt. The finer-grained strata usually are found in closed depressions. Maximum thickness is probably about 25 ft.

Qty

Younger terrace alluvium (late Pleistocene)—Chiefly stream alluvium underlying terraces that range from about 14 to 45 ft above modern stream level. The unit consists mostly of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix that was deposited as glacial outwash. Fine-grained overbank deposits are locally present. Locally, younger terrace alluvium may be capped by a single thin loess sheet. Clasts are mainly subrounded to rounded and are generally unweathered or only slightly weathered. Deposits along the Crystal River generally are rich in clasts of middle Tertiary hypabyssal rocks and contain distinctive clasts of green hornfels. Deposits along the Roaring Fork River above Carbondale are rich in Precambrian plutonic clasts. Thickness of the unit varies, but typically averages about 30 to 40 ft.

North of the quadrangle, at the rest area on Highway I-70 in west Glenwood Springs, peat interbedded with tufa that overlies a 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 is correlative to some of the deposits in unit Qty in the Carbondale quadrangle. Unit Qty also correlates with deposits in terrace T7 in the Carbondale-Glenwood Springs area that were described by Piety (1981). Unit Qty was probably deposited during the latter part of the late Pleistocene Pinedale glaciation. Deposits of younger terrace alluvium are affected by evaporite deformation. Several sinkholes exist in areas mapped as unit Qty, and a subsidence trough has formed in deposits of unit Qty near the east edge of the quadrangle.

Qtm

Intermediate terrace alluvium (late Pleistocene)—Composed of stream alluvium underlying terraces about 55 to 110 ft above modern stream level. The unit consists mostly of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix that was deposited as glacial outwash. Fine-grained overbank deposits locally are present. Deposits of intermediate terrace alluvium locally are capped by a single thin loess sheet. Clasts within deposits of unit Qtm are chiefly subround to round and are generally only slightly weathered. Unit Qtm averages about 20 to 50 ft thick. Intermediate terrace alluvium correlates with deposits in terrace T6 (Carbondale-Glenwood Springs area) of Piety (1981) and is interpreted as glacial outwash deposited early during the late Pleistocene Pinedale glaciation. In an exposure near the mouth of Crystal Spring Creek, an area which in 1996 was actively being mined for sand and gravel, Piety (1981) described a stacked sequence of sediments that consisted of terrace deposits of differing ages. The younger overlying deposit is correlative with our unit Qtm. Clasts in the underlying deposit were more weathered than those in overlying deposit. This indicates unit Qtm may locally overlie older terrace deposits in the quadrangle. Sinkholes and a subsidence trough affect deposits of unit Qtm.

Qto

Older terrace alluvium (late middle Pleistocene)—Includes deposits of stream alluvium in terraces on the west side of the confluence of the Roaring Fork and Crystal Rivers and on the east side of the Crystal River southeast of Carbondale. The terrace surfaces on unit Qto are about 160 to 200 ft above modern stream level. Older terrace alluvium generally consists of clast-supported cobble or pebble gravel in a sand matrix, but may range to a matrix-supported gravelly sand or silt. Locally it may contain fine-grained overbank deposits. Clasts are chiefly subround to round, with varied lithologies that reflect the rock types found in the drainage basin. Clasts are slightly or moderately weathered at shallow depths. Exposed thicknesses range from 28 to 39 ft. Maximum thickness is estimated at about 60 ft. Unit Qto may correlate with deposits in terraces T4 and T5 in the Glenwood Springs-Carbondale area (Piety, 1981) and with terrace C deposits described by Bryant (1979). Unit Qto was probably deposited during the late middle Pleistocene Bull Lake glaciation. Sinkholes and at least one subsidence trough affect deposits of unit Qto. Folded and faulted older terrace alluvium and overlying older alluvium and colluvium (unit Qaco) associated with a subsidence trough are well exposed in the roadcut along County Road 108 near the mouth of Edgerton Creek.

MASS-WASTING DEPOSITS—Sediments on valley sides, valley floors, and hill slopes that were mobilized, transported and deposited primarily by gravity.

Qlsr **Recent landslide deposits (latest Holocene)-** Includes two small, recently active landslides with fresh morphological features. One of the recently active landslide deposits is in Barbers Gulch; the second is on a terrace riser southwest of the confluence of the Roaring Fork River and Crystal River. Both occurred on moderately steep slopes mantled with a thin veneer of colluvium. The landslides initiated in gravel deposits overlying either the Eagle Valley Evaporite or Eagle Valley Formation. Both deposits consist of unsorted, unstratified gravel, sand, and silt. Maximum thickness is probably about 20 ft.

Qc **Colluvium (Holocene and late Pleistocene)—** Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Colluvium locally grades to sheetwash deposits on flatter slopes and to debris-flow deposits in some drainages. Deposits are usually coarser grained in upper reaches of a colluvial slope and finer grained in distal areas where sheetwash processes may be important. Clasts typically are angular to subangular. Colluvium commonly is unsorted or poorly sorted with weak or no stratification. Locally the unit includes talus, landslide deposits, sheetwash, and debris-flow deposits that are too small to be mapped separately or are indistinct on aerial photographs. Colluvium also locally includes deposits that are suspected, but not proven, of landslide origin. The unit grades to and interfingers with alluvium and colluvium (unit Qac), younger debris-flow deposits (unit Qdfy), sheetwash deposits (unit Qsw), and colluvium and sheetwash (unit Qcs) along some tributary drainages and hillslopes. Maximum thickness is probably about 40 to 60 ft.

Qt **Talus (Holocene and late Pleistocene)—** Angular, cobbly and bouldery rubble on steep slopes that is derived from hard indurated outcrops of basalt (unit Tb) or basalt-rich collapse debris (unit QTcd), and transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Talus commonly lacks matrix material. Maximum thickness is estimated at about 40 ft.

Qls **Landslide deposits (Holocene and Pleistocene)—**Highly variable deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Locally, landslide deposits contain large blocks of basalt. Landslide deposits are associated with landforms that have recognizable, but sometimes subdued, geomorphic features such as hummocky ground, lobate form, headscarps, and closed depressions, which are characteristic of slopes that have failed. The unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. The unit also includes collapse debris in which there appears to be a significant horizontal component to the movement, such as the large landslide on the east side of Spring Valley. The maximum thickness of landslide deposits is probably about 200 ft, but typically they are much thinner.

Qco **Older colluvium (Pleistocene)—**Includes erosional remnants of colluvium that lie on ridge lines, drainage divides, and dissected hillslopes. Genesis, texture, and bedding are similar to colluvium (unit Qc). Older colluvium averages 10 to 25 ft thick and has a maximum thickness about 60 ft.

Qlso **Older landslide deposits (Pleistocene)—** Includes landslide deposits that are deeply dissected by erosion and that lack the distinctive geomorphic features associated with young landslides. Older landslide deposits are similar in texture, bedding, and sorting to landslide deposits (unit Qls). The type of landslide movement generally is not identifiable. Maximum thickness of unit Qlso locally may exceed 80 ft.

ALLUVIAL AND MASS-WASTING DEPOSITS— These deposits include alluvial and mass-wasting material that is mapped as a single unit because (1) they are juxtaposed and are too small to show individually, or (2) they have contacts that are not clearly defined. Fan deposits are classified as mixed alluvial and mass-wasting deposits because in addition to alluvium, they also include significant volumes of debris-flow deposits, 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 and late Pleistocene)—**Includes 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. They vary from matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble and cobble gravel in a silty, sandy, or clayey matrix. The unit commonly is very bouldery, particularly near fan heads. Mudflow and sheetwash deposits are present in the distal parts of some fans. Younger debris-flow deposits are locally interfingered or interbedded with recent alluvium adjacent to perennial stream channels. Clasts are mostly angular to subrounded sedimentary rock and basalt fragments up to about 6 ft in diameter. The original depositional surfaces are usually preserved on deposits of unit Qdfy, except where they have been disturbed by human activities. Maximum thickness of the unit is about 50 ft. Studies of younger debris fan deposits in the vicinity of Bowles Gulch and Holland Gulch by Dames & Moore (1996) suggest a debris-flow recurrence interval of 103 to 154 years for Bowles Gulch, 200 to 266 years for Holland Gulch, and 265 to 342 years for an unnamed gulch between Bowles and Holland Gulches.

Qac **Alluvium and colluvium, undivided (Holocene and late 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 present along valley walls. Locally, areas mapped as unit Qac include younger debris-flow deposits and earth-flow deposits. The alluvial fraction typically is composed of poorly sorted to well-sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel. Colluvial deposits within the unit commonly are unsorted, unstratified or poorly stratified, and consist of clayey, silty sand, bouldery sand, and sandy silt. The estimated thickness of unit Qac typically is 5 to 20 ft, and its maximum thickness probably is 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 (see unit Qsw) on flatter slopes. Unit Qcs is used where the contact between colluvium and sheetwash deposits is very gradational and difficult to locate accurately. Thickness of unit Qcs averages 10 to 30 ft.

Qdfm **Intermediate debris-flow deposits (Holocene? and late Pleistocene)—**Intermediate debris-flow deposits are similar in texture, lithology, and depositional environment to younger debris-flow deposits (unit Qdfy), but they are older. The geomorphic character of the original depositional surfaces on intermediate debris-flow deposits is commonly recognizable, but active stream channels have incised 20 to 100 ft into the deposits. Maximum thickness of unit Qdfm is about 60 to 80 ft.

Qaco **Older alluvium and colluvium, undivided (Pleistocene)—**Includes deposits of alluvium and colluvium that underlie terraces and hillslopes that range from about 10 to 200 ft above adjacent small perennial, intermittent, and ephemeral streams. Lithologic characteristics of strata in unit Qaco are similar to those in unit Qac. Locally, unit Qaco includes debris-flow and sheetwash deposits. In a subsidence trough the NW ¼ of section 4, T. 8 S., R. 88 W., approximately 30 to 35 ft of older alluvium and colluvium overlie a 2 to 3 ft thick bed of volcanic ash identified by Izett and Wilcox (1982) as the Lava Creek B ash (~640 ka). This location is denoted by the triangle symbol on the geologic map. The ash, which is less well exposed on the opposite wall of Barbers Gulch, rests on alluvial gravels that are either middle to early Pleistocene or late Tertiary. Bedding in the ash appears to strike N16°E and dip 3° northwest, which suggests subsidence in the trough occurred both before ash deposition (to create the trough in which the ash is preserved) and after ash deposition (to tilt the ash). Maximum thickness of the unit is estimated at about 50 feet.

Qdfo **Older debris-flow deposits (Holocene? and Pleistocene)—**Includes remnants of older debris fans found on mesas and adjacent to tributaries of Cattle Creek and the Roaring Fork and Crystal Rivers. These deposits range from about 20 to 160 ft above the valley floors of adjacent streams. Unit Qdfo is lithologically similar to younger debris-flow deposits (unit Qdfy). Clasts are unweathered to moderately weathered. Unit Qdfo typically is about 20 to 40 ft thick.

EOLIAN DEPOSITS—Sediments deposited by wind

Qlo

Loess (late and middle? Pleistocene)— Consists of slightly clayey, sandy silt and silty, very fine to fine sand. Loess typically is unstratified, friable, and plastic or slightly plastic when wet. Sand grains are sometimes frosted. Thickness ranges from about 5 to 20 ft. Deposition occurred during at least two periods of eolian activity. At least one and perhaps multiple sheets of loess overlie older terrace deposits (unit Qto) and basalt (unit Tb) along the western edge of the quadrangle. The mapped distribution of loess is very approximate, chiefly due to the poor geomorphic expression of loess. Small unmapped deposits of loess are locally preserved within collapse debris (unit QTcd).

LACUSTRINE DEPOSITS—Sediments deposited in lakes.

Ql_2/Ql_1

Lacustrine deposits (Holocene and Pleistocene)—Stratified deposits of light- to dark-gray, organic-rich, silty clay and silt, reddish-brown, yellow-brown clayey silt, and well-sorted, fine to coarse sand. Includes deposits beneath the floor of Spring Valley (unit Ql_2) and deposits beneath surfaces that are elevated 20 to 40 ft higher than the valley floor (unit Ql_1), which may be of different ages. The unit is very poorly exposed; most information on the lacustrine deposits is from a drill hole in the SW¼ NE¼ of section 29, T. 6 S., R. 88 W. in the Shoshone quadrangle. This test hole was drilled to a depth of about 570 ft by Wright Water Engineers and did not encounter bedrock (Robin Verschneider, 2001, oral commun.). Most material penetrated by the well was fine-grained silt and clay with gray and red-brown colors. From a depth of about 250 to 300 ft, the drilled sediments were rich in volcanic ash that was identified as the Lava Creek B ash by A. Sarna-Wojcicki (2002, written commun.), which is 639 ka (Lanphere and others, 2002).

According to Calvin Cox (1994, oral commun.), a lake existed in Spring Valley until near the end of the last century (1900). His ancestors excavated a ditch across northwest end of Spring Valley to drain the lake, and then farmed the exposed lake bottom to demonstrate agricultural use of the land for homesteading purposes. Land ownership was transferred from the federal government to his ancestor in 1896, therefore dewatering of the lake occurred prior to that year. The lake in Spring Valley did not result from landsliding or glaciation that blocked the outlet. The valley apparently formed in response to evaporite tectonism, either as a half graben or pull-apart structure (Kirkham, Streufert, and others, 2002). The lacustrine deposits in Spring Valley are at least 570 ft thick.

UNDIFFERENTIATED SURFICIAL DEPOSITS—

Q

Surficial deposits, undivided (Quaternary)— Shown only on cross section. Unit may include any of the above surficial deposits.

ALLUVIAL, MASS-WASTING, LACUSTRINE, AND DELTAIC DEPOSITS—

QTm

Sediments of Missouri Heights (early Quaternary and/or late Tertiary)—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Coulter Creek region in alluvial, colluvial, lacustrine, and deltaic environments. The unit is generally very poorly exposed in the quadrangle. At the northern end of Missouri Heights, in both the S ½ of section 7 and N ½ of section 17, T. 7 S., R. 87 W., the unit is predominantly gravelly sandy silt, clayey silt, and cross-bedded fine-grained to very fine-grained sands of lacustrine and deltaic origin. Clasts within unit QTm are mostly subangular to subround basalt, red sandstone, and quartzite, but many other rock types are present in sparse quantities. The fine-grained sediments in the northern Missouri Heights area are well exposed in a few drainages and irrigation ditches. In these exposures they are slightly to moderately oxidized, slightly to moderately indurated, and dip 6 to 9 degrees to the south or southwest.

The sediments of Missouri Heights were deposited in a local basin formed by collapse or subsidence related to dissolution or flowage of salt deposits in the underlying Eagle Valley Evaporite (Kirkham, Streufert, and others, 2002). The collapse basin and sediment infill extends eastward into the Leon quadrangle (Kirkham, Widmann, and Streufert, 2008). Maximum thickness of unit QTm may exceed 150 ft, but typically is much thinner. Unit QTm usually overlies Miocene and Pliocene volcanic rocks. Underlying volcanic rocks are commonly more deformed than are the sediments of Missouri Heights, which suggests significant salt-related collapse and deformation occurred before deposition of unit QTm. Tilting of the sediments in unit QTm indicates additional or continuing deformation after deposition of the unit. Unit QTm is similar in origin to the sediments of Cottonwood Bowl (unit QTc), which were mapped by Streufert, Kirkham, and others (2008) in the Cottonwood Pass quadrangle, but the age relationship between unit QTc and unit QTm is not known.

COLLAPSE DEPOSITS—

QTcd

Collapse deposits (Pleistocene and late Tertiary)—Consists of heterogeneous deposits of moderately to severely deformed and dislocated bedrock, as well as overlying undeformed to moderately deformed surficial deposits. Collapse deposits formed in areas complexly deformed by evaporite tectonism, chiefly collapse or subsidence related to dissolution of thick underlying beds of evaporite, primarily halite, and/or flowage of the evaporitic rocks out from beneath the area (Kirkham, Streufert, and others, 2002). Highly fractured and locally brecciated blocks of basaltic flows comprise the predominant types of bedrock within the collapse deposits at the ground surface. Seven basaltic flows within the collapse debris were chemically analyzed (Appendix A). Budahn and others (2002) classified five of these samples as compositional group 1b, and the other two samples were correlated with group 3b (Table 1).

Small blocks of deformed and dislocated Maroon Formation locally occur within the collapse deposits. Small windows of evaporite also exist within areas mapped as collapse debris, as seen in the excavated slopes adjacent to the soccer fields at Colorado Mountain College. Various types of surficial deposits, including sheetwash, alluvium, colluvium, loess, and talus, were deposited over the collapsing debris at various times. These surficial deposits were sometimes incorporated into the collapse deposits during subsequent collapse or subsidence. Collapse deposits laterally grade to folded and faulted bedrock that is less deformed, therefore the contacts between collapse deposits and bedrock are very approximately located. Maximum thickness of unit QTcd is unknown, but it probably exceeds 100 ft.

BEDROCK

Tta

Trachyandesitic flows, undifferentiated (Pliocene)—Includes multiple moderately dense to highly vesicular lava flows in the northeast part of the quadrangle. Locally, unit Tta includes volcaniclastic deposits and flow breccias. Petrographically most flows are olivine basalt with xenocrysts of quartz, sanidine, and plagioclase as much as about 0.3 inches in length. Olivine phenocrysts are euhedral to subhedral and are often altered to hematite and iddingsite. The groundmass consists of olivine, pyroxene, and fine fresh laths of plagioclase. Accessory minerals include biotite, hematite, and magnetite. Quartz xenocrysts are rounded, corroded anhedra, and the sanidine xenocrysts are fairly fresh to moderately weathered and have inclusions of plagioclase and quartz. Geochemically these flows classify as basaltic trachyandesite or trachyandesite (Appendix A; samples CD8, CD197, CD199, CD206, CD209, CD215, CD216). Budahn and others (2002) included these seven samples in their chemical compositional groups 6a and 6a′. None of the group 6a and 6a′ rocks sampled in the region were dated, but their chemical composition and stratigraphic relationships suggest they are Pliocene in age. Thickness of individual flows generally ranges from about 5 to 30 ft, and the maximum thickness of the entire flow sequence is about 60 ft.

Tb

Basaltic flows (Miocene)—Multiple light- to dark-gray basaltic flows and minor flow breccias. Lenses of slightly indurated tan to light-brown sediments locally are intercalated with or underlie the volcanic flows and breccias of unit Tb. Flow rocks range from slightly to highly vesicular and locally contain amygdules of calcite and iron-rich clay. Petrographically most flows are olivine basalt, and many are porphyritic. The phenocrysts are chiefly olivine and less commonly plagioclase. The groundmass is predominantly plagioclase and pyroxene, with lesser amounts of olivine, glass, pigeonite, augite, and magnetite. Accessory minerals include apatite, iddingsite, and hematite.

Thirty-eight samples collected from unit Tb in the quadrangle were chemically analyzed by Unruh and others (2001) (see Appendix A). Most samples classify as basalt or basaltic andesite using the total alkali-silica plot of Le Bas and others (1986), but a few analyses were in the basaltic trachyandesite field. Budahn and others (2002) recognized seven compositional groups in samples collected from unit Tb within the quadrangle (Table 1); two of the samples were of an unknown compositional group. Nineteen of the samples were correlated with compositional group 1b, three samples were correlated with group 1c, three with group 1c", three with group 1d, four with group 3b, and three with group 4b. These rocks are middle Miocene in age and range from 9.68 to 10.84 Ma on the basis of ^{40}Ar/^{39}Ar ages on samples collected in the region (Kunk and others, 2002). Two of the samples were correlated with compositional group 12a. They yielded ^{40}Ar/^{39}Ar ages of 13.29 ± 0.28 Ma (sample CD152) and 13.38 ± 0.06 Ma (sample L223). Group 12a and 4b rocks were encountered only in the southeast part of the quadrangle south of the Roaring Fork River; group 1c rocks were found on both the south and north sides of the Roaring Fork River; and rocks from all other groups were observed only north of the Roaring Fork River. Individual basaltic flows range in thickness from about 5 to 25 ft. Thickness of the entire sequence of flows averages 20 to 40 ft in the quadrangle and attains a maximum total thickness of about 300 ft.

Ts

Sedimentary deposits (Miocene)—Weakly indurated to unconsolidated deposits of mostly clast-supported, fluvial, silty, sandy pebble and cobble gravel, gravelly sand, and silty sand, and matrix-supported gravelly silt and sand. Unit Ts typically is very poorly exposed in quadrangle. It crops out in the southeast part of the quadrangle and is believed to have been deposited within the Sopris Bowl, a topographic depression formed by early stage evaporite deformation (Kirkham, Streufert, and others, 2002). Clasts within unit Ts are well rounded to subrounded and are moderately to very highly weathered. The clasts within unit Ts are composed of Proterozoic crystalline rocks, middle Tertiary hypabyssal rocks, quartzite, red sandstone, and minor basalt, which suggests both the ancestral Roaring Fork and Crystal Rivers carried sediment into Sopris Bowl. At least three erosion surfaces of differing ages are cut into unit Ts deposits, and a thin veneer of younger sediments may overlie unit Ts deposits at those locations.

Unit Ts deposits underlie 13.3 to 13.4 Ma basaltic flows that crop out on a ridge locally known as "The A's". In Basalt quadrangle, unit Ts sediments overlie a 35.21 ± 0.03 Ma ash-flow tuff. These dates constrain the minimum and maximum ages for unit Ts. The sediments are considered to be mostly Miocene in age, because flows in the Basalt quadrangle that are intercalated with unit Ts yielded dates of about 13.6 to 13.8 Ma. However, strata in the lower part of the unit Ts may be Oligocene in age and perhaps even as old as latest Eocene. Unit Ts is several hundred feet thick in the Carbondale quadrangle and is over 1,500 ft thick to the south in the deepest part of Sopris Bowl (Kirkham, Streufert, and others, 2002)

PℙPm

Maroon Formation (Lower Permian and Upper Pennsylvanian)—Pale-red to pinkish-red and grayish-red arkosic micaceous sandstone, conglomerate, siltstone, and mudstone, with shale and minor, thin beds of gray limestone. Sandstone beds are coarse to fine grained and moderately to poorly sorted. Sand grains are generally angular to subrounded. Only the basal part of the Maroon Formation is exposed in the quadrangle. To the north in the Glenwood Springs quadrangle (Kirkham, Streufert, Cappa, and others, 2008) and in the Shoshone quadrangle (Kirkham, Streufert, and Cappa, 2008) reported a thickness of 3,000 to 5,000 ft for the formation, and to the southeast Freeman (1972) indicated a thickness of about 3,000 ft. The formation was deposited in fluvial, eolian, alluvial fan, and fan-delta environments within the Central Colorado Trough (Johnson and others, 1988; 1990).

ℙe

Eagle Valley Formation (Middle Pennsylvanian)—Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, sandstone, shale, gypsum, and carbonate rocks. The Eagle Valley 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. Thickness of the formation is variable, ranging from about 500 ft to perhaps as much as 3,000 ft on the west side of the Cattle Creek Anticline. The Eagle Valley Formation is conformable and intertongues with the overlying Maroon Formation and underlying Eagle Valley Evaporite. The contact with the Maroon Formation is placed at the top of the uppermost evaporite bed or light-colored clastic bed that is below the predominantly red bed sequence of the Maroon Formation. The Eagle Valley Formation was deposited in the Central Colorado Trough on the margin of an evaporite basin in fluvial, eolian, and marine environments.

ℙee **Eagle Valley Evaporite (Middle Pennsylvanian)—**Sequence of evaporitic rocks consisting of massive to laminated gypsum, anhydrite, halite, beds of light-colored mudstone and fine-grained sandstone, thin limestones, and black shale. The Eagle Valley Evaporite may include eolian deposits similar to those described by Schenk (1987). Beds commonly are intensely folded, faulted, and ductily deformed by diapirism, flowage, dissolution-related subsidence or collapse, load metamorphism, hydration of anhydrite, and Laramide tectonism. Part of the formation is well exposed on the valley walls near the confluence of Cattle Creek and the Roaring Fork River. The Eagle Valley Evaporite is at least 2,700 ft thick near Catherine. The Champlin Oil Blue No. 1 well penetrated 2,320 ft of Eagle Valley Evaporite, and an additional 400 ft of the formation is exposed on the hillslope north of the well. Mallory (1971) suggested the formation may be as much as 9,000 ft thick to the north in the core of the Cattle Creek Anticline. Presence of a thick halite sequence near the mouth of Cattle Creek on the adjacent Cattle Creek quadrangle was reported by Mallory (1966), chiefly on the basis of the Shannon Oil Company Rose No. 1 well, which encountered 60 ft of alluvial gravel, 2,065 ft of gypsum, anhydrite, and siltstone, and 935 ft of predominantly halite (unpublished lithologic log by American Stratigraphic Company). Drilling stopped in halite; therefore the total thickness of both the halite and the formation is unknown. The contact with the 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. The Eagle Valley Evaporite was deposited in a marine evaporitic basin known as the Eagle Basin, which formed as the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1989) recognized multiple transgressive-regressive cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment.

GEOLOGIC SETTING

The oldest exposed rocks in the Carbondale quadrangle are the Middle Pennsylvanian Eagle Valley Evaporite. They were deposited in the elongate Eagle Basin, an element of the Central Colorado Trough (Brill, 1944; De Voto, 1980). The trough was flanked by northwest-trending uplifts commonly referred to as the Ancestral Rocky Mountains. The uplift to the east of the quadrangle was the Ancestral Front Range Highland, and the one to the west was the Ancestral Uncompahgre Highland. As the uplifts rose, lower Paleozoic strata were stripped off the uplifts, exposing the underlying Precambrian rocks. During the Pennsylvanian and continuing into the Permian, clastic sediments eroded from the uplifts and accumulated in the Central Colorado Trough, first on the margins of the trough and later across the entire basin.

Carbonaceous marine shales, thin limestones, and minor gypsum within the Belden Shale were the initial fill deposited in the Eagle Basin. These sediments may exist in the subsurface in the quadrangle, but they do not crop out in it. Evaporitic sediments of the Eagle Valley Evaporite, including halite and gypsum, accumulated over the Belden Shale as sea water slowly evaporated. Highly soluable evaporite minerals like halite were not observed in outcrop in the quadrangle, probably because they dissolve quickly when in contact with fresh shallow ground water and surface water, but they were encountered in an oil test hole drilled nearby. The high concentration of dissolved sodium and chloride in hot springs in the region also attests to the existence of halite in the subsurface.

Lower Permian and Upper Pennsylvanian red beds of sandstone, conglomerate, and siltstone in 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 these rocks were removed by erosion and none 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 quadrangle, formed during the late Cretaceous-Eocene Laramide orogeny (Tweto, 1975). The Grand Hogback Monocline, which is west of the quadrangle, formed the western margin of the the White River Uplift. Evidence reported by Donnell (1961) and Tweto (1975) indicate the Grand Hogback Monocline 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 (Larson and others, 1975; Kirkham, Kunk, and others, 2001; Kunk and others, 2002; Steven, 2002), a broad low-relief erosion surface was cut across the region. Fluvial sediments in unit Ts were deposited in a topographic depression called Sopris Bowl that probably formed on the erosional unconformity north of the Mount Sopris stock (see Streufert, 2008; Kirkham, Streufert, and others, 2001). In Basalt quadrangle the sediments of unit Ts locally rest on an ash-flow tuff dated at 35.2 Ma, and in the Carbondale quadrangle 13.3 to 13.4 Ma basaltic flows (unit Tb) locally overlie the sediments. These dated volcanic rocks provide constraints on the maximum and minimum ages of the sediments. Basaltic flows dated at about 13.6 Ma and 13.8 Ma are intercalated with the sediments, which supports a conclusion that the sediments are mostly or entirely Miocene. The lithologies of clasts in the sediments of unit Ts indicate ancestral Roaring Fork River and ancestral Crystal River flowed into Sopris Bowl.

Basaltic eruptions (unit Tb) continued during the Miocene from about 10.8 Ma to 9.7 Ma. By 9.7 Ma the entire Carbondale quadrangle may have been blanketed by volcanic flows. Also during the Miocene, the Roaring Fork 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. 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 entire Carbondale quadrangle lies within the Carbondale Collapse Center, one of two large evaporite collapse centers that formed in the region. As collapse occurred, the Miocene basaltic rocks (unit Tb) were lowered as much as 4,000 ft (Kirkham, Streufert, and others, 2002), and synclinal sags like Heusckel Park and Crystal Trough formed. The basaltic rocks are lowered as much as 1,000 ft by these local structural features. Numerous sinkholes in the quadrangle are a result of evaporite dissolution.

Evidence of evaporite flow also exists in the quadrangle. The intrusive contact between the Eagle Valley Evaporite and Eagle Valley Formation exposed on the east valley wall of the Roaring Fork River south of Cattle Creek is related to evaporite flow in the Roaring Fork diapir. The edges of several of the terraces that are adjacent to the Roaring Fork and Crystal Rivers slope away from the modern river channels. Much and perhaps all of this tilting is due to diapiric upwelling of evaporite beneath the modern river channels, an area where lithostatic pressure on the evaporite is the lowest. An excellent example of a terrace and overlying debris-flow deposits tilted by evaporite flow is the Bershenyi terrace south of Glenwood Springs (Kirkham, Streufert, and others, 2002).

The structure responsible for Spring Valley in the northwest corner of the map is depicted as a west-tilted half graben on the geologic map, but it may be a pull-apart structure related to evaporite tectonism (Kirkham, Streufert, and others, 2002). Volcanic ash encountered from about 250 to 300 ft below the ground surface in a test well in Spring Valley (Robin VerSchneider, 2001, personal commun.) was identified as the Lava Creek B ash by A.M. Sarna-Wojcicki (2002, written commun.), which was dated at 639 ka by Lanphere and others (2002). Based on the depth and age of the ash, the sedimentation rate in the valley is very high, especially considering that much of the sediment overlying the ash is clay and silt deposited in a lacustrine environment. If Spring Valley is a pull-apart structure, then evaporite flow may be the primary mechanism responsible for creating the Spring Valley structure. The block of rock that underlies Los Amigos Mesa (the basalt-capped rolling surface west of Spring Valley) protrudes about one-half mile into the Roaring Fork River Valley. This block may be moving or rafting towards the Roaring Fork River, as underlying evaporite flows westward (Kirkham, Streufert, and others, 2002). The large landslide complex on the east side of Spring Valley likely failed in response to removal of the toe of the slope as the Spring Valley pull-apart structure gradually widened.

Pliocene volcanic rocks of unit Tta were erupted as collapse continued. Much of the collapse post-dates the Pliocene volcanic rocks, because the Pliocene volcanic rocks in the Leon and Cottonwood Pass quadrangles are deformed nearly as much as the Miocene volcanic rocks (Kirkham, Streufert, and others, 2002).

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 Collapse Center and Eagle Collapse Center 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).

Fifty-two samples from volcanic flows in the Carbondale quadrangle were chemically analyzed by Unruh and others (2001) and correlated compositionally by Budahn and others (2002) as part of the collaborative CGS-USGS investigation (see Appendix A and Table 1). Five samples were dated by Kunk and others (2002) (**see Table 1**). Locations of these samples are shown on the accompanying geologic map, and the latitude and longitude of the samples locations are listed in Appendix A after the chemical analyses. Nine of the compositional groups identified by Budahn and others (2002) in the region (groups 1b, 1c, 1c″, 1d, 3b, 4b, 6a, 6a′, and 12a) were recognized in the samples collected in the Carbondale quadrangle. Two of the analyzed samples were from unknown compositional groups.

Table 1. Compositional geochemical groups and preferred $^{40}Ar/^{39}Ar$ ages of volcanic rocks in the Carbondale quadrangle (from Budahn and others, 2002; Kunk and others, 2002). Sample locations are shown on the accompanying geologic map. Latitude and longitude for each sample location is listed at the end of Appendix A.

Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)
CD5	Tb	1b	
CD6	Tb	1b	
CD17	Tb	1b	
CD31	Tb	1b	
CD51A	Tb	1b	
CD51B	Tb	1b	
CD53B	Tb	1b	
CD53C	Tb	1b	
CD53D	Tb	1b	
CD59	Tb	1b	
CD65	Tb	1b	
CD124A	Tb	1b	
CD124B	Tb	1b	
CD156	Tb	1b	
CD179	QTcd	1b	
CD180	QTcd	1b	
CD181B	QTcd	1b	
CD181C	QTcd	1b	
CD191B	QTcd	1b	
CD192	Tb	1b	
CD193B	Tb	1b	
CD193C	Tb	1b	
CD193D	Tb	1b	
CD218	Tb	1b	
K97-10-8A (same outcrop as CD6)	Tb	1b§	9.89 ± 0.06 Ma
K97-10-8E (same outcrop as CD53D)	Tb	1b§	9.75 ± 0.06 Ma
CD12	Tb	1c	
CD109	Tb	1c	
CD150C	Tb	1c	

Table 1. Continued

Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)
CD138	Tb	1c”	
CD203	Tb	1c”	
CD204	Tb	1c”	
CD42	Tb	1d	
CD45A	Tb	1d	
CD45B	Tb	1d	
CD19	Tb	3b	
CD53A	Tb	3b	
CD181A	QTcd	3b	
CD187	QTcd	3b	
CD193A	Tb	3b	
K97-10-8F (same outcrop as CD53A)	Tb	3b§	9.91 Ma#
CD135	Tb	4b	
CD150A	Tb	4b	
CD150B	Tb	4b	
CD197	Tta	6a	
CD199	Tta	6a	
CD206	Tta	6a	
CD215	Tta	6a	
CD8	Tta	6a’	
CD209	Tta	6a’	
CD216	Tta	6a’	
CD152	Tb	12a	13.29 ± 0.28 Ma
L223	Tb	12a	13.38 ± 0.06 Ma
CD23	Tb	U*	
L76	Tb	U	

* unknown compositional group

§ compositional group based on analysis of another sample that was collected from the same outcrop

\# no age uncertainty reported

About half of the analyzed samples were in compositional group 1b, which was erupted during a 1 m.y. period of time from about 9.8 Ma to 10.8 Ma. These flows are widely distributed across most of the quadrangle but were not recognized south of the Roaring Fork River. Group 1b flows are useful to characterize deformation in the quadrangle. For example, group 1b flows were identified on the ridge north of Heuschkel Park and also in the floor of the park. A major down-to-south structure with about 1,000 ft of post-middle Miocene movement is required along the north wall of Heuschkel Park to explain these relationships.

Although only three group 1c flows were detected in the quadrangle, they are spread across the quadrangle from east of Spring Valley to near “The A’s” south of the Roaring Fork River. Similarly, the locations of the three samples from group 1c” were widespread, extending from the northeast corner of the quadrangle to near “The A’s”. Group 1d rocks were encountered only on Red Hill. Group 3b rocks were identified in the north-central part of the quadrangle. The group 4b rocks, which were erupted from Basalt Mountain east of the Carbondale Collapse Center (Kirkham, Widmann, and Streufert, 2008), were limited to the area between the Roaring Fork River and “The A’s”. The oldest flows in the quadrangle, the 13.3 Ma to 13.4 Ma group 12a rocks, were recognized only in “The A’s”.

Five samples from the quadrangle were dated by Kunk and others (2002) using ^{40}Ar/^{39}Ar methods. Sample K97-10-8A, which is from the same flow and outcrop as the group 1b sample CD6, yielded an age of 9.89 ± 0.06 Ma. An age of 9.75 ± 0.06 Ma was obtained on sample K97-10-8E, which was from the same flow and outcrop as the group 1b sample CD53D. This sample was collected from the upper flow in a stacked flow sequence on the ridge north of the eastern end of Heuschkel Park. The basal flow in this stacked sequence, sample K97-10-8F, yielded a poorly constrained age of 9.91 Ma, but this age is in agreement with the stratigraphic relationships exposed in the stacked flow sequence. Another sample from this basal flow (CD53A) was correlated with compositional group 3b. The stratigraphic relations between the group 3b flow and overlying group 1b flows in the stacked flow sequence exposed on the ridge north of the eastern end of Heuschkel Park were also observed at two other locations with stacked flow sequences (NE ¼ of section 14, T. 7 S., R. 88 W. and section 7, T. 7 S., R. 87 W.).

Two samples from “The A’s” also were dated by Kunk and others (2002). Sample L223 yielded an age of 13.38 ± 0.06 Ma, and an age of 13.29 ± 0.28 Ma was obtained on sample CD152. These dates provide a minimum age constraint for the unit Ts sediments deposited in Sopris Bowl, in that the flows overlie the sediments.

GEOLOGIC HAZARDS AND CONSTRAINTS

Several types of geologic hazards and constraints exist in the Carbondale 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 and evaporite karst hazards in the Roaring Fork River Valley. The hydrocompaction potential of sheetwash deposits (unit Qsw), fine-grained colluvium (unit Qc) and alluvium and colluvium, undivided (unit Qac) was classified as moderate to high. These deposits, along with the older debris-flow deposits (unit Qdfo), also were considered to 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 sheetwash, rockfall, small debris flows, mudflows, and landslides.

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 interpreted to be the result of collapse over evaporite beds were detected during this project and are shown on the geologic map. At least one new sinkhole formed in the quadrangle since the field work was performed in 1996 for the original CGS geologic map of the quadrangle. The new sinkhole suddenly opened up in a soccer field at Colorado Mountain College during February 2003 (Kirkham and others, 2003). Modern rates of ground movement related to regional and local 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 in the Heuschkel Park structure and Crystal Trough. 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). Some areas mapped as colluvium (unit Qc) also have rockfall hazards. Large gravel clasts and boulders contained within surficial deposits can be hazardous when exposed in the walls of excavations and in roadcuts.

Two small recently active landslides (unit Qlsr) demonstrate that future landslides may occur in the quadrangle. These recent slope failures involved movement of a thin veneer of colluvium that mantled either the Eagle Valley Evaporite or Eagle Valley Formation. Large landslide deposits formed in Miocene sedimentary deposits (unit Ts) in the southeast part of the quadrangle. Volcanic flows were involved in the large landslides in the northeast part of the quadrangle, along Cattle Creek downstream of its confluence with Coulter Creek, and on the east side of Spring Valley. The large landslide complex on the east side of Spring Valley may be related to evaporite deformation. As the Spring Valley structure developed, the toe of the slope that supported the hills east of Spring Valley was gradually altered, which created over-steepened and unstable slopes east of the valley. The timing and the rate of slope movements in the landslide complex east of Spring Valley may be directly controlled by the timing and rate of evaporite deformation in Spring Valley.

Historic earthquakes have shaken the region on numerous occasions (Kirkham and Rogers, 2000). A sequence of small earthquakes shook the area in April and May 1984 (Goter and others, 1988). This sequence, called the Carbondale Colorado earthquake swarm, included 34 located events. The largest had a local magnitude of 3.2. Nine of the earthquakes were felt in Carbondale. Future earthquakes, some possibly strong enough to cause damage and trigger secondary effects such as landslides and rockfall, may affect the quadrangle.

ECONOMIC GEOLOGY

Sand and gravel are the primary mineral resource in the quadrangle. Several active sand and gravel operations demonstrate the suitability of the material and the need for the resource. Other mineral commodities with possible economic potential in the quadrangle include gypsum, riprap, and perhaps scoria. Oil and gas resources also may exist in the quadrangle. In that hot springs exist in the region, there also is a potential for geothermal resources.

Many of the surficial deposits have sand and gravel potential. Units Qa, Qty, and Qtm have high potential for sand and gravel resources. The sand and gravel potential of units Qto, Qac, Qdfy, Qaco, Qdfo, QTm, and Ts is moderate to low, because either the clasts within these units are decomposed or the deposits contain undesirable amounts of fine-grained matrix.

The Eagle Gypsum Company produces gypsum from an open pit developed in the Eagle Valley Evaporite at their Eagle Gypsum Mine located north of the town of Gypsum. The gypsum is manufactured into wallboard and other products at a calcining and production facility. The Eagle Valley Evaporite may contain economic deposits of gypsum within the quadrangle.

Riprap might be obtained from volcanic flows in the quadrangle (units Tb and Tta). Large blocks of reworked volcanic rock that potentially could be suitable for riprap, may also exist in units QTcd, Qt, Qls, and Qc. Although scoria was not observed during this study, it potentially could exist in areas with volcanic rock (units Tb and Tta).

Only one well, the Champlin Oil Blue no. 1 well near Catherine, has been drilled to test the oil and gas potential in the quadrangle. Circulation was lost in the well at a depth of 2,320 ft, and the well was abandoned. It failed to penetrate through the entire evaporite sequence.

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APPENDIX A

Major element, whole-rock XRF analyses of volcanic rocks in the Carbondale quadrangle. Sample locations are given in the second table and are also shown on the accompanying geologic map. All analyses by Unruh and others (2001).

	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**
CD5	52.44	15.44	7.77	7.13	3.23	1.03	11.47	0.16	0.32	1.42	-0.28	100.13
CD6	51.32	15.13	7.88	7.76	2.86	1.08	12.38	0.16	0.31	1.45	-0.28	100.05
CD8	55.05	15.42	5.99	4.30	3.28	3.57	8.41	0.11	0.54	1.36	1.00	99.03
CD12	51.04	15.54	8.40	6.23	3.01	1.54	10.75	0.15	0.41	1.44	1.06	99.57
CD17	52.42	15.63	7.94	6.97	3.07	0.99	11.06	0.15	0.29	1.37	0.09	99.98
CD19	50.98	15.51	7.61	7.18	3.09	1.45	11.57	0.16	0.50	1.54	0.10	99.69
CD23	50.46	17.02	9.46	2.79	3.48	2.12	9.08	0.09	0.70	1.98	2.10	99.28
CD31	52.03	15.27	8.09	6.80	2.85	0.83	11.09	0.14	0.29	1.38	1.38	100.15
CD42	51.45	15.47	8.03	7.02	3.04	1.21	11.35	0.15	0.35	1.43	0.09	99.59
CD45A	51.01	15.22	8.23	6.89	2.90	1.08	10.92	0.14	0.36	1.41	1.40	99.56
CD45B	50.95	15.24	8.30	6.79	2.90	1.04	10.99	0.14	0.34	1.41	1.58	99.68
CD51A	51.47	15.13	8.21	6.68	2.80	0.83	10.65	0.14	0.28	1.37	2.32	99.88
CD51B	52.51	15.48	8.10	6.79	2.97	1.02	11.01	0.15	0.29	1.37	0.36	100.05
CD53A	51.48	15.55	7.38	6.95	2.99	1.73	11.24	0.15	0.55	1.60	0.16	99.78
CD53B	52.21	15.45	7.92	6.96	3.14	1.04	11.32	0.15	0.31	1.43	-0.01	99.92
CD53C	52.21	15.45	7.99	6.96	3.07	1.06	11.33	0.15	0.31	1.41	0.05	99.99
CD53D	52.36	15.44	7.87	6.92	3.04	0.95	12.01	0.16	0.29	1.38	-0.44	99.98
CD59	51.68	15.50	8.18	7.13	3.05	0.95	11.25	0.15	0.31	1.40	0.52	100.12
CD65	52.21	15.45	8.03	6.97	3.11	0.96	11.17	0.15	0.31	1.41	0.20	99.91
CD109	52.35	15.92	8.02	6.27	3.08	1.62	10.47	0.15	0.43	1.47	0.09	99.87
CD124A	51.33	15.75	8.16	7.00	2.96	0.98	11.43	0.15	0.29	1.38	0.03	99.46
CD124B	51.66	15.44	8.00	7.33	2.92	1.09	11.63	0.16	0.30	1.45	-0.13	99.85
CD135	52.21	15.67	7.10	6.11	3.19	2.18	10.49	0.14	0.69	1.60	0.02	99.40
CD138	51.28	15.65	8.25	6.80	2.98	1.42	11.05	0.15	0.39	1.43	0.46	99.86
CD150A	51.59	15.56	7.33	5.82	2.93	2.10	10.13	0.13	0.67	1.59	1.52	99.37
CD150B	51.63	16.23	7.29	6.08	3.13	2.08	10.72	0.15	0.70	1.64	0.28	99.93
CD150C	51.02	15.97	8.00	6.68	2.99	1.29	11.43	0.17	0.40	1.48	0.49	99.92
CD152	55.24	15.96	6.38	4.46	3.64	2.84	9.18	0.15	0.47	1.38	0.14	99.84
CD156	51. 40	15.22	8.25	6.85	2.88	0.99	10.76	0.14	0.31	1.37	1.79	99.96
CD179	52.38	15.53	8.05	6.73	3.05	0.98	11.15	0.15	0.30	1.38	0.29	99.99
CD180	52.34	15.66	8.09	6.80	3.05	0.96	11.20	0.15	0.29	1.39	0.04	99.97
CD181A	51.94	15.69	7.22	6.94	3.11	1.81	11.16	0.15	0.43	1.59	0.06	100.10
CD181B	52.43	15.48	7.90	6.89	3.20	1.06	11.34	0.15	0.32	1.44	0.05	100.26
CD181C	52.47	15.59	7.95	6.90	3.05	0.91	11.11	0.15	0.30	1.37	0.19	99.99
CD187	51.56	15.46	7.37	7.21	3.08	1.73	11.44	0.15	0.55	1.60	0.04	100.19
CD191B	52.42	15.57	8.14	6.70	3.06	1.04	11.15	0.15	0.30	1.39	0.39	100.31
CD192	52.08	15.56	8.08	7.00	3.10	1.05	11.44	0.16	0.31	1.41	0.00	100.19

Appendix A, Continued

	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
CD193A	51.36	15.38	7.44	7.15	2.99	1.67	11.40	0.15	0.52	1.55	0.09	99.70
CD193B	52.06	15.58	7.94	6.68	3.04	1.06	11.50	0.16	0.31	1.44	0.26	100.03
CD193C	51.75	15.58	8.06	6.92	3.01	1.02	11.60	0.15	0.31	1.42	0.30	100.12
CD193D	51.76	15.54	8.05	7.11	3.02	0.98	11.41	0.15	0.30	1.38	0.30	100.00
CD197	56.01	15.78	5.95	4.94	3.28	3.63	7.99	0.13	0.43	1.40	0.07	99.61
CD199	54.71	15.73	5.89	5.11	3.37	3.44	8.33	0.13	0.31	1.39	0.75	99.16
CD203	51.54	15.92	7.89	6.67	3.00	1.34	10.97	0.15	0.32	1.42	0.73	99.95
CD204	51.21	16.14	7.93	6.50	2.96	1.25	11.22	0.15	0.27	1.46	0.59	99.68
CD206	54.21	16.02	6.36	5.40	3.36	3.57	8.31	0.13	0.40	1.44	0.18	99.38
CD209	54.01	16.00	6.35	5.30	3.34	3.56	8.37	0.12	0.47	1.45	0.38	99.35
CD215	54.66	15.94	5.98	4.86	3.27	3.45	8.50	0.12	0.35	1.45	0.71	99.29
CD216	55.86	15.58	5.98	4.72	3.23	3.50	7.87	0.12	0.46	1.37	0.60	99.29
CD218	51.47	15.81	8.28	6.61	2.99	0.91	10.82	0.15	0.30	1.37	0.74	99.45
L76	48.54	15.84	8.05	7.02	3.07	2.79	10.15	0.16	0.75	1.67	1.23	99.27
L223	56.03	15.83	5.97	4.35	3.73	3.09	8.07	0.14	0.49	1.30	0.14	99.14

*LOI = loss on ignition.

Refer to analysis for CD6 for composition of sample K97-10-8a; to analysis for CD53d for sample K97-10-8e; and to analysis for CD53a for sample K97-10-8f, as each sample pair was collected from the same outcrop and flow.

Sample Locations (NAD27)

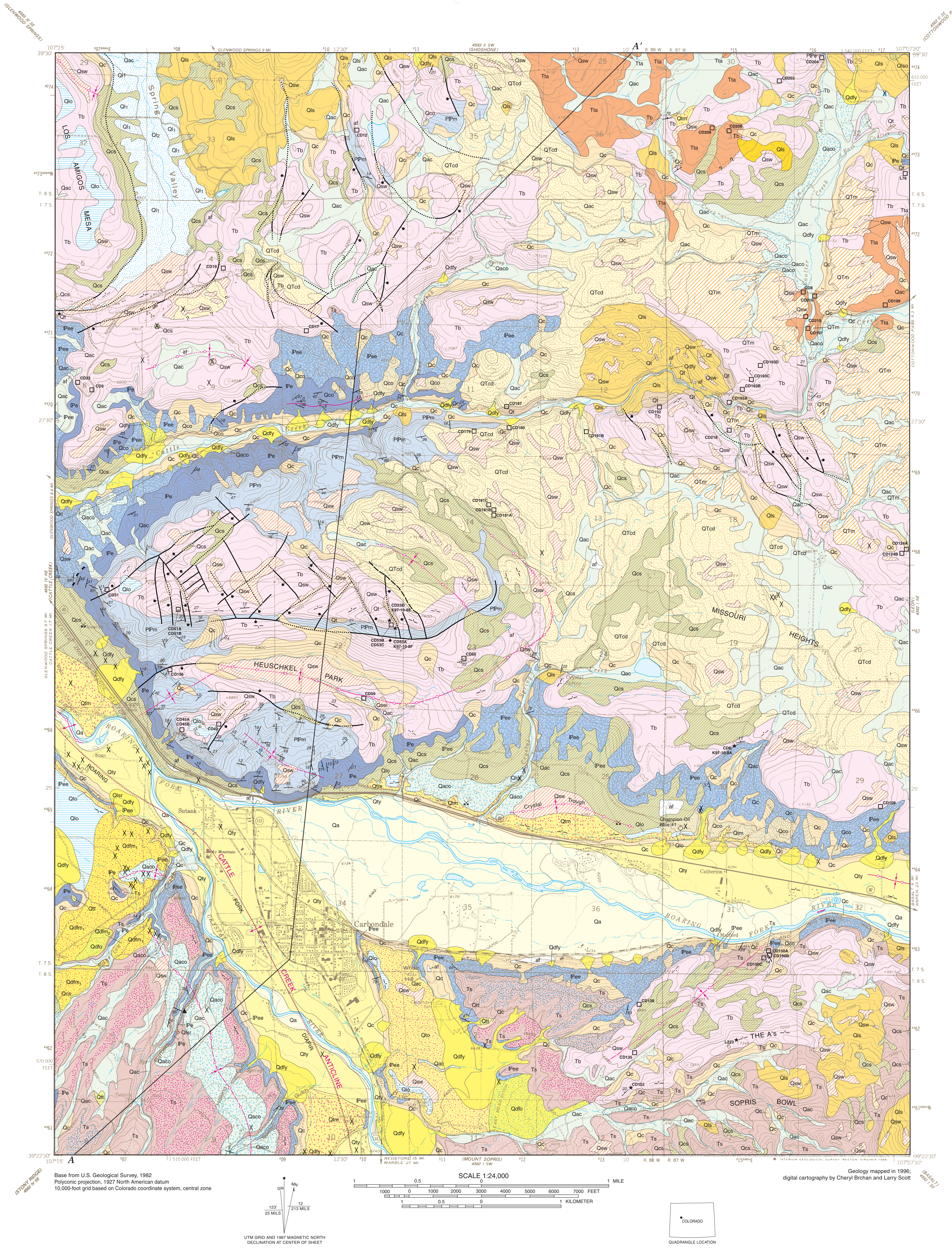
		Location				Location	
Sample ID	Map Unit	Latitude	Longitude	Sample ID	Map Unit	Latitude	Longitude
CD5	Tb	39.4616° N	107.2445° W	CD150A	Tb	39.3983° N	107.1455° W
CD6	Tb	39.4214° N	107.1511° W	CD150B	Tb	39.3976° N	107.1456° W
CD8	Tta	39.4730° N	107.1409° W	CD150C	Tb	39.3973° N	107.1459° W
CD12	Tb	39.4912° N	107.2061° W	CD152	Tb	39.3827° N	107.1659° W
CD17	Tb	39.4687° N	107.2139° W	CD156	Tb	39.4301° N	107.2337° W
CD19	Tb	39.4757° N	107.2253° W	CD179	QTcd	39.4575° N	107.1892° W
CD23	Tb	39.4626° N	107.2466° W	CD180	QTcd	39.4576° N	107.1839° W
CD31	Tb	39.4390° N	107.2429° W	CD181A	QTcd	39.4475° N	107.1856° W
CD42	Tb	39.4238° N	107.2262° W	CD181B	QTcd	39.4480° N	107.1859° W
CD45A	Tb	39.4233° N	107.2324° W	CD181C	QTcd	39.4486° N	107.1866° W
CD45B	Tb	39.4232° N	107.2325° W	CD187	QTcd	39.4600° N	107.1835° W
CD51A	Tb	39.4234° N	107.2321° W	CD191B	QTcd	39.4574° N	107.1723° W
CD51B	Tb	39.4234° N	107.2320° W	CD192	Tb	39.4599° N	107.1620° W
CD53A	Tb	39.4351° N	107.2004° W	CD193A	Tb	39.4605° N	107.1515° W
CD53B	Tb	39.4352° N	107.2006° W	CD193B	Tb	39.4617° N	107.1497° W
CD53C	Tb	39.4353° N	107.2007° W	CD193C	Tb	39.4631° N	107.1484° W
CD53D	Tb	39.4354° N	107.2009° W	CD193D	Tb	39.4647° N	107.1473° W
CD59	Tb	39.4268° N	107.2057° W	CD197	Tta	39.4685° N	107.1403° W
CD65	Tb	39.4311° N	107.1902° W	CD199	Tta	39.4718° N	107.1272° W
CD109	Tb	39.4145° N	107.1291° W	CD203	Tb	39.4968° N	107.1441° W
CD124A	Tb	39.4437° N	107.1255° W	CD204	Tb	39.4994° N	107.1381° W
CD124B	Tb	39.4435° N	107.1258° W	CD206	Tta	39.4913° N	107.1517° W
CD135	Tb	39.3865° N	107.1654° W	CD209	Tta	39.4914° N	107.1541° W
CD138	Tb	39.3918° N	107.1653° W	CD215	Tta	39.4738° N	107.1414° W

Sample Locations, continued

Sample ID	Map Unit	Location	
		Latitude	Longitude
CD216	Tta	39.4725° N	107.1393° W
CD218	Tb	39.4571° N	107.1514° W
K97-10-8A	Tb	39.4214° N	107.1511° W
K97-10-8E	Tb	39.4354° N	107.2009° W
K97-10-8F	Tb	39.4351° N	107.2004° W
L76	Tb	39.4863° N	107.1256° W
L223	Tb	39.3880° N	107.1504° W

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER COLORADO

MAP SERIES 36
GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE,
GARFIELD COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1982
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

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

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—Sediments deposited in stream channels, flood plains, glacial outwash terraces, and sheetwash areas

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. Includes terraces up to about 12 ft above modern river level

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, and in basinal areas

Qty **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 14–45 ft above modern stream level. May include fine-grained overbank deposits

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55–110 ft above modern streams

Qto **Older terrace alluvium (late middle Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts slightly to moderately weathered. Underlies terraces 160–200 ft above modern streams

MASS-WASTING DEPOSITS—Sediments on valley sides, valley floors, and hillslopes transported and deposited primarily by gravity

Qlsr **Recent landslide deposits (latest Holocene)**—Includes active and recently active landslides with fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified gravel, sand, and silt

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

Qt **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of basalt or basalt-rich collapse debris (QTcd)

Qls **Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris. Ranges from recently active landslides to long-inactive Pleistocene landslides

Qco **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. Generally not subject to future deposition.

Qlso **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion lacking distinctive landslide geomorphology. Similar in texture to landslide deposits (Qls)

ALLUVIAL AND MASS-WASTING DEPOSITS—Sediments in debris fans, stream channels, flood plains, and hillslopes along tributary valleys

Qdfy **Younger debris-flow deposits (Holocene and late Pleistocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Moderately well-sorted to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt

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

Qdfm **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similar in texture and depositional environment to younger debris-flow deposits (Qdfy), but found 20–100 ft above Edgerton Creek. Numeric subscripts on unit symbol indicate relative ages of deposits, with $Qdfm_1$ being older than $Qdfm_2$. Generally not subject to future deposition except during unusually large events or when drainage channels plug with debris and are overtopped

Qaco **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes above the floor of tributary valleys. Includes locally derived sediments and the Lava Creek B volcanic ash that were deposited within a large subsidence trough developed in oldest terrace alluvium (Qtt) southwest of Carbondale

Qdfo **Older debris-flow deposits (Holocene? and Pleistocene)**—Remnants of inactive debris fans found on mesas and adjacent to stream drainages 20–160 ft above nearby streams. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

EOLIAN DEPOSITS–sediments deposited by wind

Qlo **Loess (late and middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind on level to gently sloping surfaces. Usually unstratified, friable, and plastic or slightly plastic when wet

LACUSTRINE DEPOSITS

Ql_2/Ql_1 **Lacustrine deposits (Holocene and Pleistocene)**—Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, yellow-brown clayey silt, and medium-red-brown, well-sorted, fine to coarse sand deposited in Spring Valley. Locally includes thick deposits of Lava Creek B ash. Numeric subscripts indicate relative ages of deposits. Ql_1 deposits are older than and lie 20–40 ft above Ql_2

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q **Surficial deposits, undifferentiated (Quaternary)**— Shown only on cross section. May include any of the above surficial deposits

ALLUVIAL, MASS-WASTING, LACUSTRINE, AND DELTAIC DEPOSITS

QTm **Sediments of Missouri Heights (early Quaternary and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Cottonwood Pass region in alluvial, mass-wasting, and either lacustrine or deltaic environments. Deposited in areas topographically lowered by collapse or subsidence related to dissolution or flow of salt deposits in the underlying Eagle Valley Evaporite. Overlies Miocene basaltic rocks (Tb) and Pliocene trachyandesitic rocks (Tta). Typically is less deformed than underlying rocks

COLLAPSE DEPOSITS

QTcd **Collapse deposits (Pleistocene and late Tertiary)**—Heterogeneous deposits of slightly to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Locally includes large intact blocks of basalt (Tb) that are lowerd by collapse. Several flows in these blocks were geochemically analyzed. Formed in response to differential collapse resulting from dissolution of underlying evaporite

BEDROCK

Tta **Trachyandesite undifferentiated (Pliocene)**—Multiple flows of basaltic trachyandesite and trachyandesite. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts

Tb **Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments

Ts Ts Ts Ts **Sedimentary deposits (Miocene)**—Mostly fluvial, clast-supported, silty, sandy pebble and cobble gravel, but locally contains silty and sandy deposits of probable alluvial and/or colluvial origin. Locally slightly to moderately indurated. Patterns indicate a younger erosion surface is present on the unit. Thin mantle of younger sediments locally underlies these erosion surfaces. Upper pattern indicates erosion surface is of late middle Pleistocene age; middle pattern indicates a middle and early? age; lower pattern indicates early Pleistocene and/or late Tertiary age

Pℙm **Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle

ℙe **Eagle Valley Formation (Middle Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and intertonguing with the Maroon Formation and Eagle Valley Evaporite

ℙee **Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with marine mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed

MAP SYMBOLS

Contact—Dashed where approximately located; queried where very uncertain

Diapiric contact—Contact between evaporitic formations and overlying formations where the evaporitic rocks are intrusive or piercing into the overlying formations. Teeth are on the intrusive side of the contact

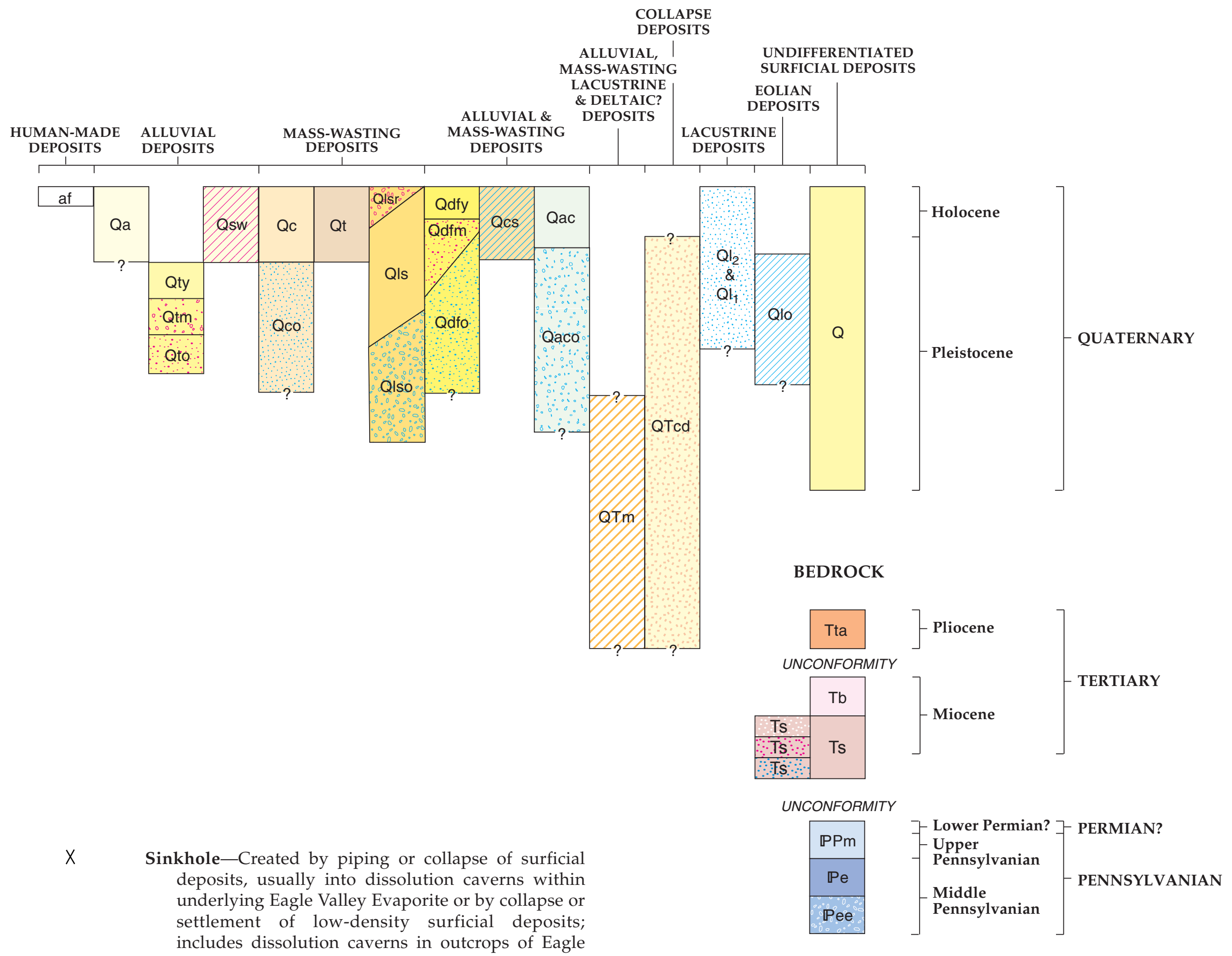
Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; includes faults related to dissolution and flowage of evaporite

Anticline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axis indicates direction of plunge

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; these structures may be synclinal sags, but they lack supportive evidence for this origin

Synclinal sag or subsidence trough—Showing axial trace of synclinal sag or subsidence trough related to evaporite tectonism; synclinal sags occur in bedrock, subsidence troughs are in river terraces and overlying deposits; dashed where approximately located; dotted where concealed; limbs of synclinal sags and subsidence troughs may be faulted; closed and nearly closed depressions in collapse debris (QTcd), which likely are at least in part sags or troughs, are not mapped

CORRELATION OF MAP UNITS



Sinkhole—Created by piping or collapse of surficial deposits, usually into dissolution caverns within underlying Eagle Valley Evaporite or by collapse or settlement of low-density surficial deposits; includes dissolution caverns in outcrops of Eagle Valley Evaporite; many small sinkholes other than those shown on the map are probably present in the quadrangle

Strike and dip of beds—Angle of dip shown in degrees; most attitudes in basalt and terrace deposits were measured on top of apparent surface

23 **Inclined beds**

Vertical beds

Inclined beds—Showing approximate attitude of surface on terraces and basalt flows as determined from stereoscopic models set on a Kelsh PG-2 plotter; dip between 0 and 30

65 **Strike and dip of foliation or flow layering in volcanic rocks**—Angle of dip shown in degrees

Zone of shearing and bleaching

Gravel pit

☐ CD42 **Location and identification number of rock sample with geochemical analysis (Unrah and others, 2001; Budahn and others, 2002). See table 1 and Appendix A in booklet**

★ CD53D **Location and identification number of rock sample with geochemical analysis (Unrah and others, 2001; Budahn and others, 2002) and $^{40}Ar/^{39}Ar$ age date (Kunk and others, 2002). See Table 1 and Appendix A in booklet**

▲ **Outcrop of Lava Creek B volcanic ash**—Ash correlated by Izett and Wilcox (1982)

A——*A′* **Alignment of cross section**

Oil or gas exploration test hole—Plugged and abandoned; operator, well name, and total depth shown

ACKNOWLEDGEMENTS

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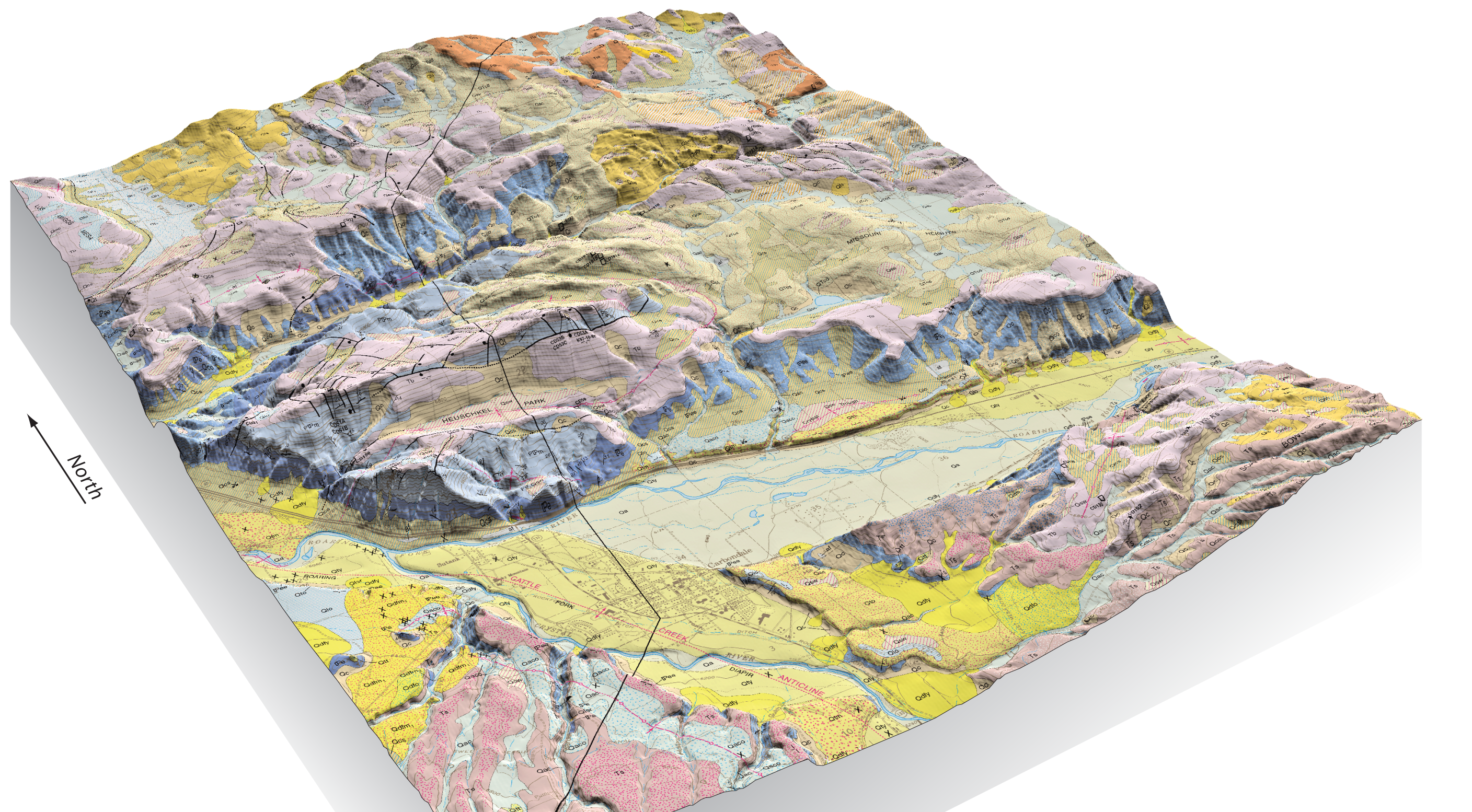

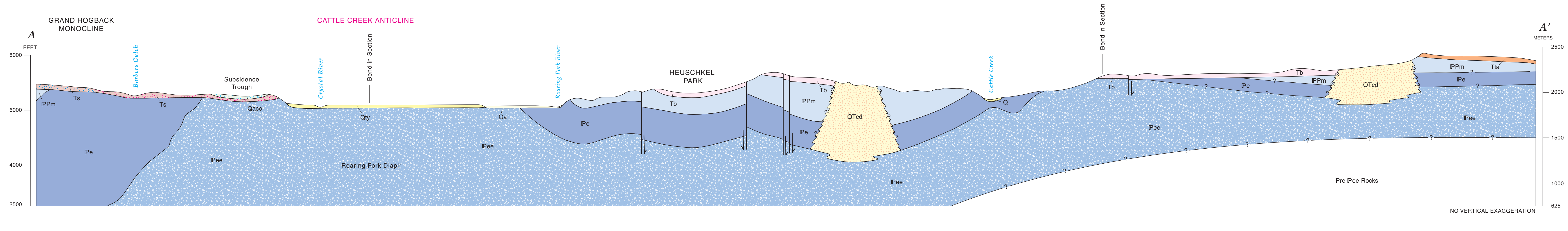

GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE, GARFIELD COUNTY, COLORADO

By Robert M. Kirkham and Beth L. Widmann
2008

Bill Ritter Jr., Governor
State of Colorado

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Department of Natural Resources

Vincent Matthews
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