Map Series 40

Geologic Map of the Leon Quadrangle, Eagle and Garfield Counties, Colorado

By Robert M. Kirkham, Beth L. Widmann, and Randall K. Streufert

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

Map Series 40

Geologic Map of the Leon Quadrangle, Eagle and Garfield Counties, Colorado

By Robert M. Kirkham, Beth L. Widmann, and Randall K. Streufert

Colorado Geological Survey
Denver, Colorado
2008

FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Map Series 40, *Geologic Map of the Leon 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-HQ-97-AG-1811 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

Our original geologic map of the Leon quadrangle was published as CGS Open-File Report 98-3, and it benefited from reviews by Jeff Hynes, Jim Cappa, and Nancy Bauch. Jim Cappa also provided petrographic descriptions of many of the volcanic rocks. Jane Ciener served as the technical editor of the earlier map. Jim Messerich set photogrammetric models of our annotated aerial photographs on a Kern PG-2 plotter. Several colleagues, including Bruce Bryant, Mick Kunk, Jon White, Jim Cappa, Ralph Shroba, Dick Moore, Wayne Shelton, Ralph Mock, Jim Budahn, and Bill Perry, contributed data or advice. Tony Svatos pointed out the existence of gravel deposits along the north edge of the Basalt Mountain shield volcano, provided a log of a test pit into these deposits, and initiated arrangements that allowed us to set up a field trailer on U.S. Forest Service land. We thank the USGS for loaning us the field trailer. Louis Meyer graciously provided a copy of a geotechnical report for a property within the quadrangle.

We appreciate the many landowners and property managers who gave permission to enter their property. Sue Rodgers, Dwayne Gilfrey, Sarah McNulty, Jim Griffith, Jim MacDonald, Bill Joy, Bob Joy were especially helpful.

CONTENTS

FIGURES

TABLE

APPENDIX

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 Leon 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 98-3 (Kirkham and others, 1998). 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 Leon quadrangle, six other quadrangles in the Glenwood Springs area are being digitally updated. They include the Glenwood Springs, Shoshone, Carbondale, Cottonwood Pass, Basalt, and Mount Sopris quadrangles (Fig. 1).

Most of the modifications to this updated digital geologic map of the Leon 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-File Report 98-3. The

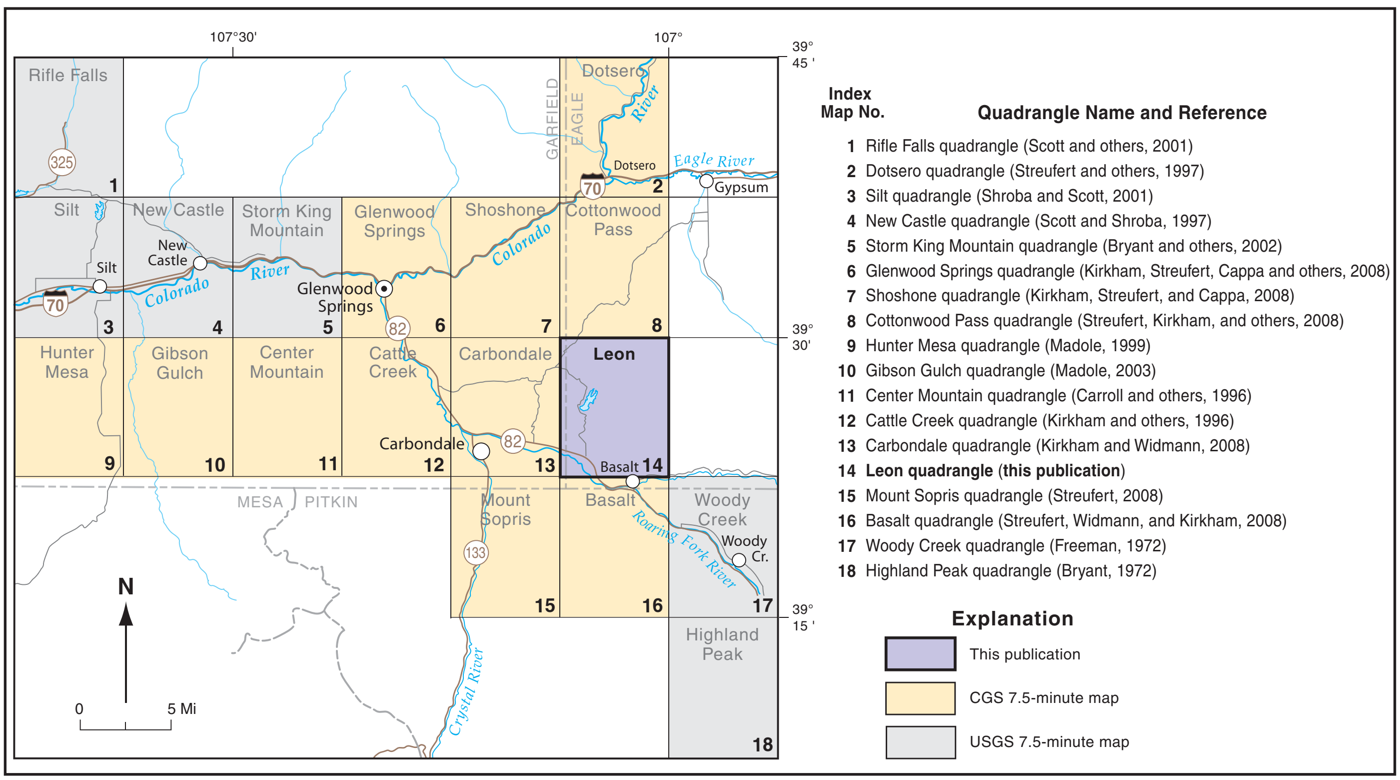


Figure 1. Geologic maps of 7.5-minute quadrangles in the vicinity of the Leon quadrangle.

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. 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). Forty-four samples of volcanic rocks from Leon 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 Leon 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 Leon quadrangle covers about 58 square miles in Eagle and Garfield Counties, which are in west-central Colorado, and includes the towns of Basalt and El Jebel. Colorado Highway 82, which parallels the Roaring Fork River Valley, crosses the southwest corner of the quadrangle. Basalt Mountain, the highest peak in the quadrangle, towers over the balance of the quadrangle. Most of the land in the northeastern and east-central parts of the quadrangle is public land administered by the White River National Forest. Private land that historically was used mainly for ranching, but which now is rapidly developing, lies along the Roaring Fork River valley and in the northwest part of the quadrangle. The remainder of the quadrangle is public land managed by the 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.

Mapping responsibilities for the geologic map of Leon quadrangle were as follows: R.M. Kirkham the mapped the surficial deposits and Cenozoic rocks throughout the quadrangle and the Paleozoic and Mesozoic rocks in most of the mapped area; R.K. Streufert mapped the Paleozoic and Mesozoic sedimentary rocks in the northeast corner of the quadrangle; and B.L. Widmann served as their field assistant. 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

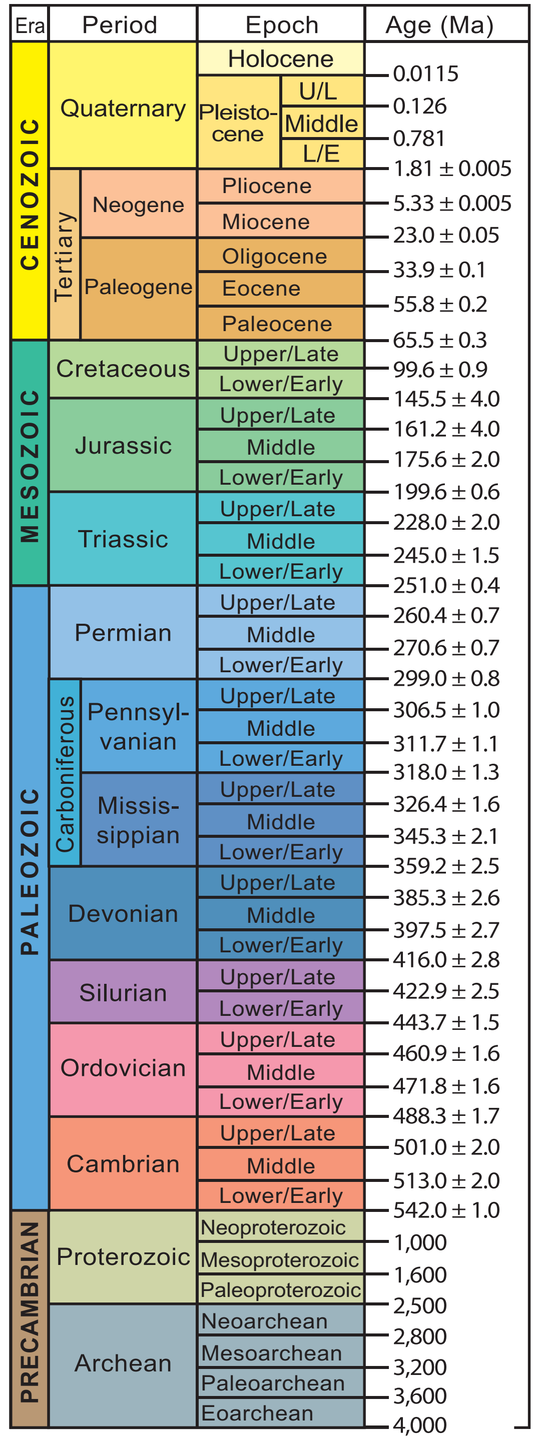
Previously published small-scale geologic maps of the Leon quadrangle include 1:500,000-scale maps by Burbank and others (1935) and Tweto (1979), and the 1:250,000-scale map of Tweto and others (1978). F.M. Fox and Associates (1974) mapped the western part of the quadrangle at a scale of 1:48,000. The 1:50,000-scale mapping of Soule and Stover (1985), which covered a very small area in the southwestern part of the quadrangle, emphasized surficial deposits. CGS originally mapped the Leon quadrangle at a scale of 1:24,000 and released it as Open-File Report 98-3 (Kirkham and others, 1998).

MAPPING METHODS AND TERMINOLOGY

Most field work in Leon quadrangle was conducted by the authors during the 1997 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**.



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, although 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 Leon 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 dam and roads, and trash placed in landfills. Most earthen materials in artificial fill consist of unsorted silt, sand, and rock fragments. Maximum thickness is about 50 ft.

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

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)—**Includes modern alluvium and other deposits underlying the Roaring Fork and Fryingpan Rivers, adjacent flood-plain deposits, and low-terrace alluvium that is 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. It is sometimes interbedded with and often overlain by sandy silt and silty sand. The unit is poorly to moderately well sorted and moderately well to well bedded. Clasts within the unit are subangular to well rounded, and their varied lithology reflects the diverse types of bedrock in their provenance. Fine-grained sediments, including silt and clay, are present in some of the subsidence troughs formed in unit Qa. The maximum estimated thickness is 50 ft. Flood-plain and terrace deposits included in this unit correlate with sediment in terrace T8 in the Carbondale–Glenwood Springs area of Piety (1981).

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)—**Includes deposits locally derived from weathered bedrock and surficial materials that are 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. 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 15 to 52 ft above modern stream level. Locally younger terrace alluvium may be capped by a single, thin loess sheet. 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. Clasts are mainly subrounded to rounded and are generally unweathered or only slightly weathered. Thickness of the unit ranges widely but averages about 30 to 40 ft.

North of the quadrangle, at the rest area on Highway I-70 in West Glenwood, 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 deposit is correlative to some of the deposits in unit Qty in Leon quadrangle. Unit Qty also correlates with deposits in terrace T7 in the Carbondale-Glenwood Springs area described by Piety (1981). Unit Qty was probably deposited late during the Pinedale glaciation.

Qtm

Intermediate terrace alluvium (late Pleistocene)—Composed of stream alluvium underlying terraces about 55 to 100 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 of the Carbondale–Glenwood Springs area of Piety (1981) and is interpreted as glacial outwash deposited early during the Pinedale glaciation.

Qtt

Oldest terrace alluvium (middle and early? Pleistocene)—Consists of stream alluvium in a single small terrace remnant about 380 to 400 ft above the Fryingpan River in the southeast corner of the quadrangle. The deposit is poorly exposed, but it appears to be poorly sorted to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. Clasts within unit Qtt are moderately to strongly weathered. Thickness is about 15 to 25 ft. Unit Qtt is correlated with deposits in terrace T2 of Piety (1981) in the Carbondale-Glenwood Springs area.

QTg

High-level gravel (early Pleistocene and/or late Tertiary)—Occurs on a subtle ridge line about 1 mile east of El Jebel about 1,300 to 1,350 ft above the Roaring Fork. Unit QTg consists of clast-supported, sandy and silty, pebble and cobble gravel and gravelly sand and silt. Clasts are subround to subangular and composed chiefly of quartzite, white sandstone, red sandstone, quartz, and chert, with sparce rounded to well-rounded pebbles of Proterozoic metamorphic and plutonic rocks. Clasts are moderately to very highly weathered. The high-level gravel deposit is about 20 to 30 ft thick.

QTm

Sediments of Missouri Heights (early Pleistocene and/or late Tertiary)—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights area in alluvial, lacustrine, deltaic, or colluvial environments. The unit may include unmapped pediment deposits derived from and deposited on the sediments of Missouri Heights in the area between Spring Park Reservoir and Cattle Creek. The unit is generally very poorly exposed in the quadrangle; however, it is well exposed in an incised irrigation ditch north of Spring Park Reservoir along the boundary between sections 10 and 11. Within the quadrangle the sediments of Missouri Heights typically range from sandy and silty pebble, granule, or cobble gravel to gravelly silty sand. Kirkham and Widmann (2008) reported that in the Carbondale quadrangle this unit is predominantly gravelly sandy silt, clayey silt, and cross-bedded, fine-grained to very fine-grained sand. Clasts are mostly subangular to subround basalt, red sandstone, and quartzite, but many other rock types are present in trace amounts. Unit QTm lies about 1,000 to 1,650 ft above the Roaring Fork River. 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). Their maximum thickness may exceed 300 ft. 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 the sediments. Tilting of the sediments in unit QTm indicates deformation subsequent to their deposition. Unit QTm is similar in origin to the sediments of Cottonwood Bowl (unit QTc) mapped by Streufert, Kirkham, and others (2008) in the Cottonwood Pass quadrangle, but their age relationship is not known.

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 one small, recently active landslide with very fresh morphological features near the northeast corner of the quadrangle in the center of section 35. The deposit consists of unsorted, unstratified rock debris, sand, and silt. Maximum thickness is probably about 15 ft. The recent landslide in this quadrangle occurred on a moderately steep slope underlain by a thin veneer of colluvium that mantles the Entrada Sandstone.

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 is derived from weathered bedrock and surficial deposits and is transported downslope primarily by gravity. 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 or indistince on aerial photographs to be mapped separately. Colluvium also locally includes deposits that are of suspected, but not proven, 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 50 ft.

Qt

Talus (Holocene and late Pleistocene)—Angular, cobbly and bouldery rubble on steep slopes that is derived from hard, indurated outcrops of basalt, trachyandesite, or Dakota Sandstone and transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Talus commonly lacks matrix material. Locally talus is underlain by or incorporated into landslides. Maximum thickness is estimated at about 60 ft.

Qbf

Boulder-field deposits (Holocene and late Pleistocene)—Deposits of angular boulders and cobbles of basalt with little or no matrix on moderate to steep slopes. Boulder-field deposits are common on the flanks of Basalt Mountain, where they generally overlie landslide deposits or basalt flows. Many of the clasts within the boulder-field deposits originated as talus derived from steep cliffs of basalt and have been transported downslope by landslides. Locally the surface developed on boulder-field deposits has linear or sinuous ridges and swales. Such features are suggestive of movement as a rock glacier or the effects of periglacial processes. Thickness of the unit averages 20 to 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, which are characteristic of slopes that have failed. The unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. The large landslide complex on the southwest side of Basalt Mountain includes prominent linear ridges that are underlain by mostly intact but displaced and rotated blocks of basalt or basaltic rubble. Small, thin, unmapped deposits of loess locally overlie the landslide deposits on the southwest side of Basalt Mountain. The maximum thickness of landslide deposits locally exceeds 400 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 15 to 20 ft thick and has a maximum thickness about 30 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. In the southwest corner of the quadrangle, numeric subscripts are used to indicate relative ages of younger debris-fan deposits. Sediments labeled $Qdfy_1$ are younger than and derived from deposits labeled $Qdfy_2$. 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.

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 on 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 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 may include lacustrine sediments beneath Kodiak ski lake in the subsidence trough about one-half mile southeast of El Jebel. Thickness of unit Qcs averages 10 to 30 ft, but it may be thicker in some subsidence troughs.

Qaco

Older alluvium and colluvium, undivided (Pleistocene)—Includes deposits of alluvium and colluvium that underlie terraces and hillslopes that range from about 10 to 60 ft above adjacent small streams. Lithologic characteristics of strata in unit Qaco are similar to those in unit Qac. Locally, unit Qaco includes debris-flow and sheetwash deposits. Maximum thickness of the unit is about 60 feet.

Qcso

Older colluvium and sheetwash deposits, undivided (Pleistocene)—Composed of deposits of colluvium and sheetwash that underlie surfaces 20 to 160 ft above adjacent drainages. Unit Qcso is lithologically similar to unit Qcs, although the clasts in unit Qcso commonly are more weathered than those in unit Qcs. The thickness of unit Qcso averages 20 to 40 ft.

Qdfo

Older debris-flow deposits (Pleistocene)— Includes a single small remnant of older debris-flow deposits that underlies a ridgeline in the southeast corner of the quadrangle. These deposits are about 80 to 120 ft above the adjacent stream bed. Unit Qdfo is lithologically similar to younger debris-flow deposits (unit Qdfy), except the clasts in unit Qdfo are more weathered than those in unit Qdfy. Unit Qdfo typically is about 10 to 20 ft thick.

SINTER DEPOSITS-Chemical sediments deposited by a mineral spring

Qtu

Tufa (Holocene and late Pleistocene?)—Includes a single deposit of low-density, porous, calcium carbonate deposited as chemical precipitate from a now inactive mineral spring. The tufa underlies a prominent ledge along the Basalt Mountain Fault in the northeast part of the quadrangle, immediately north of where the fault crosses Cattle Creek. Thickness of the tufa deposit averages 6 to 7 ft.

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q

Surficial deposits, undivided (Quaternary)— Shown only on cross section A—A'.

COLLAPSE DEPOSITS

QTcd

Collapse deposits (Quaternary 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 complexly deformed areas west of the Basalt Mountain Fault in response to major differential vertical collapse or regional subsidence resulting from 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 basalt and trachyandesite comprise the predominant types of bedrock within the collapse deposits at the ground surface. Lesser amounts of deformed and dislocated Maroon Formation locally occur within the collapse deposits. Various types of surficial deposits, including sheetwash, alluvium, colluvium, loess, and talus, have been deposited over the collapsing debris at various times. These surficial deposits often were caught up within and incorporated into the deposit as it underwent further collapse. Collapse deposits laterally grade to folded and faulted bedrock that is less deformed.

Three samples of basaltic flows contained within unit QTcd (samples L-25; L-26; K97-8-15A) are correlated with compositional group 1c flows (Budahn and others, 2002). One of these samples (K97-8-15A) yielded a preferred ^{40}Ar/^{39}Ar age of 10.60 ± 0.07 Ma (Kunk and others, 2002). Thickness of unit QTcd is unknown, but it probably exceeds 100 ft.

Three samples of basaltic flows contained within unit QTcd (samples L-25; L-26; K97-8-15A) are correlated with compositional group 1c flows (Budahn and others, 2002). One of these samples (K97-8-15A) yielded a preferred ^{40}Ar/^{39}Ar age of 10.60 ± 0.07 Ma (Kunk and others, 2002). Thickness of unit QTcd is unknown, but it probably exceeds 100 ft.

BEDROCK

Tsp

Trachyandesite of Spring Park (Pliocene)— Medium-gray trachyandesitic flows that crop out about one-quarter to one-half mile east of the dam for Spring Park Reservoir. Petrographically the unit is xenocrystic olivine basalt. Its groundmass is predominantly plagioclase and pyroxene, and it contains sparse phenocrysts of mainly olivine and rarely plagioclase. These flows locally contain abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically the flows are basaltic trachyandesite (Appendix A; samples L-233, L-244, L-246) and are included in the group 6b' rocks of Budahn and others (2002). Field relationships and the geochemical correlations of Budahn and others (2002) indicate these rocks were erupted from the vent associated with unit Tspc. A preferred ^{40}Ar/^{39}Ar age of 2.90 ± 0.002 Ma was obtained on sample L-244 (Kunk and others, 2002). Exposed thickness of unit Tsp ranges from about 10 to 40 ft.

Tspc

Cinder deposits of Spring Park (Pliocene)— Red and red-brown, scoriaceous, unconsolidated cinder deposits associated with an eroded and tilted eruptive center about one-half mile east of the dam for Spring Park Reservoir. The unit is mostly light weight and highly vesicular cinders, agglutinate, and other pyroclasts, but locally includes thin discontinuous flows that are only slightly to moderately vesicular. Petrographically the rock is olivine basalt with locally abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically these rocks are basaltic trachyandesite (Appendix A; samples L-28, L-245) and are included in the group 6b' rocks of Budahn and others (2002). Sample L-245 yielded a preferred $^{40}Ar/^{39}Ar$ age of 2.96 ± 0.02 Ma (Kunk and others, 2002).

Tcc

Trachyandesitic flows of Cattle Creek (Pliocene)—Multiple flows of moderately dense to highly vesicular basaltic trachyandesite and trachybasalt that crop out along both sides of Cattle Creek upstream of the confluence with Shippes Draw. Petrographically most flows are xenocrystic olivine basalt with xenocrysts of quartz, sanidine, and plagioclase up to about 0.3 inches in diameter. Quartz xenocrysts are rounded, corroded anhedra. Sanidine xenocrysts range from fairly fresh to moderately weathered and have inclusions of plagioclase and quartz. Plagioclase occurs as rounded, zoned, corroded anhedra and euhedra. Olivine phenocrysts are euhedral to subhedral crystals and are sometimes altered to hematite and iddingsite. The groundmass consists of olivine, pyroxene, and fine, fresh laths of plagioclase. Accessory minerals include biotite, hematite, and magnetite. Geochemically these flows are basaltic trachyandesite and trachybasalt (Appendix A; samples K97-8-12H, L-1, L-48, L-52). Budahn and others (2002) included all four samples in their group 6c rocks, which are correlative with the cinder deposits of unit Tccc. Field relationships support this correlation. Kunk and others (2002) reported a preferred $^{40}Ar/^{39}Ar$ age of 3.09 ± 0.02 Ma for sample K97-8-12H. Thickness of individual flows generally ranges from about 5 to 20 ft, whereas the maximum thickness of the entire flow sequence is about 40 ft.

Tccc

Trachyandesite cinder deposits of Cattle Creek (Pliocene)—Dark-gray to black, scoriaceous cinders, agglutinate, other pyroclastic material, and local thin, lenticular flows exposed in a cinder quarry on the north side of Cattle Creek between Shippes Draw and Sleepy Creek. The deposit appears to be an eroded remnant of a tilted cinder cone that is only weakly lithified. Petrographically this deposit is xenocrystic olivine basalt with abundant xenocrysts of quartz and rare sanidine. Sparse xenoliths of red sandstone and gypsum also are present. Geochemically it is basaltic trachyandesite (Appendix A; sample L-3) and is included in geochemical group 6c (Budahn and others, 2002). Sample K97-8-12G, which was collected from the same outcrop as sample L-3, yielded a preferred $^{40}Ar/^{39}Ar$ age of 3.01 ± 0.01 Ma (Kunk and others, 2002).

Tta

Trachyandesitic flows, undifferentiated (Pliocene)—Includes trachyandesitic flows and flow breccias in the northwest part of the quadrangle. Petrographically most flows are xenocrystic olivine basalt with xenocrysts of quartz and sanidine. Olivine phenocrysts are euhedral to subhedral crystals and are sometimes altered to hematite and iddingsite. The groundmass consists of olivine, pyroxene, and fine, fresh laths of plagioclase. 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 are basaltic trachyandesite (Appendix A; samples L-6, L-7). Budahn and others (2002) chemically correlated sample L-7 with the group 6b rocks found at Little Buck Point on Shoshone quadrangle (Kirkham, Streufert, and Cappa, 2008), which were dated at 3.97 ± 0.08 Ma (sample SH267; Kunk and others, 2002). Sample L-6 was included in compositional group 7a'. Thickness of individual flows generally ranges from about 5 to 25 ft, and the maximum thickness of the entire flow sequence is about 50 ft.

Tsb

Sediments of Basalt Mountain (Pliocene or Miocene)—Chiefly clast-supported, medium-red-brown, weakly indurated pebble and cobble conglomerate with a sandy or silty matrix. The unit locally is bouldery. Clasts are subrounded to angular and are composed mostly of red sandstone and siltstone with lesser amounts of tan, brown, and white sandstone, which suggests Red Table Mountain, a prominent landform east of Leon quadrangle, was the provenance. Three isolated erosional remnants of unit Tsb overlie Miocene basalt (unit Tb) on the north flank of Basalt Mountain. The sediments probably were deposited by ancestral Cattle Creek prior to incision of the modern valley of Cattle Creek through the Miocene basalt flows on the north flank of Basalt Mountain. Maximum thickness of unit Tsb is about 20 to 30 ft in the quadrangle, but may be much thicker east of the quadrangle.

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 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, many of which 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 and hematite. Some flows contain rare xenocrysts of quartz or xenoliths of quartzite.

Thirty-four samples collected from unit Tb were chemically analyzed (Appendix A). Most samples are classified as trachybasalt, basaltic trachyandesite, basalt, or basaltic andesite, and a few were trachyandesite. Budahn and others (2002) recognized seven compositional groups in unit Tb within the quadrangle (Table 1). Twenty-one of the samples were correlated with middle Miocene compositional groups 4b, 4b', 1c, 1b, and 2b', which range in age from about 9.6 to 10.8 Ma and are widespread across the entire Roaring Fork River valley. Seventeen of the middle Miocene samples are in groups 4b or 4b'; these samples were collected from the Basalt Mountain shield volcano and from correlative flows deformed by and within the Basalt Mountain Monocline. Six of the samples from unit Tb (CP106, L-4, L-56, L-60, L-68, L-78) were correlated with the late Miocene compositional group 5a. These 7.7 to 7.8 Ma rocks were recognized only north of Cattle Creek. One sample of unit Tb collected in the quadrangle (L-27) is chemically distinct from all other samples in the region and is classified as an unknown compositional group.

Individual basaltic flows range in thickness from about 5 to 50 ft. Thickness of the entire sequence of flows averages 40 to 80 ft in the quadrangle, but it may be as much as 600 ft on the south side of the Basalt Mountain shield volcano.

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. There are two distinct deposits included in unit Ts, one in the southwest corner of the quadrangle and a second in the northeast part of the quadrangle west of the Basalt Mountain Fault.

Unit Ts deposits in the southwest corner of the quadrangle were deposited in a large evaporite-collapse structural depression on the northern side of Mount Sopris that was named Sopris Bowl by Kirkham, Streufert, and others (2002). Clasts within unit Ts in Sopris Bowl are well rounded to subrounded and are moderately to very highly weathered. They 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 (Streufert, Widmann, and Kirkham, 2008). In Basalt quadrangle, unit Ts sediments in Sopris Bowl overlie a 35.21 ± 0.03 Ma ash-flow tuff, and in the Carbondale quadrangle basaltic flows with an average age of 13.3 Ma overlie or are intercalated with the uppermost sediments in unit Ts (Kirkham, Streufert, and others, 2002). These dates provide maximum and minimum ages for unit Ts. Maximum thickness of unit Ts in the southwest corner of Leon quadrangle is about 600 ft, but they are much thicker to the west in the center of Sopris Bowl (Kirkham, Streufert, and others, 2002). Isolated hills in the southwest corner of the quadrangle that are mapped as Tertiary sedimentary deposits may be part of an ancient landslide complex that subsequently has undergone intense erosion.

Unit Ts sedimentary deposits in the northeast part of the map area appear to have more fine-grained interbeds than the unit Ts deposits in the southwest part of the quadrangle, and the clasts tend to be smaller. Clasts in unit Ts in the northeast part of the quadrangle are well rounded to subrounded, moderately to very highly weathered, and composed of red sandstone, quartz, quartzite, Proterozoic plutonic rocks, Tertiary hypabyssal rocks, and minor amounts of Proterozoic metamorphic lithologies. The hypabyssal clasts are similar to ones in late Pleistocene Colorado River deposits upstream of Dotsero (Streufert and others, 1997b), suggesting the ancestral Colorado River may have deposited these sediments in a paleovalley. The deposits of unit Ts that are in the northeast part of the quadrangle are overlain by late Miocene basaltic flows dated at 7.7 to 7.8 Ma. These late Miocene flows also may have dammed the paleovalley and forced the ancestral into modern Glenwood Canyon (Kirkham, Kunk, and others, 2001). Deposits of unit Ts in the northeast part of the quadrangle have a maximum thickness slightly in excess of 200 ft.

Km

Mancos Shale (Upper Cretaceous)—Predominantly light- to dark-gray and black, carbonaceous, silty to sandy shale with minor bentonite beds, limy gray shale, and thin light- to medium-gray, grayish-yellow-weathering, clayey sandstone. As mapped, the Mancos Shale may include other formations or members such as the Niobrara and Juana Lopez, but these subdivisions of the Mancos Shale were not recognized or mapped in the Leon quadrangle, chiefly because exposures are very poor and limited, and because slopes underlain by the Mancos Shale are frequently mantled with landslides and other surficial deposits. Total thickness of the Mancos Shale to the southeast in Woody Creek quadrangle is 5,200 ft (Freeman, 1972). The upper part of the formation is not preserved in Leon quadrangle, therefore its thickness in the Leon quadrangle is probably less than 5,200 ft. The Mancos Shale was deposited in a low-energy, off-shore marine environment

Kd

Dakota Sandstone (Lower Cretaceous)—Light-gray to tan, medium- to very coarse-grained, quartzose sandstone and conglomeratic sandstone interbedded with carbonaceous siltstone, sandstone, and shale. Sandstone beds within the formation commonly are well sorted, silica cemented, and have angular to subrounded sand grains. Conglomeratic clasts generally are pebble-sized chert and quartz. Thickness ranges from about 125 to 175 ft. To the south, in Woody Creek quadrangle, Freeman (1972) mapped strata underlying the Dakota Sandstone as the Burro Canyon Formation. In the southern part of the Leon quadrangle our Dakota Sandstone unit may include the Burro Canyon Formation or equivalent strata. Unit Kd is conformable with the overlying Mancos Shale. The upper contact of the Dakota Sandstone is placed at the top of the uppermost quartzose sandstone beneath the Mancos Shale. Sandstone beds within the formation are often well exposed, and in the northeast part of the quadrangle they form prominent flatiron dip slopes. The Dakota Sandstone was deposited in a transgressive environment at or near the shoreline of a lower coastal plain and in shallow marine embayments.

Jm

Morrison Formation (Upper Jurassic)—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to tan sandstone, and gray limestone. Strata in the lower half of the formation, which include thin beds of sandstone, may be equivalent to the Salt Wash Member in nearby areas. A 10- to 20-ft-thick, coarse-grained, oolitic, tan- and white-weathering, medium- to dark-gray limestone is at the base of the formation and rests directly on the Entrada Sandstone. This limestone is included in the Curtis Formation in some publications (Freeman, 1972; Baker and others, 1936). Thickness of the Morrison Formation is variable but typically averages about 350 to 400 ft. The Morrison Formation is poorly exposed in much of the quadrangle, but is fairly well exposed on the steep hillslope south of Basalt Mountain. The contact with the overlying Dakota Sandstone is sharp and unconformable, but it is rarely exposed. The Morrison Formation was probably deposited in a lacustrine-dominated, fluviolacustrine environment.

Je

Entrada Sandstone (Upper Jurassic)—Light-gray, tan, and white, cross-bedded, medium- to very fine-grained, well sorted, poorly indurated sandstone. Sand grains within the formation are mostly well-rounded to subrounded quartz. The basal few inches of the Entrada may include small pebbles or coarse sand comprised of chert and quartz. The contact with the overlying Morrison Formation is sharp and conformable. Thickness of the Entrada Sandstone averages about 50 to 75 ft. The Entrada Sandstone is poorly exposed in most areas, probably due to weak cementation; however, it is fairly well exposed on the steep hillslope below the cliffs of basalt on the southern margin of the Basalt Mountain shield volcano. Cross-bed sets are large-scale and are usually interpreted as evidence of an eolian origin, probably in an extensive dune field.

ŦRc

Chinle Formation (Upper Triassic)—Consists of thin, even-bedded, and structureless 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. Dubiel (1992) recognized a very thin, basal sandstone in the Chinle Formation exposed along South Canyon Creek and correlated it with the Gartra Member; however, this member was not observed in the quadrangle. The contact with the overlying Entrada Sandstone is fairly sharp and unconformable. The Chinle Formation is well exposed on the steep hill slope south of Basalt Mountain. At this location the formation is about 100 to 150 ft thick. To the southeast in Woody Creek quadrangle the Chinle thickens to over 1,000 ft (Freeman, 1972). The upper or red bed portions of the formation are possibly lateral-accretion and flood-plain deposits, while the basal Gartra Member, if present, was deposited as active channel-fill and valley-fill deposits (Dubiel, 1992).

TRPsb **State Bridge Formation (Lower Triassic and Permian)—**Reddish-orange, grayish-red, and pale-reddish-pink silty sandstone, clayey siltstone, arkosic sandstone, conglomeratic sandstone, and very minor gray dolomite. Includes the lower subunit of Freeman (1971, 1972), which he called the lower siltstone and sandstone member, and perhaps his Toner Creek Member. Included within Freeman's lower siltstone and sandstone member is a medium-gray, silty and sandy limestone and dolomite that he correlated with the South Canyon Creek Dolomite Member of Bass and Northrop (1950) and Stewart and others (1972). The South Canyon Creek Dolomite occurs about 200 ft above the base of the State Bridge Formation in Leon quadrangle. It is as much as about 18 inches thick, but appears to be in lenses, as it could not be traced across hillslopes that are only partially covered by residuum and colluvium.

The section of rocks thought to correlate with the Toner Creek member of Freeman (1971, 1972) lies immediately below the Chinle Formation and is well exposed on the steep hillslope south of Basalt Mountain. It consists of a sequence of red-brown, sandy, pebble and cobble conglomerate and conglomeratic sandstone, the basal part of which has been strongly bleached. Clasts are rounded to subrounded and are composed of chert, quartz, potassium feldspar, red sandstone and siltstone, Proterozoic plutonic rocks, and hornfels. Prominent, near-vertical veinlets of milky quartz are locally numerous within the bleached beds. The veinlets are up to 4 inches in width and 7 to 8 ft in length. Bleaching is locally very intense along the veinlets.

Sandstone beds in the formation are thin to thick bedded, well sorted, fine to medium grained, and laterally continuous without any obvious lensing. Sand grains have a high degree of sphericity. The State Bridge Formation contains several conglomeratic sandstone beds. They are up to about 10 ft thick and are massive to very slightly cross-bedded, contain mostly pebble-sized clasts of quartz, chert, sedimentary rock fragments, and Proterozoic plutonic rocks. The State Bridge Formation is micaceous, although generally less so than the underlying Maroon Formation. The contact with the overlying Chinle Formation is sharp and unconformable.

Where exposed in Leon quadrangle the State Bridge Formation is around 1,000 ft thick. In adjacent quadrangles the formation thickness varies greatly. In the Cattle Creek quadrangle, Kirkham and others (1996) reported a combined thickness for the Chinle and State Bridge of only 150 to 200 ft. Thickness of the State Bridge Formation increases from about 200 to over 1,000 ft from east to west across Basalt quadrangle (Streufert, Widmann, and Kirkham, 2008). In the Woody Creek quadrangle the State Bridge Formation is as much as 2,400 ft thick (Freeman, 1971). These relatively abrupt thickness changes may result from syn-deposition basin subsidence associated with tectonic movement on faults such as the Basalt Mountain Fault or to structural collapse related to flowage of underlying evaporitic rocks (Tweto, 1977; Streufert, Widmann, and Kirkham, 2008). The State Bridge Formation was deposited in a marginal-marine, fluvio-lacustrine environment (Dubiel, 1992).

TRPcs **Chinle and State Bridge Formations, undivided (Triassic and Permian)—**Includes the Chinle and State Bridge Formations in the northern part of the quadrangle where poor exposures prevent recognition of the contact between the two formations.

PIPm **Maroon Formation (Lower Permian and Upper Pennsylvanian)—**Pale-red to pinkish-red and grayish-red arkosic sandstone, conglomerate, siltstone, and mudstone, with shale and minor, thin beds of gray limestone. The Maroon Formation is very micaceous, noticeably more so than most strata in the overlying State Bridge Formation. It also contains more grains composed of feldspar than does the State Bridge Formation. Sandstone beds are coarse to fine grained and moderately to poorly sorted, and sand grains are generally angular to subrounded. These characteristics distinguish the sandstones of the Maroon Formation from the sandstones in the overlying State Bridge Formation, whose grains have high in sphericity and beds are well sorted. The color change from the pale-reddish-pink color of the Maroon Formation to the orange-red and brownish-red colors of the State Bridge Formation is sometimes useful in identifying the contact between the two formations. The entire Maroon Formation is not exposed in the quadrangle. To the north, Kirkham, Streufert, Cappa, and others, (2008), and Kirkham, Streufert, and Cappa, (2008) reported a thickness of 3,000 to 5,000 ft 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 formation is not known in Leon quadrangle, but ranges from 500 to 3,000 ft thick to the northwest in the Carbondale quadrangle (Kirkham and Widmann, 2008). 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.

Pℙme

Maroon and Eagle Valley Formations, undivided (Lower Permian and Upper and Middle Pennsylvanian)—Includes the Maroon and Eagle Valley Formations where the contact between the two formations is not mappable.

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. Parts of formation are fairly well exposed in road cuts on Upper Cattle Creek Road north of El Jebel. Thickness of the formation in the Leon quadrangle is poorly constrained, as the base of the formation is not exposed. In adjacent areas the thickness may be as much as 9,000 ft (Mallory, 1971). To the northwest in the Carbondale quadrangle, Kirkham and Widmann (2008) reported a minimum thickness of 2,700 ft. 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

Rocks ranging in age from Pennsylvanian to the Pliocene crop out in the Leon quadrangle. Quaternary surficial deposits conceal the underlying bedrock in much of the quadrangle. 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 Leon quadrangle, which lies within the Eagle Basin part of the Central Colorado Trough, received several thousand feet of sediment stripped from the uplifts.

The oldest Pennsylvanian rocks exposed in the quadrangle are the Eagle Valley Evaporite, which were deposited in an evaporite basin within the Central Colorado Trough. Gypsum and fine-grained clastic sedimentary rocks comprise most outcrops of the Eagle Valley Evaporite. 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 within the Central Colorado Trough. 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. Permian, Triassic, and Jurassic fluvial, eolian, and shoreline deposits, represented by the State Bridge through Morrison Formations, record the gradual erosion and eventual submergence of the Ancestral Rocky Mountain uplifts.

During the Cretaceous, a broad seaway spread across the region. A blanket of intertonguing marine and continental sediments, as much as 10,000 ft thick in adjacent quadrangles (Bryant and others, 2002; Kirkham and others, 1996), was deposited as the Cretaceous sea transgressed and regressed across the area. The Dakota Sandstone and Mancos Shale were deposited at this time. 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, and the Grand Hogback Monocline, which trends northwest-southeast and lies east of the of the quadrangle, formed late during the Laramide orogeny (Tweto, 1975).

The Basalt Mountain Fault is the largest Laramide structure within the quadrangle. It is a down-to-the-east, high-angle fault with a minimum of 5,600 ft of throw. Pennsylvanian evaporitic rocks are displaced against the Cretaceous Mancos Shale where the fault attains its greatest stratigraphic throw between Cattle Creek in the northern part of Leon quadrangle and near Emma in Basalt quadrangle. Depending on which part of the Eagle Valley Evaporite is faulted against which part of the Mancos Shale, maximum displacement on the Basalt Mountain Fault could exceed 10,000 ft. A prominent synclinal drag fold occurs on the east side of the fault at the north end of the quadrangle and continues into Cottonwood Pass quadrangle. Streufert, Kirkham, and others (2008) reported that this drag folding suggests reverse movement on the fault. Conclusive evidence of the dip of the Basalt Mountain Fault was not found in Leon quadrangle. We show the fault as a high-angle reverse fault on cross section A—A'.

Sometime after the Laramide orogeny, perhaps initially during late Eocene time, a broad angular erosional surface was cut across the region (Scott, 1975). This surface was later modified by one or more subsequent periods of erosion (Kirkham, Streufert, and others, 2001; Steven, 2002). 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? erosion surface (Larson and others, 1975; Kirkham, Kunk, and others, 2001; Kunk and others, 2002). Stratigraphic relationships between the sediments of Basalt Mountain (unit Tsb) and flows from the Basalt Mountain shield volcano (unit Tb), along with the relatively low relief erosion surface onto which the middle Miocene Basalt Mountain shield volcano was constructed, provide strong evidence of the paleotopography setting of this area during the late Tertiary. Flows from the Basalt Mountain shield volcano flowed northward across the low-relief erosion surface and filled a paleovalley of ancestral Cattle Creek. The lava flows completely filled the shallow paleovalley, and ancestral Cattle Creek subsequently flowed over the basalt cap.

The Miocene and younger incision also triggered flow and dissolution of halite and gypsum in the Eagle Valley Evaporite, which led to widespread collapse of the ground surface in the region (Kirkham, Streufert, and others, 2001, 2002; Kirkham, Scott, and Judkins, 2002; Lidke and others, 2002; Scott and others, 2002). The western half of the Leon quadrangle is within the Carbondale Collapse Center, one of two large evaporite collapse areas in the region. The Laramide Basalt Mountain Fault serves as the eastern margin of the Carbondale Collapse Center in the quadrangle. The direction of movement during late Cenozoic collapse was opposite to Laramide slip on the fault, and collapse is manifested as monoclinal folding across a relatively broad zone rather than discrete faulting in a narrow zone. 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. Much of the collapse on the eastern margin of the Carbondale Collapse Center is localized along the Basalt Mountain Monocline, which lies on the west side of the Basalt Mountain Fault.

Sediments of probable Miocene age (unit Ts) were deposited locally on the late Eocene and younger erosion surfaces. Miocene and Pliocene volcanic rocks (units Tb, Tta, Tccc, Tcc, Tspc, and Tsp) locally were erupted onto these erosion surfaces or onto older sediments or volcanic flows that mantled the erosion surfaces. Unit Ts also was deposited in Sopris Bowl, a large structural depression caused by evaporite tectonism. Sopris Bowl is somewhat anomalous, in that it may be a localized evaporite collapse feature that originated prior to the regional evaporite collapse, which was initiated by Miocene river incision. In Basalt quadrangle, unit Ts sediments in Sopris Bowl overlie a 35.21 ± 0.03 Ma ash-flow tuff, and in the Carbondale quadrangle basaltic flows with an average age of 13.3 Ma overlie or are intercalated with the uppermost sediments in unit Ts (Kirkham, Streufert, and others, 2002). These stratigraphic relationships suggest Sopris Bowl began to form in late Eocene or early Oligocene time and continued to fill with sediments and local volcanic flows until the middle Miocene. This "premature" evaporite collapse may have been triggered by increased geothermal gradients and other hydrologic changes associated with the intrusion of the Mount Sopris stock about 34–35 Ma (Kirkham, Streufert, and others, 2002).

Evaporite collapse also is responsible for the creation of a broad depositional basin in which the sediments of Missouri Height (unit QTm) accumulated on the west side of the Basalt Mountain Monocline. Lacustrine and deltaic sediments in unit QTm indicate the collapse formed closed topographic depressions which contained one or more lakes. The closed topographic depressions of Leon Trough, the unnamed depression at the Kodiak ski lake northeast of and across Highway 82 from Leon Trough, and Blue Creek Trough formed in late Pleistocene deposits along the floor of the Roaring Fork River Valley.

Middle Miocene basaltic lavas that were originally erupted onto the low-relief subhorizontal erosion surface provide critical evidence of the evaporite collapse that constrains the timing, rate, lateral extent, and amount of vertical collapse. For example, the ~ 10 Ma flows from the Basalt Mountain shield volcano are lowered at least 1,900 ft by evaporite collapse across the Basalt Mountain Monocline. Much of this collapse occurred after the eruption of the 2.90 Ma flows of unit Tsp, because these Pliocene flows are tilted about the same amount as are the Miocene flows (Kirkham, Streufert, and others, 2002). Where the collapsed volcanic terrain is highly disrupted, and recognition and mapping of individual lava flows is not possible at a scale of 1:24,000, the collapsed material is included in unit QTcd (collapse debris).

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 indicate that the evaporite dissolution and collapse is active. Sinkholes and subsidence troughs in late Quaternary deposits support this conclusion.

The structural juxtapositioning along the Basalt Mountain Fault that places readily dissolvable evaporite against shale highly prone to landsliding has created an unusual geologic setting. Regional collapse due to dissolution and/or flowage of relatively shallow evaporite predominates on the western side of the fault. On the eastern side of the fault, large-scale landsliding that involves the Mancos Shale and overlying Miocene basalt prevails along and below the exposed edge of the protective cap of Basalt Mountain shield volcano.

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, a comprehensive 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 concentrations were 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, age dates, and petrographic data to identify 46 distinct compositional groups of volcanic rocks. These compositional groups were erupted during significant 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 eruptions occurred in the region about 7.8 to 7.7 Ma, 4 Ma, 3 Ma, 1.3 Ma, and 4 ka (Kunk and others, 2002).

Forty-four samples of volcanic rocks from the Leon quadrangle were chemically analyzed as part of the collaborative CGS-USGS investigation, and $^{40}Ar/^{39}Ar$ ages were obtained on twenty-four volcanic rock samples (**Table 1**). These rocks were erupted during one of the significant pulses of regional volcanism (11 to 9 Ma) and during three of the smaller, more widely spaced eruptions (7.8 to 7.7 Ma, 4 Ma, and 3 Ma). One sample, L-12, was chemically analyzed as part of the original mapping of the quadrangle but was not re-analyzed during the cooperative investigation. Locations of all forty-five samples are shown on the accompanying geologic map, chemical analyzes are in Appendix A, and the latitude and longitude of the sample locations are listed in Appendix B.

Ten of the compositional groups identified by Budahn and others (2002) were identified in the Leon quadrangle (Table 1). One sample, L-27, is an unknown compositional group and is not correlated with any other volcanic rocks in the region.

Fourteen of the sampled flows are included in compositional group 4b, which is part of unit Tb. Thirteen of the group 4b samples also were dated. The better constrained dates ranged from 9.68 ± 0.03 Ma to 10.49 ± 0.07 Ma. All group 4b rocks are associated with the Basalt Mountain shield volcano in the east-central part of the quadrangle. Most of these samples were collected flows that crop out around the eroded margin of the volcano. One sample (L-176) was collected from a tilted flow within the Basalt Mountain Monocline. No group 4b rocks were detected in the topographically lower parts of the quadrangle.

Three samples of volcanic rocks in the quadrangle were correlated with compositional group 4b', which also is associated with Basalt Mountain shield volcano. Two of the group 4b' rock samples were from thick ponded flows in the crater of the volcano. They yielded well-constrained ages of 9.83 ± 0.05 Ma (sample K97-8-15B) and 9.97 ± 0.06 Ma (K97-8-15C). The third group 4b' sample (L-38A) came from a flow near the top of the thick sequence of flows on the south side of the volcano. It stratigraphically overlies the group 4b flows.

Other middle Miocene flows in the Leon quadrangle include those in compositional groups 1b, 1c, and 2b'. These samples were collected from outcrops in the Missouri Heights area and an outcrop about a mile northeast of Spring Park Reservoir. These flows either are within unit Tb or are in collapse debris (unit QTcd). A sample from group 1b (K97-8-12F) yielded an age of 10.84 ± 0.06 Ma. An age of 10.60 ± 0.07 Ma was obtained on a sample from group 1c (K97-8-15A). The sample from group 2b' was 10.70 ± 0.15 Ma (K97-8-12E).

Six of the analyzed samples in the quadrangle were late Miocene flows correlated with composi-

Table 1. Compositional geochemical groups and preferred $^{40}Ar/^{39}Ar$ ages of volcanic rocks in the Leon quadrangle (from Budahn and others, 2002; Kunk and others, 2002). Sample locations are shown on the accompanying geologic map; their chemical analyses and the latitude and longitude of each sample are in Appendix A.

Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)	Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)
K97-8-12F	Tb	1b	10.84 ± 0.06	CP106	Tb	5a	
K97-8-15A	QTcd	1c	10.60 ± 0.07	L-4	Tb	5a	
L-23	Tb	1c		L-56	Tb	5a	
L-25	QTcd	1c		L-60	Tb	5a	7.75 ± 0.03
L-26	QTcd	1c		L-68	Tb	5a	
L-201	Tb	1c		L-78	Tb	5a	
K97-8-12E	Tb	2b'	10.70 ± 0.15	L-7	Tta	6b	
K97-8-11A	Tb	4b	10.49 ± 0.07	L-28	Tspc	6b'	
K97-8-11B	Tb	4b	9.87#	L-233	Tsp	6b'	
K97-8-11C	Tb	4b	10.18 ± 0.06	L-244	Tsp	6b'	2.90 ± 0.02
K97-8-11D	Tb	4b	11.39#	L-245	Tspc	6b'	2.96 ± 0.02
K97-8-11E	Tb	4b	10.07 ± 0.17	L-246	Tsp	6b'	
L-37	Tb	4b	9.84#	K97-8-12G	Tccc	6c§	3.01 ± 0.01
L-39	Tb	4b	9.75 ± 0.03	K97-8-12H	Tcc	6c	3.09 ± 0.02
L-91A	Tb	4b	9.71 ± 0.03	L-1	Tcc	6c	
L-91B	Tb	4b		L-3	Tccc	6c	
L-176	Tb	4b	9.68 ± 0.03	L-48	Tcc	6c	
L-181	Tb	4b	9.55#	L-52	Tcc	6c	
L-187A	Tb	4b	9.84 ± 0.07	L-6	Tta	7a'	
L-187B	Tb	4b	9.38#	L-27	Tb	U*	
L-187D	Tb	4b	9.75 ± 0.11				
K97-8-15B	Tb	4b'	9.83 ± 0.05				
K97-8-15C	Tb	4b'	9.97 ± 0.06				
L-38A	Tb	4b'	9.66#				

*unknown compositional group
no uncertainty reported
§ sample collected from same outcrop as L-3, which is compositional group 6c

tional group 5a. These rocks crop out north of Cattle Creek at elevations as much as 1,200 ft lower than their correlative in-place flows on Little Grand Mesa in the Cottonwood Pass quadrangle. A single group 5b rock from the quadrangle (L-60) was dated; it yielded an age of 7.75 ± 0.03 Ma.

Twelve samples of Pliocene volcanic rocks were collected in Leon quadrangle during the investigation. Six samples were from cinders (unit Tccc) or flows (unit Tcc) associated with the Pliocene volcano on the north side of Cattle Creek. These rocks are included in compositional group 6c. Two of these samples yielded ages of 3.01 ± 0.01 Ma (K97-8-12G) and 3.09 ± 0.02 Ma (K97-8-12H). The five samples from cinders (unit Tspc) and flows (unit Tsp) that are related to the volcano southeast of Spring Park Reservoir are in group 6b'. Ages of 2.90 ± 0.02 Ma (L-244) and 2.96 ± 0.02 Ma (L-245) were obtained on two of these samples. One sample from the quadrangle (L-7) was correlated with the 3.97 ± 0.08 Ma group 6b rocks, which crop out at Little Buck Point in the Shoshone quadrangle (Kirkham, Streufert, and Cappa, 2008).

Geologic Hazards and Constraints

Several types of geologic hazards and constraints pose potential problems in the Leon 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) or as alluvium and colluvium, undivided (unit Qac) are subject to flooding. Sheet flooding may affect areas mapped as sheetwash (unit Qsw) and colluvium and sheetwash (unit Qcs).

White (2002) developed a geologic hazard map that characterized collapsible soils in the nearby Roaring Fork River valley. The derivative approach to collapsible soils used by White (2002) can be applied to the units in the Leon 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.

Landslide deposits (unit Qls) are relatively widespread across the quadrangle. They are especially prevalent on the flanks of Basalt Mountain where the Mancos Shale crops out or underlies basaltic rocks, and in the southwest corner of the quadrangle in areas underlain by Tertiary sedimentary deposits (unit Ts). Areas mapped as landslide deposits are prone to reactivation, and they are indicative of the types of geologic environments that are favorable for future slope failures. A single recently active landslide near the northeast corner of the map was noted during the project. Here, a thin unmapped veneer of colluvium and residuum overlying the Entrada Sandstone slid off the hillside.

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). Several sinkholes were detected during this project and are shown on the geologic map. The sinkhole in Eagle Valley Evaporite along the county road leading north and northeast from El Jebel is an excellent example of karst formed directly in evaporitic bedrock. 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 site investigations and structural designs. Areas where differential movement is possible, such as Leon Trough, Blue Creek Trough, Shippes Bowl Sag, Shippes Draw Sag, Polaris Sag, and Basalt Mountain Monocline, deserve special consideration. 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). The volcanic cliffs around the margin of Basalt Mountain are very prone to rockfall. 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 economic potential in the quadrangle include sand and gravel, gypsum, scoria, and riprap. 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 a high percentage of the clasts within these units are decomposed, or the deposits may contain undesirable amounts of matrix.

Gypsum within the Eagle Valley Evaporite may be suitable for wallboard and other uses. Scoriaceous cinder deposits in eroded volcanic eruptive centers of Cattle Creek (unit Tccc) and the cinder deposits of Spring Park (unit Tspc) have been utilized for various purposes in the past and may be suitable for future use as lightweight aggregate, landscaping materials, surfacing of roads, and other uses. High-quality riprap or landscaping boulders may be obtained from deposits of talus (unit Qt) and from the volcanic flows in units Tb, Tcc, and Tsp. Boulder and cobbles of basaltic rock in unit QTbg also may be sources of riprap or landscaping boulders.

No oil or gas test holes have been drilled in the quadrangle. Hydrocarbon resources may exist in the quadrangle, but the geologic relationships exposed at the ground surface suggest the potential for future drilling and production is low.

REFERENCES CITED IN BOOKLET AND MAP

Baker, A.A., Dane, C.H., and Reeside, J.B., Jr., 1936, Correlation of the Jurassic Formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geological Survey Professional Paper 183, 63 p.

Barrett, J.K., and Pearl, R.H., 1976, Hydrogeologic data of thermal springs and wells in Colorado: Colorado Geological Survey Information Series 6, 124 p.

Bass, N.W., and Northrop, S.A., 1950, South Canyon Creek Dolomite Member, a unit of Phosphoria age in Maroon Formation near Glenwood Springs, Colorado: American Association of Petroleum Geologists Bulletin, v. 34, no. 7, p. 1540–1551.

Brill, K.G., Jr., 1944, Late Paleozoic stratigraphy, west-central and northwestern Colorado: Geological Society of America Bulletin, v. 55, no. 5, p. 621–656.

Bryant, Bruce, 1972, Geologic map of the Highland Peak quadrangle, Pitkin County, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-932, scale 1:24,000.

Bryant, Bruce, Shroba, R.R., and Harding, A.E., 2002, Geologic map of the Storm King Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2389, scale 1:24,000.

Budahn, J.R., Unruh, D.M., Kunk, M.J., Byers, F.M., Jr., Kirkham, R.M., and Streufert, R.K., 2002, Correlation of late Cenozoic basaltic lava flows in the Carbondale and Eagle Collapse Centers in west-central Colorado based on geochemical, isotopic, age, and petrographic data: Constraints on the timing of evaporite related collapse and incision of the Colorado River, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 167–196.

Burbank, W.S., Lovering, T.S., Goddard, E.N., and Eckel, E.B., 1935, Geologic map of Colorado: U.S. Geological Survey, in cooperation with Colorado State Geological Survey Board and Colorado Metal Mining Fund, scale 1:500,000.

Carroll, C.J., Kirkham, R.M., and Stelling, P.L., 1996, Geologic map of the Center Mountain quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-2, scale 1:24,000.

Chafin, D.T., and Butler, D.L., 2002, Dissolved-solids-load contributions of the Pennsylvanian Eagle Valley Evaporite to the Colorado River, west-central Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 149–155.

Cruden, D.M., and Varnes, D.J., 1996, Landslide types and processes, *in* Turner, A.K., and Schuster, R.L., eds., Landslides—Investigation and mitigation: National Research Council, Transportation Research Board Special Report 247, p. 36–75.

De Voto, R.H., 1980, Pennsylvanian stratigraphy and history of Colorado, *in* Kent, H.C., and Porter, K.W., eds., Colorado geology: Rocky Mountain Association of Geologists, p. 71–101.

Dubiel, R.F., 1992, Sedimentology and depositional history of the Upper Triassic Chinle Formation in the Uinta, Piceance, and Eagle Basins, northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 1787-W, 25 p.

F.M. Fox & Associates, 1974, Roaring Fork and Crystal Valleys—An environmental and engineering geology study, Eagle, Garfield, Gunnison, and Pitkin Counties, Colorado: Colorado Geological Survey Environmental Geology 8, 64 p.

Folk, R.L., and Ward, W.C., 1957, Brazos River bar; A study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3–26.

Freeman, V.L., 1971, Stratigraphy of the State Bridge Formation in the Woody Creek quadrangle, Pitkin and Eagle Counties, Colorado: U.S. Geological Survey Bulletin 1324-F, 17 p.

Freeman, V.L., 1972, Geologic map of the Woody Creek quadrangle, Pitkin and Eagle Counties, Colorado: U.S. Geological Survey Geological Quadrangle Map GQ-967, scale 1:24,000.

Fullerton, D.S., Bush, C.A., and Pennell, J.N., 2003, Map of surficial deposits and materials in the eastern and central United States (east of 102° west longitude): U.S. Geological Survey Geologic Investigations Series I-2789, scale 1:2,500,000.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulations in desert soils: Soil Science, v. 101, p. 347–360.

Guthrie, R.L., and Witty, J.E., 1982, New designations for soil horizons and layers and the new soil survey manual: Soil Science Society of America Journal, v. 46, p. 443–444.

Hudson, M.R., Harlan, S.S., and Kirkham, R.M., 2002, Paleomagnetic investigation of the structural deformation and magnetostratigraphy of Neogene basaltic flows in western Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 197–212.

Hungr, O., Evans, S.G., Bovis, M.J., and Hutchinson, J.N., 2001, A review of the classification of landslides of the flow type: Environmental & Engineering Geoscience, v. 7, no. 3, p. 221–238.

Ingram, R.L., 1989, Grain-size scale used by American geologists, *in* Dutro, J.T., Jr., Dietrich, R.V., and Foose, R.M., eds., AGI data sheets for geology in the field, laboratory, and office: Alexandria, Virginia, American Geological Institute, Data Sheet 29.1.

Johnson, S.Y., Schenk, C.J., Anders, D.L., and Tuttle, M.L., 1990, Sedimentology and petroleum occurrence, Schoolhouse member, Maroon Formation (Lower Permian), northwest Colorado: American Association of Petroleum Geologists Bulletin, v. 74, p. 135–150.

Johnson, S.Y., Schenk, C.J., and Karachewski, J.A., 1988, Pennsylvanian and Permian depositional cycles in the Eagle Basin, northwest Colorado, *in* Holden, G.S., ed., Geological Society of America field trip guidebook: Colorado School of Mines Professional Contributions 12, p. 156–175.

Kirkham, R.M., Bryant, B., Streufert, R.K., and Shroba, R.R., 1996, Field trip guidebook on the geology and geologic hazards of the Glenwood Springs area, Colorado: Colorado Geological Survey Special Publication 44 (CD-ROM).

Kirkham, R.M., Kunk, M.J., Bryant, Bruce, and Streufert, R.K., 2001, Constraints on timing and rates of late Cenozoic incision by the Colorado River in Glenwood Canyon, Colorado: A preliminary synopsis, *in* Young, R.A., and Spamm, E.E., eds., The Colorado River: Origin and Evolution: Grand Canyon, Arizona, Grand Canyon Association Monograph 12, p. 113–116.

Kirkham, R.M., and Rogers, W.P., 2000, Colorado earthquake information, 1867–1996: Colorado Geological Survey Bulletin 52, 160 p.

Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., 2002, Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, 234 p.

Kirkham, R.M., Streufert, R.K., Budahn, J.R., Kunk, M.J., and Perry, W.J., 2001, Late Cenozoic regional collapse due to evaporite flow and dissolution in the Carbondale Collapse Center, west-central Colorado: The Mountain Geologist, v. 38, no. 4, p. 193–210.

Kirkham, R.M., Streufert, R.K., Cappa, J.A., Shaw, C.A., Allen, J.L., and Jones, J.V., 2008, Geologic map of the Glenwood Springs quadrangle, Garfield County, Colorado: Colorado Geological Survey Map Series 38, scale 1:24,000.

Kirkham, R.M., Streufert, R.K., and Cappa, J.A, 2008, Geologic map of the Shoshone quadrangle, Garfield County, Colorado: Colorado Geological Survey Map Series 35, scale 1:24,000.

Kirkham, R.M., Streufert, R.K., Hemborg, T.H., and Stelling, P.L., 1996, Geologic map of the Cattle Creek quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-1, scale 1:24,000.

Kirkham, R.M., Streufert, R.K., Kunk, M.J., Budahn, J.R., Hudson, M.R., and Perry, W.J., Jr., 2002, Evaporite tectonism in the lower Roaring Fork River valley, west-central Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 73–99.

Kirkham, R.M., and Widmann, B.L., 2008, Geologic map of the Carbondale quadrangle, Garfield County, Colorado: Colorado Geological Survey Map Series 36, scale 1:24,000.

Kirkham, R.M., Widmann, B.L., and Streufert, R.K., 1998, Geologic map of the Leon quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 98-3, scale 1:24,000.

Kunk, M.J., Budahn, J.R., Unruh, D.M., Stanley, J.O., Kirkham, R.M., Bryant, Bruce, Scott, R.B., Lidke, D.J., and Streufert, R.K., 2002, $^{40}Ar/^{39}Ar$ ages of late Cenozoic volcanic rocks within and around the Carbondale and Eagle Collapse Centers, Colorado: Constraints on the timing of evaporite related collapse and incision of the Colorado River, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 213–234.

Larson, E.E., Ozima, M., and Bradley, W.C., 1975, Late Cenozoic basic volcanism in northwest Colorado and its implications concerning tectonism and origin of the Colorado River system, *in* Curtis, Bruce, ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 155–178.

Le Bas, M.J., LeMaitre, R.W., Streckeisen, A.I., and Zanettin, B., 1986, A chemical classification of volcanic rocks based upon the total alkali-silica diagram: Journal of Petrology, v. 27, p. 747–750.

Lidke, D.J., Hudson, M.R., Scott, R.B., Shroba, R.R., Kunk, M.J., Perry, W.J., Jr., Kirkham, R.M., Budahn, J.R., Streufert, R.K., Stanley, J.O., and Widmann, B.L., 2002, Eagle Collapse Center: Interpretation of evidence for late Cenozoic evaporite-related deformation in the Eagle River Basin, Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 101–120.

Machette, M.N., 1985, Calcic soils of the southwestern United States, *in* Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1–21.

Madole, R.F., 1999, Geologic map of the Hunter Mesa quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 99-5, scale 1:24,000.

Madole, R.F., 2003, Geologic map of the Gibson Gulch quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 01-2, scale 1:24,000.

Mallory, W.W., 1971, The Eagle Valley Evaporite, northwest Colorado—A regional synthesis: U.S. Geological Survey Bulletin 1311-E, 37 p.

Mock, R.G., 2002, Geologic setting, character, and potential hazards for evaporite-related sinkholes in Eagle and Garfield Counties, northwestern Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 157–166.

Piety, L.A., 1981, Relative dating of terrace deposits and tills in the Roaring Fork Valley, Colorado: Boulder, University of Colorado, M.S. thesis, 209 p.

Schenk, C.J., 1987, Sedimentology of an eolian sandstone from the Middle Pennsylvanian Eagle Valley Evaporite, Eagle Basin, northwest Colorado: U.S. Geological Survey Bulletin 1787-B, p. 19–28.

Schenk, C.J., 1989, Sedimentology and stratigraphy of the Eagle Valley Evaporite (Middle Pennsylvanian), Eagle Basin, Colorado: Boulder, University of Colorado, Ph.D. dissertation.

Scott, G.R., 1975, Cenozoic surfaces and deposits in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 227–248.

Scott, R.B., and Shroba, R.R., 1997, Revised preliminary geologic map of the New Castle quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 97-737, scale 1:24,000.

Scott, R.B., Shroba, R.R., and Egger, A.E., 2001, Geology of the Rifle Falls quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2341, scale 1:24,000.

Scott, R.B., Bryant, Bruce, and Perry, W.P., Jr., 2002, Late Cenozoic deformation by evaporite tectonism in the Grand Hogback Monocline, southwest of the White River Uplift, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 121–147.

Shroba, R.R., and Scott, R.B., 2001, Geology of the Silt quadrangle, Garfield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-2331, scale 1:24,000.

Soil Survey Staff, 1975, Soil taxonomy: U.S. Department of Agriculture Handbook 436, 754 p.

Soule, J.M., and Stover, B.K., 1985, Surficial geology, geomorphology, and general engineering geology of parts of the Colorado River valley, Roaring Fork River valley, and adjacent areas, Garfield County, Colorado: Colorado Geological Survey Open-File Report 85-1.

Steven, T.A., 2002, Late Cenozoic tectonic and geomorphic framework surrounding the evaporite dissolution area in west-central Colorado, *in* Kirkham, R.M., Scott, R.B., and Judkins, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west-central Colorado: Geological Society of America Special Paper 366, p. 15–30.

Streufert, R.K., 2008, Geologic map of the Mount Sopris quadrangle, Garfield and Pitkin Counties, Colorado: Colorado Geological Survey Map Series 41, scale 1:24,000.

Streufert, R.K., Kirkham, R.M., Schroeder, T.S., and Widmann, B.L., 1997, Geologic map of the Dotsero quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 97-2.

Streufert, R.K., Kirkham, R.M., Widmann, B.L., and Schroeder, T.S., 2008, Geologic map of the Cottonwood Pass quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Map Series 37, scale 1:24,000.

Streufert, R.K., Widmann, B.L., and Kirkham, R.M., 2008, Geologic map of the Basalt quadrangle, Eagle, Garfield, and Pitkin Counties, Colorado: Colorado Geological Survey Map Series 39, scale 1:24,000.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

Tweto, Ogden, 1975, Laramide (Late Cretaceous–early Tertiary) orogeny in the Southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 1–44.

Tweto, O., 1977, Tectonic history of west-central Colorado, *in* Veal, H.K., ed., Exploration frontiers of the central and southern Rockies: Rocky Mountain Association of Geologists, 1977 symposium, p. 11–22.

Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000.

Tweto, Ogden, Moench, R.H., and Reed, J.C., 1978, Geologic map of the Leadville 1° x 2° quad rangle, northwest Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-999.

Unruh, D.M., Budahn, J.R., Siems, D.F., Byers, F.M., Jr., 2001, Major- and trace-element geochemistry; lead, strontium, and neodymium isotopic compositions; and petrography of late Cenozoic basaltic rocks from west central Colorado: U.S. Geological Survey Open-File Report 01-477, 90 p.

White, J.L., 2002, Collapsible soils and evaporite karst hazards map of Roaring Fork River corridor, Garfield, Eagle and Pitkin Counties, Colorado: Colorado Geological Survey Map Series 34, scale 1:50,000.

Widmann, B.L., Bartos, P.J., Madole, R.F., Barba, K.E., and Moll, M.E., 2004, Geologic map of the Alma quadrangle, Park and Summit Counties, Colorado: Colorado Geological Survey Open-File Report 04-3, scale 1:24,000.

APPENDIX A

Appendix A: Major element, whole-rock XRF analyses of volcanic rocks in Leon 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) except for sample L-12, which was analyzed by Chemex Labs Inc., Sparks, Nevada.

	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
CP106	49.97	15.30	8.02	7.40	3.19	2.23	11.05	0.16	0.71	1.81	-0.24	99.6
K97-8-11A	50.69	15.37	8.05	6.55	2.95	1.91	10.62	0.15	0.66	1.57	1.35	99.87
K97-8-11B	51.55	15.66	7.36	5.95	2.99	2.21	10.30	0.15	0.71	1.59	1.07	99.54
K97-8-11C	51.81	15.71	7.26	5.93	3.09	2.28	10.33	0.14	0.71	1.62	0.49	99.37
K97-8-11D	51.80	15.78	7.43	5.85	3.21	2.18	10.41	0.16	0.70	1.62	0.31	99.45
K97-8-11E	53.19	15.66	6.72	5.21	3.27	2.50	9.67	0.14	0.75	1.60	0.44	99.15
K97-8-12E	50.69	15.23	8.09	6.14	3.16	1.24	11.21	0.13	0.36	1.47	2.15	99.87
K97-8-12F	51.12	15.32	8.20	6.87	2.89	1.10	10.95	0.13	0.31	1.43	1.70	100.20
K97-8-12G	(See L-3)											
K97-8-12H	50.05	14.92	8.71	5.60	3.06	2.94	9.08	0.15	0.57	1.36	2.90	99.34
K97-8-15A	52.75	15.93	7.82	5.81	3.20	1.77	10.03	0.14	0.47	1.49	0.40	99.81
K97-8-15B	57.63	15.29	5.20	2.99	3.41	3.33	8.43	0.11	0.79	1.53	0.92	99.63
K97-8-15C	57.47	15.62	5.58	2.72	3.40	3.12	8.41	0.12	0.74	1.53	0.51	99.22
L-1	49.58	14.76	9.18	6.05	3.01	2.82	9.40	0.15	0.57	1.41	2.44	99.37
L-3	51.49	14.98	8.00	6.30	3.12	3.04	9.95	0.15	0.59	1.35	0.47	99.44
L-4	48.82	14.80	8.96	6.75	3.07	2.20	10.74	0.16	0.68	1.75	1.66	99.59
L-6	54.08	15.07	6.66	6.09	3.25	3.55	8.54	0.13	0.62	1.41	-0.04	99.36
L-7	55.44	15.42	6.23	5.02	3.30	3.47	8.18	0.13	0.57	1.37	0.26	99.39
L-12	60.45	15.70	4.43	1.55	3.95	4.00	6.63	0.08	0.38	1.14	0.98	99.30
L-23	51.84	15.75	7.91	6.93	3.18	1.41	11.00	0.15	0.41	1.40	0.14	100.12
L-25	52.37	15.71	7.72	6.36	3.36	1.68	10.26	0.14	0.48	1.44	0.04	99.56
L-26	51.42	15.45	7.97	7.17	3.03	1.40	11.03	0.15	0.41	1.41	0.63	100.07
L-27	47.04	14.40	11.79	6.22	2.80	1.01	10.50	0.15	0.30	1.26	3.99	99.46
L-28	51.91	15.30	7.12	6.20	3.42	3.18	9.12	0.14	0.66	1.54	0.23	98.82
L-37	52.98	15.77	6.84	4.81	3.49	2.40	10.09	0.14	0.78	1.60	0.35	99.25
L-38A	57.12	15.46	5.28	2.84	3.49	3.16	8.38	0.10	0.83	1.53	0.95	99.14
L-39	52.95	15.82	6.94	5.62	3.39	2.40	10.24	0.14	0.77	1.63	-0.06	99.84
L-48	52.61	15.66	7.09	6.16	3.37	3.22	9.07	0.15	0.60	1.38	-0.21	99.10
L-52	52.01	15.60	7.41	6.21	3.19	3.10	9.12	0.14	0.60	1.37	0.69	99.44
L-56	48.47	14.61	7.71	8.00	3.04	2.19	10.69	0.15	0.72	1.73	2.37	99.68
L-60	48.00	14.93	8.30	8.42	3.33	1.82	11.28	0.16	0.77	1.78	0.99	99.78
L-68	49.67	15.14	8.03	7.30	3.24	2.20	10.95	0.16	0.75	1.79	0.32	99.55

Appendix A, Continued

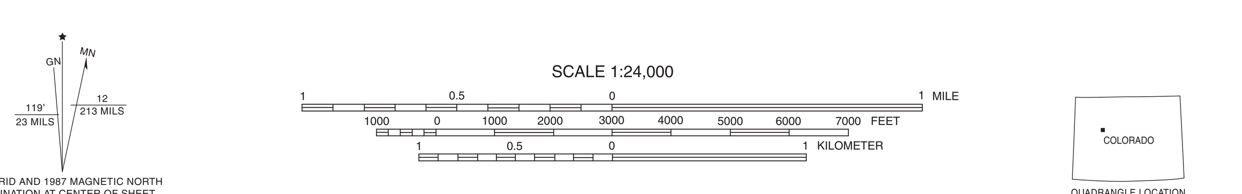
Sample ID	Weight Percent											
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	P_2O_5	TiO_2	LOI*	Total
L-78	48.58	14.67	8.16	7.29	3.15	2.30	10.75	0.15	0.76	1.77	2.04	99.62
L-91A	52.61	15.79	7.01	6.31	3.19	2.46	10.35	0.14	0.76	1.62	0.69	100.93
L-91B	52.77	15.73	6.93	5.47	3.31	2.48	10.15	0.14	0.77	1.61	0.42	99.78
L-176	52.44	15.72	7.13	6.25	3.33	2.23	10.47	0.14	0.73	1.60	-0.08	99.96
L-181	53.90	15.58	6.43	4.98	3.23	2.76	9.67	0.13	0.80	1.59	0.67	99.74
L-187A	52.45	15.69	7.03	6.26	3.29	2.24	10.53	0.14	0.73	1.60	0.09	100.05
L-187B	52.47	15.71	6.97	6.10	3.22	2.26	10.38	0.14	0.73	1.60	0.40	99.98
L-187D	53.03	15.73	6.88	5.58	3.44	2.41	10.07	0.14	0.78	1.62	0.09	99.77
L-201	52.22	15.93	7.91	5.61	3.18	1.71	10.60	0.15	0.49	1.55	0.55	99.90
L-233	52.10	15.13	7.29	6.36	3.39	3.09	9.13	0.14	0.66	1.54	0.70	99.53
L-244	52.34	15.39	7.10	5.96	3.49	3.26	9.29	0.14	0.67	1.56	0.39	99.59
L-245	52.31	15.57	7.27	5.07	3.70	3.20	9.38	0.14	0.68	1.57	0.56	99.45
L-246	52.17	15.26	7.28	6.30	3.56	3.12	9.19	0.14	0.67	1.55	0.50	99.74

*Loss On Ignition

Sample Locations (NAD27)

Sample ID	Map Unit	Location		Sample ID	Map Unit	Location	
		Latitude	Longitude			Latitude	Longitude
CP106	Tb	39.4983° N	107.0532° W	L-28	Tspc	39.4339° N	107.0800° W
K97-8-11A	Tb	39.3981° N	107.0038° W	L-37	Tb	39.4119° N	107.0154° W
K97-8-11B	Tb	39.3981° N	107.0038° W	L-38A	Tb	39.3986° N	107.0016° W
K97-8-11C	Tb	39.3981° N	107.0038° W	L-39	Tb	39.4413° N	107.0391° W
K97-8-11D	Tb	39.3981° N	107.0038° W	L-48	Tcc	39.4692° N	107.1225° W
K97-8-11E	Tb	39.3981° N	107.0038° W	L-52	Tcc	39.4625° N	107.1037° W
K97-8-12E	Tb	39.4090° N	107.0981° W	L-56	Tb	39.4757° N	107.1103° W
K97-8-12F	Tb	39.4094° N	107.0982° W	L-60	Tb	39.4751° N	107.0615° W
K97-8-12G	Tccc	39.4678° N	107.1091° W	L-68	Tb	39.4783° N	107.1169° W
K97-8-12H	Tcc	39.4634° N	107.1096° W	L-78	Tb	39.4907° N	107.0892° W
K97-8-15A	QTcd	39.4214° N	107.0915° W	L-91A	Tb	39.4417° N	107.0332° W
K97-8-15B	Tb	39.4113° N	107.0143° W	L-91B	Tb	39.4415° N	107.0342° W
K97-8-15C	Tb	39.4111° N	107.0147° W	L-176	Tb	39.4126° N	107.0658° W
L-1	Tcc	39.4634° N	107.1096° W	L-181	Tb	39.4441° N	107.0179° W
L-3	Tccc	39.4678° N	107.1091° W	L-187A	Tb	39.4315° N	107.0455° W
L-4	Tb	39.4762° N	107.1195° W	L-187B	Tb	39.4313° N	107.0452° W
L-6	Tta	39.4979° N	107.1188° W	L-187D	Tb	39.4314° N	107.0446° W
L-7	Tta	39.4769° N	107.1227° W	L-201	Tb	39.4597° N	107.0647° W
L-12	QTcd	39.4042° N	107.0889° W	L-233	Tsp	39.4362° N	107.0766° W
L-23	Tb	39.4096° N	107.0981° W	L-244	Tsp	39.4329° N	107.0826° W
L-25	QTcd	39.4150° N	107.0929° W	L-245	Tspc	39.4339° N	107.0800° W
L-26	QTcd	39.4085° N	107.1110° W	L-246	Tsp	39.4362° N	107.0766° W
L-27	Tb	39.4240° N	107.0793° W				

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 1997
Digital map prepared 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

Qa — **Modern stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. May locally include clayey deposits in some subsidence troughs. 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 ephem-eral and intermittent stream valleys, on gentle hillslopes, and in basins

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 15 to 52 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 to 100 ft above modern streams

Qtt — **Oldest terrace alluvium (middle and early? Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts moderately to highly wea-thered. A single small terrace remnant in the southeast corner of the quadrangle that is about 380 to 400 ft above the Frying Pan River

QTg — **High-level gravel (early Pleistocene and/or late Tertiary)** —Chiefly clast-supported, sandy, silty, cobble and pebble gravel occurring on a subtle ridge line about 1 mi east of El Jebel and about 1,300 to 1,350 ft above the Roaring Fork River. Clasts are moderately to very highly weathered

QTm — **Sediments of Missouri Heights (early Quaternary and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights area in alluvial and colluvial environments. May include pediment deposits derived from and deposited on the sediments of Missouri Heights in area between Spring Park Reservoir and Cattle Creek. Deposited in topographic depressions created by evaporite tectonism. Overlies Miocene basaltic rocks (Tb). Typically is less deformed than underlying rocks. Occurs about 1,000 to 1,650 ft above the Roaring Fork River

MASS-WASTING DEPOSITS

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes a recently active landslide near the northeast corner of the map with very fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified rock debris, 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 slope and finer grained in distal areas

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of basalt, trachyandesite, sandstone, or basalt-rich landslide deposits

Qbf — **Boulder-field deposits (Holocene and late Pleistocene)**—Angular boulders and cobbles of basalt with little or no matrix on moderate to steep slopes. Commonly has an undulatory surface suggestive of flowage as a rock glacier or related to periglacial processes

Qls — **Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris

Qco — **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes

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

ALLUVIAL AND MASS-WASTING DEPOSITS

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, hyper-concentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels. Numeric subscripts indicate relative ages of younger debris-flow deposits in the southwest corner of the quadrangle. Deposits labeled $Qdfy_1$ are younger than and derived from deposits labeled $Qdfy_2$

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

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. May locally include lacustrine deposits in large subsidence troughs

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes ranging from about 10 to 60 ft above the floor of tributary valleys

Qcso — **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Deposits texturally and depositionally similar to colluvium and sheetwash (Qcs) that underlie surfaces 20 to 160 ft above adjacent stream beds

Qdfo — **Older debris flow-deposits (Pleistocene)**—Remnant of an inactive debris fan on a ridge line about 80 to 120 ft above the adjacent stream bed near the southeast corner of the quadrangle. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

SINTER DEPOSITS

Qtu — **Tufa (Holocene and late Pleistocene?)**—Low-density, porous, calcium carbonate deposits precipitated from a mineral spring along the Basalt Mountain Fault immediately north of Cattle Creek

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

COLLAPSE DEPOSITS

QTcd — **Collapse deposits (Quaternary and late Tertiary)**—Heterogenous deposits of moderately to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits within the Carbondale Collapse Center. Locally includes large but displaced blocks of volcanic rocks. Formed in response to differential collapse resulting from dissolution and flow of underlying evaporite

BEDROCK

Tsp — **Trachyandesite of Spring Park (Pliocene)**—Medium-gray basaltic flows from an eruptive center about 0.5 mi east of the dam for Spring Park Reservoir. Petrographically the unit is xenocrystic olivine basalt, while geochemically it is a basaltic trachyandesite. Groundmass predominantly plagioclase and pyroxene. Contains sparse phenocrysts of mainly olivine and rare plagioclase. Locally contains abundant xenocrysts of quartz, sanidine, and plagioclase. Included in compositional group 6b′ of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 2.90 ± 0.02 Ma (Kunk and others, 2002)

Tspc — **Cinder deposits of Spring Park (Pliocene)**—Red and red-brown scoriaceous, unconsolidated cinder deposits associated with an eroded eruptive center about 0.5 mi east of the dam for Spring Park Reservoir. Petrographically the rock is olivine basalt with locally abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically these rocks are basaltic trachyandesite and are included in compositional group 6b′ of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 2.96 ± 0.02 Ma (Kunk and others, 2002)

Tcc — **Trachyandesitic flows of Cattle Creek (Pliocene)**—Medium- to dark-gray basaltic trachyandesite and trachybasalt flows along Cattle Creek between Shippes Draw and Sleepy Creek. Contains varying amounts of quartz and sanidine xenocrysts. Included in compositional group 6c of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 3.09 ± 0.02 Ma (Kunk and others, 2002)

Tccc — **Trachyandesite cinder deposits of Cattle Creek (Pliocene)**—Dark-gray to black, scoriaceous, cinder deposit exposed in cinder quarries along Cattle Creek between Shippes Draw and Sleepy Creek. Petrographically this deposit is a xenocrystic olivine basalt; geochemically it is basaltic trachyandesite. Included in compositional group 6c of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 3.01 ± 0.01 Ma (Kunk and others, 2002)

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

Tsb — **Sediments of Basalt Mountain (Pliocene or Miocene)**—Chiefly medium-red-brown, weakly indurated, pebble and cobble gravel in a sandy or silty matrix. Locally bouldery. Deposited over basalt flows on northern edge of Basalt Mountain shield volcano by ancestral Cattle Creek

Tb — **Basaltic flows (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. Included in compositional groups 1b, 1c, 2b′, 4b, and 4b′ of Buhdan and others (2002). $^{40}Ar/^{39}Ar$ age dates range from 7.75 ± 0.03 Ma to 10.84 ± 0.06 Ma.

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

Km — **Mancos Shale (Upper Cretaceous)**—Light- to dark-gray, carbonaceous, silty to sandy shale and thin bentonite beds, gray limestone, and light- to medium-gray, grayish-yellow-weathering, clayey sandstone. Includes the Fort Hays Limestone Member, a thick-bedded, coarse-grained, gray limestone

Kd — **Dakota Sandstone (Lower Cretaceous)**—Light-gray to tan, medium- to very coarse-grained, quartzose sandstone and conglomeratic sandstone interbedded with carbonaceous siltstone, sandstone, and shale. May include Burro Canyon Formation in southern part of quadrangle

Jm — **Morrison Formation (Upper Jurassic)**—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to tan sandstone, and gray limestone. A thick-bedded, coarse-grained, oolitic, tan- and white-weathering, medium-dark-gray limestone at the base of the formation overlies the Entrada Sandstone

Je — **Entrada Sandstone (Upper Jurassic)**—Light-gray, tan, and white, medium- to very fine-grained, well-sorted sand-stone with large-scale crossbedding. Weakly to mod-erately indurated

T̵Rc — **Chinle Formation (Upper Triassic)**—Thin, even-bedded, and structureless beds of dark-reddish-brown, orangish-red, and purplish-red, calcareous siltstone and mudstone and scattered thin lenses of light-purplish-red and gray lime-stone and limestone-pebble conglomerate. Locally in-cludes a thin, basal conglomeratic sandstone

T̵RPsb — **State Bridge Formation (Lower Triassic and Permian)**—Reddish-orange, grayish-red, and pale-reddish-pink silty sandstone, clayey siltstone, arkosic sandstone, and conglomeratic sandstone. Includes lenses of sandy dolo-mite and limestone of the South Canyon Creek Dolomite Member that are up to 18 inches thick and occur about 200 ft above the base of the formation. Sandstone beds are well sorted, equigranular, and have rounded to sub-rounded sand grains with a high degree of sphericity

T̵RPcs — **Chinle and State Bridge Formations, undivided (Triassic and Permian)**

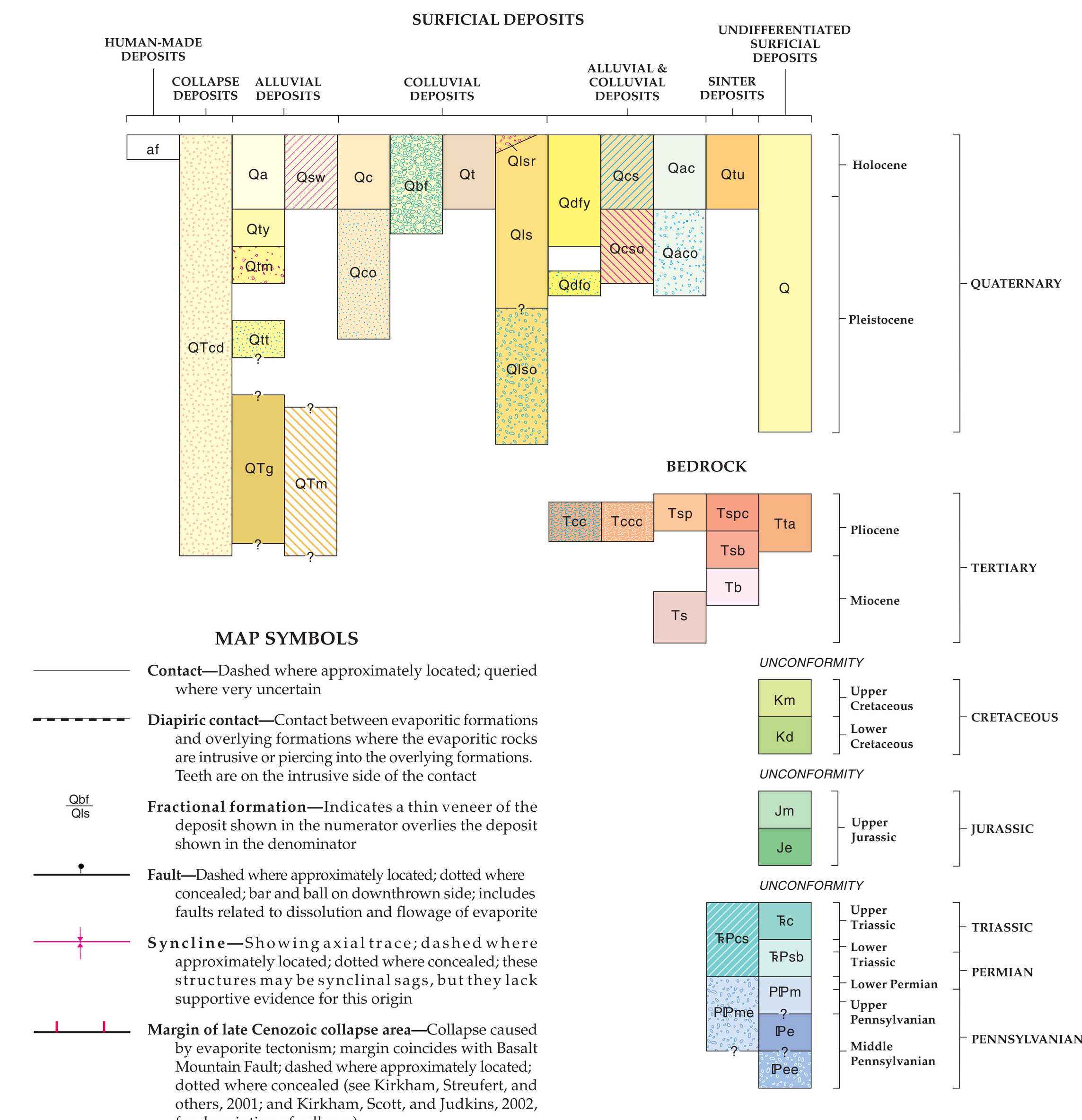
PIPm — **Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone

IPe — **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

PIPme — **Maroon and Eagle Valley Formations, undivided (Lower Permian and Upper and Middle? Pennsylvanian)**

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

CORRELATION OF MAP UNITS



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

$\frac{\text{Qbf}}{\text{Qls}}$ **Fractional formation**—Indicates a thin veneer of the deposit shown in the numerator overlies the deposit shown in the denominator

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

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

Margin of late Cenozoic collapse area—Collapse caused by evaporite tectonism; margin coincides with Basalt Mountain Fault; dashed where approximately located; dotted where concealed (see Kirkham, Streufert, and others, 2001; and Kirkham, Scott, and Judkins, 2002, for description of collapse)

Synclinal sag or subsidence trough—Showing axial trace of synclinal sag or subsidence trough related to evaporite dissolution and/or flowage; synclinal sags occur in bedrock, subsidence troughs are found on river terraces; 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

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; "x" denotes one or more small sinkholes; many small sinkholes other than those shown on the map are probably present in the quadrangle

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

Inclined beds—Showing approximate attitude of surface on 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 in extrusive flow rocks**—Includes measurements on flows within collapse debris (QTcd). Angle of dip shown in degrees

Linear ridge within landslide on west side of Basalt Mountain— Ridge is underlain by tilted slump blocks of basalt that range from nearly intact to very rubbly flows

Linear swale of uncertain origin along the Basalt Mountain Fault

Approximate boundary of a subsidence trough developed in surficial deposits—Resultant from collapse into voids created by dissolution or flowage of underlying evaporitic rocks. Queried where very approximate

Approximate boundary of a lava-filled crater at the crest of Basalt Mountain—Exposed part of crater has been filled with two thick, ponded lava flows. The lower flow averages about 200 to 250-ft thick and the upper flow averages about 40 to 50-ft thick

Adit

Gravel pit

Cinder quarry

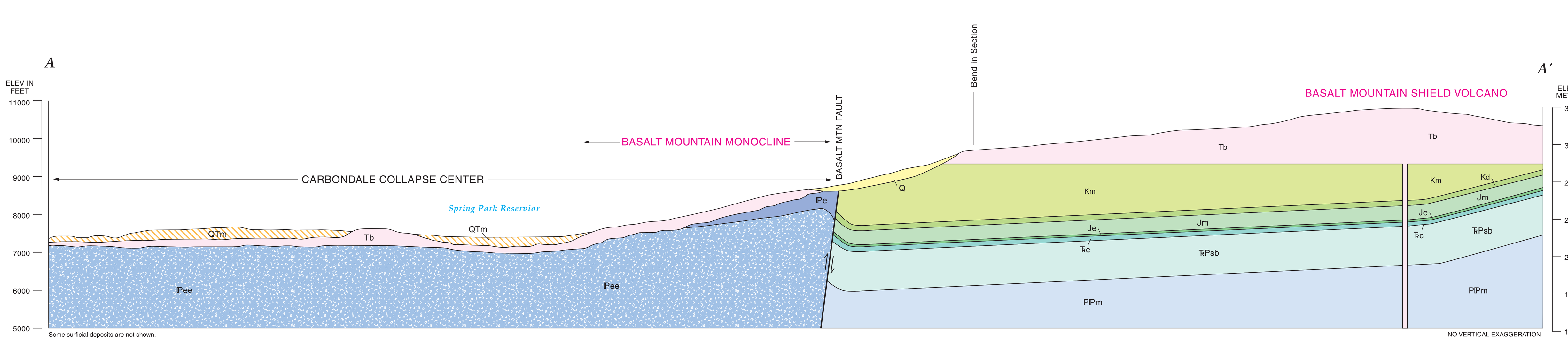
L-23 **Location and identification number of geochemical rock sample—(Table l and Appendix A in booklet; Unruh and others, 2001; Budahn and others, 2002)**

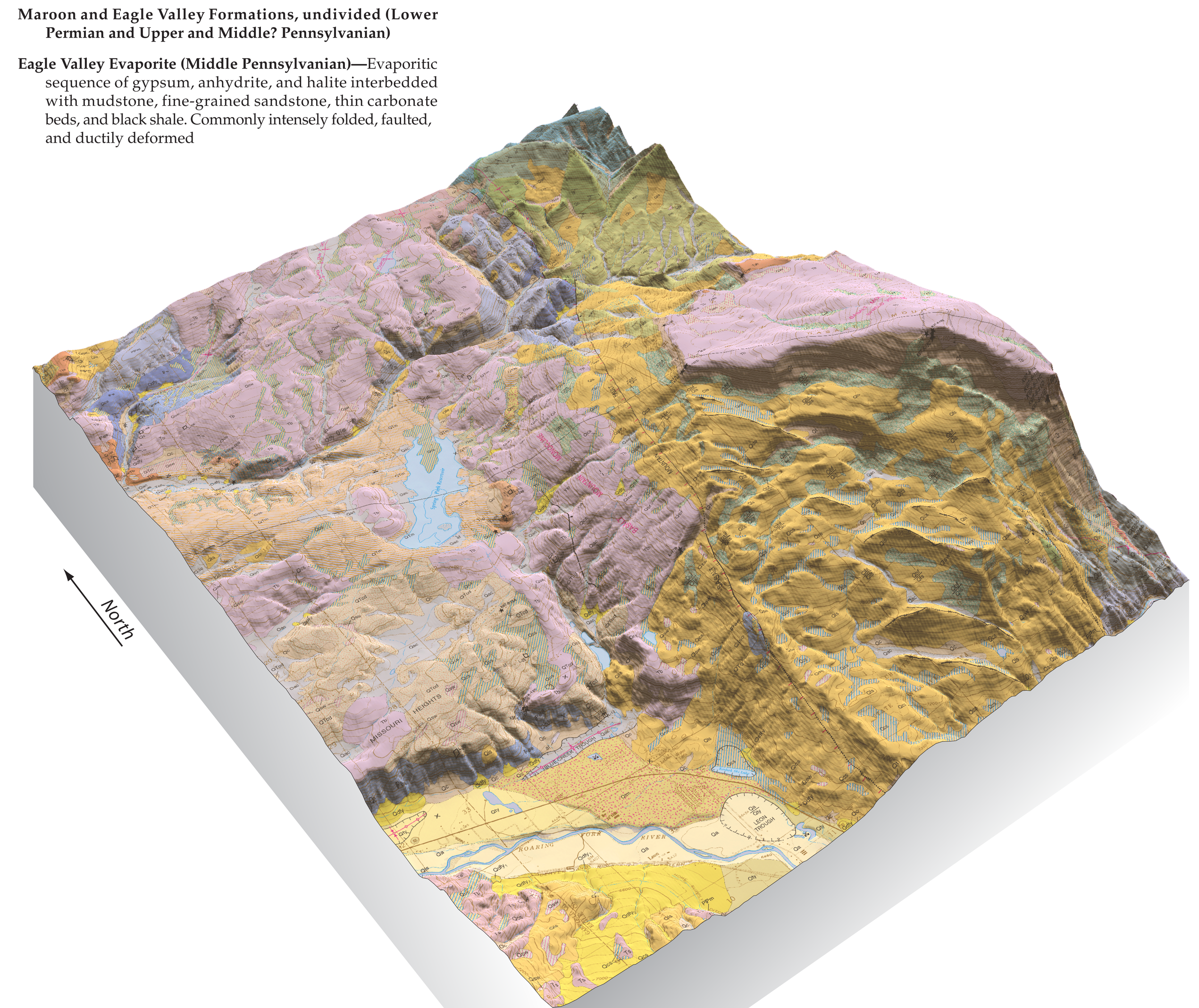
L-39 **Location and identification number of rock sample with geochemical analysis (Unruh and others, 2001; Budahn and others, 2002) and $^{40}Ar/^{39}Ar$ age date (Kunk and Snee, 1998; Kunk and others, 2001). See Table 1 and Appendix A in booklet**

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

ACKNOWLEDGEMENTS

This geologic map was funded in part by the U.S. Geological Survey National Geologic Mapping Program and by State of Colorado General Funds and Colorado Department of Natural Resources Severance Tax Operational Funds.





GEOLOGIC MAP OF THE LEON QUADRANGLE, EAGLE AND GARFIELD COUNTIES, COLORADO

By Robert M. Kirkham, Beth L. Widmann, and Randall K. Streufert

2008

Bill Ritter Jr., Governor
State of Colorado

Harris D. Sherman, Executive Director
Department of Natural Resources

Vincent Matthews
State Geologist and Director
Colorado Geological Survey