MAP SERIES 38

Geologic Map of the Glenwood Springs Quadrangle, Garfield County, Colorado

By
Robert M. Kirkham, Randall K. Streufert, James A. Cappa, Colin A. Shaw,
Joseph L. Allen, and James V. Jones

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Map Series Report 38, *Geologic Map of the Glenwood Springs Quadrangle, Garfield County, Colorado*. Its purpose is to describe the geologic setting of this 7.5-minute quadrangle, which includes the city of Glenwood Springs.

This mapping project initially 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. 1434-94-A-1225 and 01HQAG0094). The program is authorized by the National Mapping Act of 1997. The CGS matching funds come from the Severance Tax Operational Account that is funded by taxes paid on the production of natural gas, oil, coal, and metals.

Support for the detailed mapping of Proterozoic rocks in 2005-2006 by Colin Shaw and his students came from the EDMAP component of the National Geologic Mapping Program (Agreement No. 06HQAG0128), which is administered by the USGS. Joseph Allen and his students were funded by the Petroleum Research Fund of the American Chemical Society.

Vince Matthews,
State Geologist and Division Director,
Colorado Geological Survey

Acknowledgments

The original maps produced as CGS Open-File Report 95-3 and Map Series 31 benefited from reviews by Jim Soule and Bruce Bryant. Jane Ciener served as the technical editor of the earlier maps. Several colleagues, including Ken Hon, Bruce Bryant, Pat Rogers, Barney Poole, Mick Kunk, Jim Budahn, Mark Hudson, Bob Scott, Bill Perry, Dan Unruh, Jim Soule, and Bruce Stover, contributed data or advice. Jim Messerich set photogrammetric models of our annotated aerial photographs on a Kern PG-2 plotter. We appreciate the many landowners and property managers who gave permission to enter their property. John Bershenyi, Hal Terrell, Deke Price, Charles Marsh, and Craig Wesley were especially helpful.

Peter L. Stelling served as a field assistant in 1994. Matt Grizzell, Rafaello Sacerdoti, and Vince Matthews collected additional structural attitudes on bedding planes in Glenwood Canyon during 2002. Ian Ware and Jamie Skeen, students at Concord University, assisted J.L. Allen, and Stephannie Mumma, student at Montana State University, assisted C.A. Shaw with the detailed mapping of Proterozoic Rocks during 2005 and 2006.

This project was funded by State of Colorado General Funds, Colorado's Severence Tax Operational Account, the USGS STATEMAP and EDMAP programs, and the American Chemical Society.

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INTRODUCTION

OVERVIEW

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

This publication includes the digitally produced, full-color geologic map of the Glenwood Springs 7.5-minute quadrangle. The digital map and accompanying booklet are modified from an earlier publication released by the CGS as Map Series 31.

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 Glenwood Springs quadrangle, six other quadrangles in the Glenwood Springs area are currently being digitally produced (Fig. 1). They include the Shoshone, Cottonwood Pass, Carbondale, Leon, Basalt, and Mount Sopris quadrangles.

Most modifications in this new digital geological map of the Glenwood Springs quadrangle are due to either the discovery of widespread late Cenozoic evaporite collapse in the region (see Kirkham, Scott, and Judkins, 2002) or to the detailed mapping of Proterozoic rocks in 2005 and 2006 by C.A. Shaw, J.L. Allen and their students. The recent detailed mapping of the Proterozoic

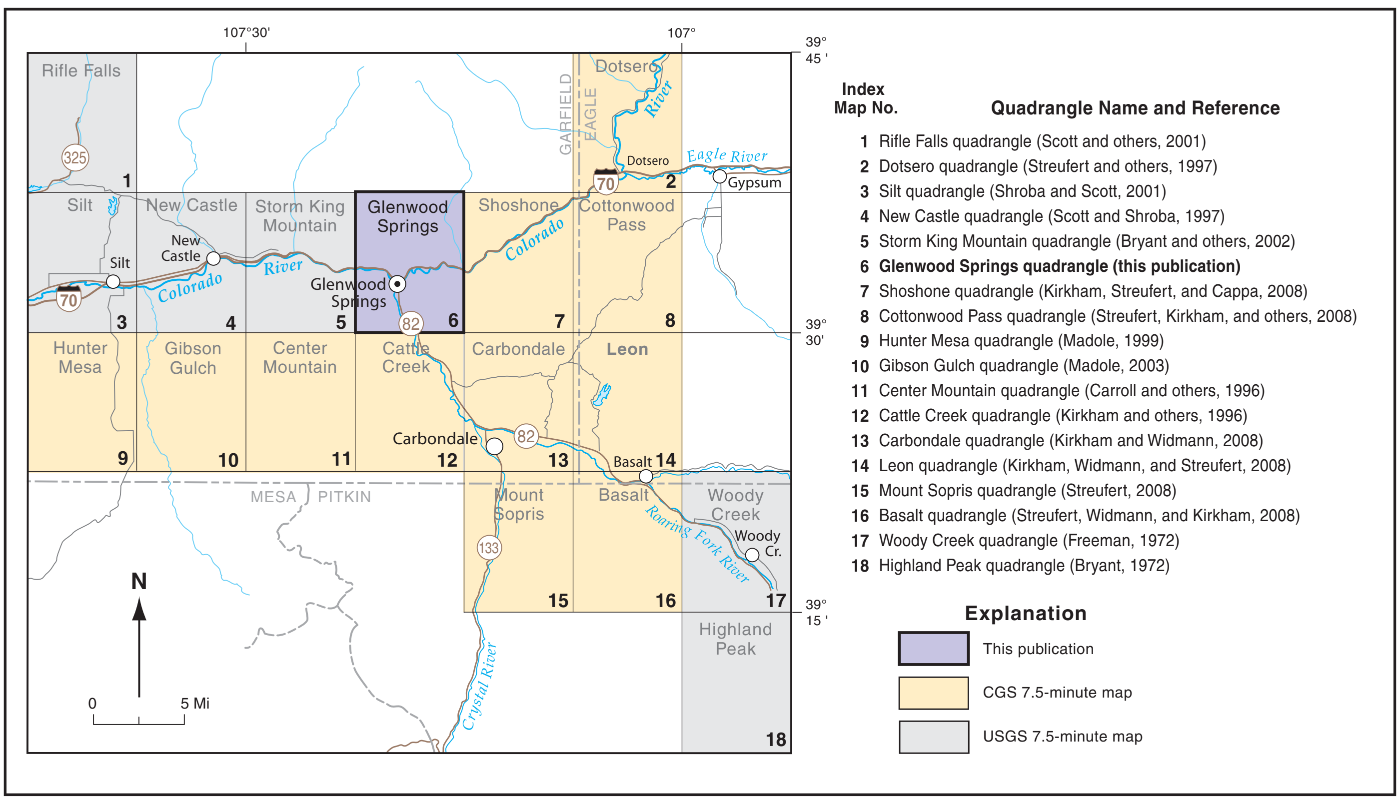


Figure 1. Geologic maps of 7.5-minute quadrangles in the vicinity of the Glenwood Springs quadrangle.

rocks resulted in the recognition and mapping of additional Proterozoic rock units, a major Proterozoic shear zone, and small Tertiary intrusions contained within the Proterozoic rocks.

The discovery of regional evaporite collapse was made early during the original mapping program, but new evidence of the collapse was found as additional quadrangles were mapped and as the data from a 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 structure and geologic units mapped in prior publications.

A key aspect of the collaborative CGS–USGS investigation involved the correlation of Neogene basaltic rocks. Numerous samples of these igneous rocks were collected, analyzed, and correlated using geochemistry, $^{40}Ar/^{39}Ar$ geochronology, magnetostratigraphy, paleomagnetism, and petrography subsequent to the publication of CGS Map Series 31. The locations of basaltic samples collected for geochemical and/or geochronologic studies both during and subsequent to the publication of Map Series 31 are included on the digital map; the correlation of the basaltic rocks is briefly discussed in a following section. Refer to Budahn and others (2002), Kunk and others (2002), and Hudson and others (2002) for additional information acquired during the collaborative CGS–USGS investigation of the basaltic rocks.

Other modifications to the map and booklet are a result of (1) edge matching the geology shown on the previously released CGS Map Series 31 to that on adjacent recently mapped quadrangles; (2) interpretation of the geology of the mapped area with respect to the regional knowledge acquired by mapping twelve contiguous quadrangles; (3) expansion of the booklet to develop a consistent format for all digitally updated maps, one that includes the new age and geochemical data; 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. Figure 1 shows the current status of geologic mapping of 7.5-minute quadrangles in the Glenwood Springs area. In addition to the twelve quadrangles mapped by the CGS, the USGS has mapped several quadrangles in the area.

The Glenwood Springs quadrangle covers about 58 sq mi in Garfield County, west-central Colorado. The town of Glenwood Springs is near the center of the quadrangle. Interstate Highway 70 runs east-west across the mapped area, generally following the course of the Colorado River; Colorado Highway 82 was constructed in the valley of the Roaring Fork River. Both the highways and the rivers join in Glenwood Springs. 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 previous geologic map contained in CGS Map Series 31 was as follows: R.M. Kirkham mapped all the surficial deposits and the Eagle Valley Evaporite and younger bedrock formations south of the Colorado River; R.K. Streufert mapped the Paleozoic sedimentary rocks north of the Colorado River and the Belden Formation and older Paleozoic strata on the south wall of Glenwood Canyon; J.A. Cappa mapped the Precambrian rocks for the original map. C.A. Shaw, J.L. Allen, and their students mapped the Proterozoic rocks in detail during 2005 and 2006. J.V. Jones did the U-Pb dating of the Proterozoic rocks. R.M. Kirkham, C.A. Shaw, and J.L. Allen are responsible for the modifications to the geologic map and booklet contained in this report.

PRIOR GEOLOGIC MAPS

Previously published small-scale geologic maps of the Glenwood Springs quadrangle include 1:500,000-scale maps by Burbank and others (1935) and Tweto (1979), and the 1:250,000-scale map of Tweto and others (1978). Bass and Northrop (1963) focused on the bedrock in their 1:31,680-scale map of the Glenwood Springs 30-minute quadrangle. The southern part of the quadrangle was mapped by F.M. Fox & Associates (1974) at a scale of 1:48,000. The 1:50,000-scale mapping of Soule and Stover (1985), which covered roughly the southwestern one-half of our mapped area, emphasized surficial deposits. Lincoln-Devore (1976, 1978) mapped the surficial and bedrock geology of the Glenwood Springs metropolitan area at scales ranging from 1:4,800 to 1:24,000.

Our mapping of the Glenwood Springs quadrangle first involved the release of a preliminary reconnaissance 1:24,000-scale map of the southern part of the quadrangle (Kirkham and Streufert, 1994). The entire quadrangle was mapped at a scale of 1:24,000 for an open-file report (Kirkham and others, 1995); this map was later published as a full-color map printed on an offset press (Kirkham and others, 1997).

MAPPING METHODS AND TERMINOLOGY

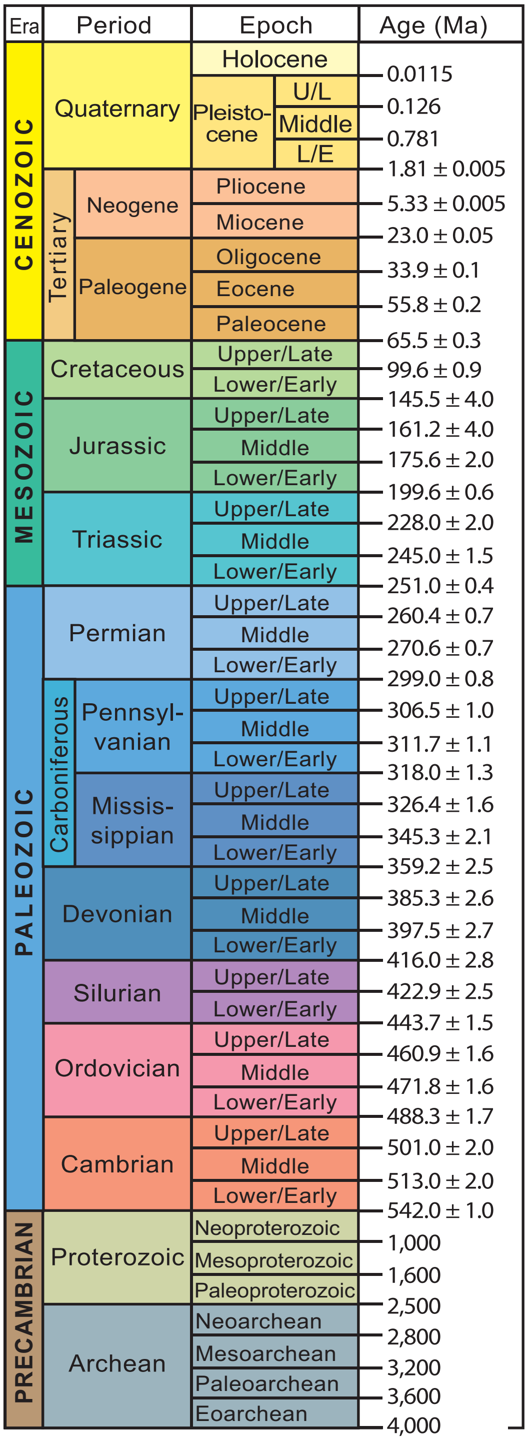
Field work in Glenwood Springs quadrangle was initially conducted by R.M. Kirkham, R.K. Streufert, and J.A. Cappa during the fall of 1993 and the field season of 1994. At that time traverses were made along all public roads in the quadrangle except for a few within the town of Glenwood Springs and along some of the private roads. Foot traverses were needed to access remote parts of the quadrangle. Mapping of the walls of Glenwood Canyon was frequently accomplished from vantage points with good views of nearby canyon walls. Aerial photography was used extensively during the project in 1993 and 1994.

During ensuing years R.M. Kirkham occasionally spent short periods of time in the field, most of which related to the collaborative CGS–USGS investigation of basaltic rocks and evaporite collapse. In 2005 and 2006 C.A. Shaw, J.L. Allen, and their students made numerous foot traverses to accomplish the detailed mapping of the Proterozoic rocks in the canyons.

Geologic information collected in the field in the southern half of the quadrangle during 1993 and 1994 was plotted using a pocket stereoscope on 1:24,000-scale color aerial photographs flown for the U.S. Bureau of Land Management; in the northern part of the mapped area 1:16,000-scale color aerial photographs flown for the U.S. Forest Service were utilized. Geologic information drawn on the aerial photographs was transferred to a mylar base map using a Kern PG-2 plotter.

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 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. Material smaller than 2 mm is dominant in matrix-supported deposits, and most clasts are separated by or embedded in matrix.

The divisions of geologic time and the age estimates of their boundaries that are used in this publication 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. Deposits associated with distinct landforms may locally be thinner than 5 ft Surficial deposits with a width of about 75 to 100 ft or less are not shown on the map because they cannot be depicted on a 1:24,000-scale map. Artificial fill of limited areal extent and residuum were not mapped. Contacts between many surficial units may be gradational and therefore should be considered as approximate boundaries.

Most of the surficial deposits in the Glenwood Springs 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 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

af — **Artificial fill (latest Holocene) —** Fill and waste rock deposited during construction and mining projects. Composed mostly of silt, sand, and rock fragments, but may include construction materials. Remnant debris from the coke ovens west of the Glenwood Springs Municipal Airport is also mapped as artificial fill. Maximum thickness about 50 ft.

ALLUVIAL DEPOSITS — Silt, sand, and gravel deposited in stream channels, flood plains, glacial outwash terraces, debris fans, and sheetwash areas along the Colorado River, Roaring Fork River, and their tributaries.

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene) —** Includes modern alluvium and other deposits along the Roaring Fork and Colorado Rivers, adjacent flood-plain deposits, and low-terrace alluvium that is as much as about 15 ft above modern stream level. Unit is mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel in a sandy or silty matrix. Unit Qa locally is interbedded with and commonly overlain by sandy silt and silty sand. Unit is poorly to moderately well sorted and is moderately well to well bedded. Clasts are well rounded to subangular. Their varied lithology reflects the diverse types of bedrock within their provenance. Unit may locally include organic-rich deposits or lacustrine clay or silt. It may be interfingered with younger debris-flow deposits where the distal ends of fans extend into modern river channels. Maximum thickness is about 154 ft in Glenwood Canyon (Bowen, 1988). Flood-plain and terrace deposits included in this unit correlate with deposits in terrace T8 of 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 which are transported chiefly by sheetwash and deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, or in basinal areas. Sheetwash deposits are common on gentle to moderate slopes underlain by limestone, shale, basalt, red beds, and landslide deposits. They typically consist of pebbly, silty sand and sandy silt. Locally sheetwash deposits are gradational and interfingered with colluvium on steeper hillslopes and with lacustrine or slackwater deposits in closed depressions. Maximum thickness of the unit is probably about 25 ft.

Qty

Younger terrace alluvium (late Pleistocene)— Chiefly stream alluvium underlying terraces that range from about 19 to 56 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 comprised of a variety of lithologies reflecting the diverse types of bedrock found in their drainage basins. Clasts are generally unweathered or only slightly weathered. Maximum thickness of the unit may locally exceed 100 ft, but is much thinner in other areas.

At the rest area on I-70 in West Glenwood Springs near Funston, the top of the unit is about 19 ft above the Colorado River and is overlain by a tufa deposit which includes an interbedded thin, 0.1- to 0.3-ft thick layer of organic-rich clayey sandy silt and peat. A conventional radiocarbon age of 12,410 ± 60 years BP was obtained on the peat (D. Trimble, 1995, written commun.; sample no. USGS-3544), providing a minimum age for this terrace. Unit includes deposits in terrace T7 in the Carbondale-Glenwood Springs area described by Piety (1981). It may also correlate with terrace A of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Bryant and others (1998) in the Storm King Mountain quadrangle. Unit Qty probably is equivalent to outwash deposited late during the Pinedale glaciation.

Qtm

Intermediate terrace alluvium (late Pleistocene) — Composed of stream alluvium underlying terraces about 58 to 95 ft above modern stream level. Locally, deposits of intermediate terrace alluvium are 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 locally are present. Clasts are chiefly subround to round and consist of various lithologies that reflect the types of bedrock found in their drainage basins. Clasts are generally only slightly weathered at shallow depths. Unit Qtm averages about 20- to 50-ft thick, with a maximum thickness of about 100 ft.

Intermediate terrace alluvium correlates with deposits in terrace T6 of the Carbondale-Glenwood Springs area of Piety (1981). It may correlate with terrace B deposits of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Bryant and others (2002) in the Storm King Mountain quadrangle. Unit Qtm probably is equivalent to outwash deposited early during the late Pleistocene Pinedale glaciation.

Qto

Older terrace alluvium (late middle Pleistocene) — Includes deposits of stream alluvium in terraces that range from about 110 to 160 ft above adjacent rivers. The unit occurs on the north side of the Colorado River near and west of Glenwood Springs, and also at the eastern edge of the quadrangle, and along the Roaring Fork River near the mouth of Threemile Creek. Older terrace alluvium was deposited as glacial outwash and is generally a clast-supported, cobble or pebble gravel in a sand matrix with occasional small boulders, but may range to a matrix-supported, gravelly sand or gravelly silt. Locally the unit includes thin, tufa-cemented gravel beds and also fine-grained overbank deposits. Clasts are chiefly subround to round, with varied lithologies that reflect the heterogeneous nature of the provenance area. Clasts are moderately weathered at shallow depths. In places, older terrace alluvium is overlain by older debris-flow deposits (unit Qdfo) or a prominent bed of tufa (unit Qtu). Unit Qto may interfinger with older debris-flow deposits (unit Qdfo) in West Glenwood Springs.

Unit Qto is tentatively correlated with terrace T5 in the Carbondale-Glenwood Springs area of Piety (1981), with terrace C of Bryant (1979) in the Aspen-Woody Creek area, and with older terrace alluvium of Bryant and others (1998), which probably are related to the late middle Pleistocene Bull Lake glaciation. Piety (1981) reported that snail shells collected from older terrace alluvium south of the Glenwood Springs quadrangle on the east side of the Roaring Fork River valley and north of Cattle Creek had amino acid ratios suggesting an age of 100 ± 80 ka. Unfortunately, the error margin for this date poorly constrains the age of the deposit. Exposed thickness of unit Qto is about 50 ft; its maximum thickness is estimated at about 130 ft.

Qtt **Oldest terrace alluvium (middle Pleistocene) —** Consists of a single deposit of stream alluvium west of the Glenwood Springs Municipal Airport that ranges from about 220 to 360 ft above the adjacent Roaring Fork River. Unit Qtt locally is overlain by older debris flow deposits (unit Qdfo). The unit is poorly to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix, and was deposited as glacial outwash. Locally unit Qtt includes thin lenses and beds of sandy silt and silty sand. Gravel clasts are commonly moderately to strongly weathered, even at considerable depth. Along with the overlying older debris-flow deposits (unit Qdfo), oldest terrace alluvium appears to have been deformed by evaporite diapirism. The deformation has altered the relative elevation difference between the older terrace deposits and the Roaring Fork River, which complicates assignment of even a relative age to this deposit. Piety (1981) tentatively mapped the remnant as a terrace T3 deposit and correlated it to deposits that contain the 639 ka Lava Creek B volcanic ash (Lanphere and others, 2002) in section 4, T. 8 S., R. 88 W. about 8 mi south-southeast of the quadrangle. Maximum thickness of unit Qtt is about 100 ft.

QTg **High-level gravel (early Pleistocene or Pliocene) —** Includes a single, very poorly exposed deposit of river gravel which caps a ridge on the south side of the Colorado River about 1,500 ft above river level near the north quarter corner of section 7, T. 6 S., R. 88 W. The deposit was recognized based on the presence of subrounded to rounded cobbles and pebbles of quartzite, granite, and pegmatite in float observed on the ground surface; the unit is not exposed. The high-level gravel probably was deposited by the ancestral Colorado River. Thickness of the unit is unknown.

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

Qlsr **Recent landslide deposits (latest Holocene)—** Includes materials deposited by active and recently active landslides with fresh morphological features, such as, ground fissures, scarps, ridges, hummocky ground, closed depressions, and water-saturated ground. Unit Qlsr consists of unsorted, unstratified rock debris, gravel, sand, silt, and clay. Recent landslide deposits near the southwest corner of the quadrangle occurred within the Mancos Shale or in landslide deposits (unit Qls) derived from the Mancos Shale. The recent landslide deposits along the former Red Hill ski hill developed in roadcuts into older debris-flow deposits (unit Qdfo), whereas those along Mitchell Creek formed when the stream eroded into the toe of landslide deposits (unit Qls) on the east side of the creek. Recent landslide deposits attain a maximum thickness of about 75 ft.

Qc **Colluvium (Holocene and latest Pleistocene)—** Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Colluvial deposits are usually coarser grained in the 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. Clast lithology is variable and dependent upon types of rocks on the slopes beneath and above the deposit. Locally the unit includes talus, landslides, sheetwash, and debris flows that are too small or too indistinct on aerial photography to be mapped separately. Colluvium grades to and interfingers with alluvium and colluvium (unit Qac), younger debris-flow deposits (unit Qdfy), and sheetwash deposits (unit Qsw) along some tributary drainages and hillslopes. Colluvial deposits locally are dissected by erosion where small drainages are advancing headward into bluffs at the toe of colluvial slopes. Maximum thickness of colluvium is estimated at 40 to 60 ft.

Qt **Talus (Holocene and late Pleistocene) —** Angular, cobbly and bouldery rubble on steep slopes that is derived from bedrock outcrops and is transported downslope principally by gravity as rockfalls, rockslides, rock avalanches, and rock topples. Talus generally is derived from well-indurated Precambrian and lower Paleozoic rocks or basalt. Locally talus lacks matrix material. Deposits mapped as talus may include alluvium and colluvium (unit Qac), particularly on narrow valley floors where talus is mapped on both sides of the valley floor. Areas delineated with a triangle pattern in No Name Creek indicate two very large deposits of talus that may have resulted from rapid rotational rockslides or large rock topples perhaps related to oversteepening of slopes due to stream erosion or glaciation. Talus attains a maximum thickness of about 80 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, geomorphologic features, such as, hummocky ground, lobate form, headscarps, and closed depressions. Unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Maximum thickness is probably around 250 ft, but landslide deposits usually are much thinner.

Qco **Older colluvium (Pleistocene) —** Erosional remnants of formerly more extensive colluvial deposits that occur on ridge lines, drainage divides, and dissected hillslopes on valley walls. Genesis, texture, bedding, and clast lithology are similar to that of colluvium (unit Qc). Unit Qco averages 10- to 25-ft thick.

Qlso **Older landslide deposits (Pleistocene) —** Includes landslide deposits deeply dissected by erosion that lack distinctive landslide morphologic features. Older landslide deposits are similar in texture, bedding, sorting, and clast lithology to landslide deposits (unit Qls). The type of landslide movement generally is not identifiable due to the eroded character of the deposits. Maximum thickness of older landslide deposits is estimated at about 60 ft.

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

Qdfy **Younger debris-flow deposits (Holocene) —** Sediments deposited by debris flows, hyperconcentrated flows, streams, and sheetwash on active fans and in stream channels. Younger debris-flow deposits range from poorly sorted to moderately well-sorted, matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble and cobble gravel in a sandy, clayey silt or silty sand matrix. The unit commonly is very bouldery, particularly near fan heads. Distal parts of some fans are characterized by mudflow and sheetwash and tend to be finer grained. Younger debris-flow deposits are locally interfingered or interbedded with modern alluvium adjacent to perennial stream channels. Clasts are mostly angular to subround sedimentary rock and basalt fragments up to about 6 ft in diameter. Original depositional surfaces are usually preserved, except where they have been disturbed by human activities. Maximum thickness of the unit possibly is as much as 120 ft.

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

Qdfm **Intermediate debris-flow deposits (Holocene and late Pleistocene) —** Similar in texture and depositional environment to younger debris-flow deposits (unit Qdfy). The geomorphic character of original depositional surfaces on intermediate debris-flow deposits is commonly recognizable, but the surface is topographically about 20 to 40 ft above active debris-flow channels.

Qaco **Older alluvium and colluvium, undivided (Pleistocene) —** Includes deposits of alluvium and colluvium that underlie terraces and hillslopes 10 to 60 ft above adjacent small perennial, ephemeral, and intermittent streams. Texture, bedding, clast lithology, sorting, and genesis of unit Qaco are similar to unit Qac. Locally, unit Qaco includes debris-flow and sheetwash deposits. Maximum thickness of unit Qaco is about 30 ft.

Qdfo

Older debris-flow deposits (Pleistocene) — Occurs on ridglines and mesas as remnants of formerly extensive debris fans deposited by tributaries to both the Roaring Fork and Colorado Rivers. Older debris-flow deposits are genetically, texturally, and lithologically similar to younger debris-flow deposits (unit Qdfy), although they can be very calcareous. Boulders in unit Qdfo may exceed 5 ft in diameter. Older debris-flow deposits locally include thin interbeds of tufa and tufa-cemented gravel near West Glenwood Springs. Original depositional surfaces on the unit are locally preserved and may be mantled with loess, but at other locations the deposits are deeply eroded and now geomorphically resemble the valley-wall topography developed on bedrock. Elevation differences between the original depositional surfaces and adjacent modern drainages range from about 40 to 320 ft. Thickness of unit Qdfo is generally about 30 to 60 ft, but locally it may exceed 160 ft.

Older debris-flow deposits west of the Glenwood Springs Municipal Airport at the mouth of Fourmile Creek have been deformed by evaporite diapirism. This locality underlies the northern boundary of an evaporite diapir (Mallory, 1966, 1971; Kirkham, Streufert, and others, 2001; Kirkham, Streufert, and others, 2002).

GLACIAL DEPOSITS — Gravel, sand, silt, and clay deposited by, adjacent to, or beneath ice in moraines.

Qm

Morainal deposits (late and late middle Pleistocene) — Heterogeneous deposits of gravel, sand, silt, and minor clay deposited by, adjacent to, or beneath ice in lateral, end, and ground moraines in the northwest corner of the quadrangle in Dry Possum Creek and in two tributaries to Mitchell Creek. The unit is dominantly unsorted or poorly sorted, unstratified or poorly stratified, matrix-supported bouldery, pebble and cobble gravel with a matrix of silty sand. Morainal deposits may locally be clast-supported where composed mostly of gravel. Clasts within this unit typically are angular to round pieces of Precambrian and lower Paleozoic bedrock that occasionally exceed 10 ft in length. The unit may include glaciofluvial deposits.

End and lateral moraines are commonly hummocky, steep-sided, and bouldery. Moraine crests are moderately well preserved, but the outermost lateral moraine on east side of Dry Possum Creek is weathered and its crest is rounded, suggesting it is older than other morainal deposits in the quadrangle. The lower limit of glaciation is at an altitude of about 9,400 ft. Stream erosion has created narrow breaches in the terminal moraines in both tributaries of Mitchell Creek, whereas the terminal moraine in Dry Possum Creek has been modified considerably by stream erosion. Although morainal deposits are not mapped along No Name Creek, glaciers may have extended into the quadrangle for about one mile down the creek from the northern boundary of the quadrangle. This conclusion is based on the geomorphic character of the canyon and the presence of till in the valley of No Name Creek immediately north of the quadrangle. The unit probably is in part equivalent to deposits of the late Pleistocene Pinedale glaciation. Some of the outermost moraines, particularly those in Dry Possum Creek, are probably equivalent to deposits of the Bull Lake glaciation, or perhaps are even older. Maximum thickness of unit Qm is estimated at about 240 ft.

LACUSTRINE DEPOSITS — Sediments deposited in lakes.

Ql

Lacustrine deposits (Quaternary) — Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, reddish-brown, well-sorted, fine to coarse sand, and volcanic ash in Spring Valley. Unit is very poorly exposed except in a depression excavated through the water table to provide for stock watering in the SW1/4 NW1/4 of section 29, T. 6 S., R. 88 W. A drill hole in adjacent Shoshone quadrangle penetrated about 570 ft of unit Ql without encountering bedrock (Robin Verschneider, 2001, oral commun.). From a depth of about 250 to 300 ft, the drilled sediments were rich in volcanic ash that was identified as the Lava Creek B ash by A. Sarna, (2002, written commun.); the ash is dated at 639 ka (Lanphere and others, 2002).

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

EOLIAN DEPOSITS — Silt, sand, and clay deposited by wind.

Qlo

Loess (late and middle? Pleistocene)—Slightly clayey, sandy silt and silty, very fine to fine sand deposited and preserved on level to gently sloping surfaces. Typically loess is unstratified, friable, and plastic or slightly plastic when wet. Sand grains within the loess are sometimes frosted. Thickness of the unit ranges from about 5 to 12 ft. Loess deposition occurred during at least two periods of eolian activity. Bryant and others (1998) mapped a single sheet of loess on deposits equivalent to younger and intermediate terrace alluvium (units Qty and Qtm) in the Storm King Mountain quadrangle immediately west of the Glenwood Springs quadrangle, but mappable deposits of loess (minimum thickness of 5 ft) were not identified overlying these units in our map area. At least one and perhaps multiple sheets of loess overlie older debris-flow deposits (unit Qdfo) which rest on older terrace deposits (unit Qto) near West Glenwood Springs. In the southeast part of the quadrangle two or more sheets of loess locally overlie basalt and the Maroon Formation. The mapped distribution of loess is very approximate due to the poor geomorphic expression of loess.

SINTER DEPOSITS — Chemical sediment deposited by a mineral spring.

Qtu

Tufa (Holocene and Pleistocene?) — Low-density, porous chemical sedimentary rocks consisting of calcium carbonate precipitated from mineral-charged spring, ground, and surface water. Tufa occurs as massive ledges and as a gravel-cementing material north of the Colorado River in and near West Glenwood Springs. An approximately 0.6-mile-long bed of tufa below the Glenwood Springs golf course forms a prominent, continuous outcrop that caps older terrace alluvium (unit Qto). Much of this ledge is resistant to erosion and forms near vertical outcrops, but in other areas tufa is easily eroded. At one locality a roadcut into tufa has been protected by a thin layer of reinforced concrete grout to reduce spalling problems. Another ledge of tufa overlies older debris-flow deposits (unit Qdfo) in lower Oasis Creek. A bed of tufa beneath the rest area on Highway I-70 in West Glenwood Springs near Funston includes an organic-rich layer of clayey, sandy silt and peat. The peat yielded a radiocarbon age of 12,410 ± 60 years BP (D. Trimble, 1995, written commun.; sample no. USGS-3544). Small, unmapped, discontinuous areas of tufa-cemented gravel were noted within both older debris-flow deposits (unit Qdfo) and older terrace alluvium (unit Qto) near the mouth of Oasis Creek and in adjacent areas. Tufa deposits also occur near Hobo hot springs in the SW1/4 SW1/4 section 4, T. 6 S., R. 89 W.

Tufa deposition is associated with both cold-water and hot-water springs. A cold-water spring with small active tufa mound occurs in Mitchell Creek above the Glenwood Springs fish hatchery. Thermal waters were encountered during 1993 in excavations for homes at the base of the prominent tufa ledge west of Glenwood Springs (location indicated on map as a thermal spring). Tufa deposition may have initiated during the Pleistocene and has continued at one or another location intermittently to the present.

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q

Surficial deposits, undifferentiated (Quaternary) — Shown only on cross sections. The unit may include any of the previously described surficial deposits.

BEDROCK

Tb

Basalt (Miocene) — Multiple flows of basalt, trachybasalt, and basaltic andesite. In places the unit includes slightly indurated sediments which range from rounded pebble and cobble gravel to slightly gravelly silt. Petrographically most flows are olivine basalt; many are porphyritic. Flow rocks range from massive to highly vesicular and locally contain amygdules of calcite, iron-rich clay, and zeolites. Groundmass of the flows is predominantly plagioclase and pyroxene, with lesser amounts of olivine, glass, pigeonite, augite, and magnetite. Accessory minerals include apatite, iddingsite, and hematite. Phenocrysts are chiefly olivine and less commonly plagioclase. Unit may contain rare xenocrysts or xenoliths of quartz or quartzite. Individual flows commonly are 5 to 25-ft thick. Maximum thickness of the entire sequence of flows is around 240 ft, but it generally is 20 to 40 ft.

A sequence of interbedded pebble and cobble gravel, silty sand, and sandy silt that is strongly oxidized at the base of the exposure apparently overlies basalt in a small gravel pit in the N1/2 N1/2 NE1/4 section 30, T. 6 S., R. 89 W. It contains abundant, well rounded clasts of granodiorite, quartz monzonite, and granite, many of which are grussified. The percentage of basaltic clasts increases from zero at the base of exposure to about 30 percent in the upper unit exposed in highwall. B. Bryant (1994, oral commun.) believes part of the clasts were derived from middle Tertiary rocks in the Aspen area, suggesting the existence of an ancestral Roaring Fork River valley at this location. Scattered rounded clasts consisting of quartzite and other Precambrian lithologies suggest mainstem fluvial deposits underlie the basalt flows northwest of Spring Valley near where sample K97-10-8B was collected.

Based on regional studies of the basaltic rocks by Unruh and others (2002) and Kunk and others (2002), the flows are included in five geochemical groups that range from about 22.6 to 7.77 Ma. Refer to a following section on the age and correlation of the basaltic rocks for additional information. Steep cliffs of basalt are a source of rockfall debris. Basalt may be very difficult to excavate and require blasting. Matrix-supported interflow sediments are prone to landsliding.

Ti

Porphyritic intrusion (Tertiary?) — Brown to red-brown, fine-grained, porphyritic rock that crops out on the saddle on the drainage divide between Grizzly Creek and No Name Creek. Contains conspicuous 0.5 to 1.0-inch-long, euhedral, white plagioclase phenocrysts, black opaque anhedra less than 0.04 inches long, and relict twinned and zoned phenocrysts. Plagioclase phenocrysts are altered and partially replaced by a fine-grained crystal aggregate (sericite). One sample of the porphyritic intrusion was chemically analyzed (sample 52-06; Appendix A). It contained 64.5 % SiO_2 and 9.3 % total alkali ($K_2O + Na_2O$) and plots in the trachyte/trachydacite field of a TAS diagram. However, available data suggest that the high concentration of alkali elements could be the result of alteration and that the unit could be an altered dacite. The unit appears to be in intrusive contact with the surrounding gneiss, but there is no evidence of contact metamorphism. On the basis of similarities with widespread hypabyssal intrusive porphyries elsewhere in Colorado the unit is tentatively assigned a Tertiary age.

Kmv

Mesaverde Group (Upper Cretaceous) — Shown only on cross section A–A′.

Km

Mancos Shale (Upper Cretaceous)—Includes in ascending order from its base a lower member, Niobrara member, and upper members. The lower member of the Mancos Shale is dominantly dark-gray shale about 300 to 400 ft that is overlain by about 100 ft of interbedded sandstone, siltstone, and shale thought to correlate with the Juana Lopez Member of the Mancos Shale (Bryant and others, 1998). Sandstone beds in this part of the unit contain pelecypod fossils. The Niobrara Member con-sists of about 125 to 200 ft of calcareous shale, shaly limestone, and light-gray limestone. The upper member is about 4,200-ft thick and consists chiefly of light- to dark-gray, carbonaceous shale that contains thin bentonite beds and concretions.

The Mancos Shale is very poorly exposed in the mapped area and frequently is covered by residuum, colluvium, landslides, sheetwash, or basalt, which prevented us from mapping each of the members as separate units in the quadrangle. Deposition occurred primarily on the continental slope in low-energy depositional environments.

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 commonly are well sorted and silica cemented, and have angular to subrounded sand grains. Conglomeratic clasts in the formation are generally pebble-sized chert and quartz. The Dakota Sandstone includes one to three fairly continuous sandstone beds that occasionally are overlain by lenses of conglomeratic sandstone which are prominent on aerial photographs. Thickness of the formation ranges from about 90 to 175 ft. The

Dakota Sandstone is conformable with and perhaps intertongues with the overlying lower member of the Mancos Shale. The upper contact of the Dakota is placed at the top of the uppermost quartzose sandstone beneath the Mancos Shale. The formation is generally well exposed, and it frequently forms conspicuous cliffs. The formation locally crops out along the Grand Hogback to the west of the quadrangle as a window of steeply dipping sandstone surrounded by basalt flows. 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 and maroon mudstone and shale with thin beds of silty sandstone in the lower part of the formation that may be equivalent to the Salt Wash Member in nearby areas (Murray, 1966). The Morrison Formation includes thin, gray limestone beds up to about 10-ft thick. The limestone beds contain abundant specimens of Charophyta (Peck, 1957). Thickness is of the Morrison is variable, but it averages about 400 to 500 ft. The formation is very poorly exposed in the mapped area and frequently is covered by residuum, colluvium, sheetwash, or basalt. The contact is with the overlying Dakota Sandstone is sharp and unconformable, but is difficult to precisely locate except where well exposed. The contact is placed at the base of the lowest quartzose sandstone and carbonaceous beds in the Dakota Sandstone. The Morrison Formation was probably deposited in a lacustrine-dominated fluvio-lacustrine environment.

Je

Entrada Sandstone (Upper Jurassic) — Light-gray to light-orange, cross-bedded, medium- to very fine-grained, well-sorted sandstone. Sand grains within the formation are mostly subrounded to well-rounded quartz grains. The contact with the overlying Morrison Formation is sharp and conformable. Thickness of the Entrada Sandstone averages about 50 to 100 ft, but it may vary significantly over a short distance. The formation is poorly exposed in the quadrangle. The Entrada Sandstone occasionally forms small outcrops, but commonly the formation is covered by residuum, colluvium, sheetwash, or basalt. Cross-bed sets are large-scale and usually are interpreted as resulting from eolian processes in extensive dune fields. The basal few inches of the Entrada may include pebbles and very coarse sand comprised of chert and quartz thought to have accumulated as an eolian lag deposit on the Chinle Formation.

TRc

Chinle Formation (Upper Triassic) — Thin, even-bedded, and structureless red beds consisting 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. An excellent exposure of the Chinle Formation is in South Canyon Creek about 2 miles west of quadrangle. It was described by Stewart and others (1972a) as including the 208-ft thick upper Chinle Red Siltstone Member and a 17-ft thick basal unit correlated with the lower Chinle Mottled Member. Dubiel (1992) recognized a very thin, basal sandstone in the Chinle Formation along South Canyon Creek and correlated it with the Gartra Member. He stated that con-tacts between the Gartra Member and mottled strata are gradational, as is the contact between the mottled strata and the overlying red siltstone.

The Chinle Formation is very poorly exposed in the quadrangle. It is partially exposed in a roadcut in the canyon of Threemile Creek, but is covered by residuum, colluvium, sheetwash, or basalt in other areas. Total formation thickness is about 225 ft in South Canyon Creek, but appears to be much thinner in the exposure along Threemile Creek. The contact with the overlying Entrada Sandstone is sharp and unconformable. Dubiel (1992) suggested the upper Chinle red siltstone beds are lateral-accretion and flood-plain deposits, while the basal conglomerate and sandstone of the Gartra Member were deposited as active channel-fill and valley-fill deposits. Numerous paleosols occur within the formation.

TRPsb

State Bridge Formation (Lower Triassic? and Permian) — Pale-red, grayish-red,reddish-brown, and greenish-gray, micaceous siltstone, clayey siltstone, shale and minor sandstone with a prominent, thin bed of sandy dolomite and sandy limestone. Bass and Northrup (1950) named the carbonate bed the South Canyon Creek Dolomite Member and included it in the Maroon Formation. Murray (1958) proposed that the South Canyon Creek Dolomite Member of the Maroon Formation be included within the State Bridge Formation. Stewart and others (1972b) also included the South Canyon Creek Dolomite in the State Bridge Formation and used it to divide the

State Bridge Formation into three members: an upper member and lower member separated by the South Canyon Creek Member.

The formation is very poorly exposed in the quadrangle, but an excellent exposure can be seen along South Canyon Creek about 2 miles west of the quadrangle. At this location, Stewart and others (1972b) indicated the upper member is 55.6-ft thick, the South Canyon Creek Member is 5.6-ft thick, and the lower member is 98.5-ft thick, yielding a total for-mation thickness of 159.7 ft. They described the South Canyon Creek Member as including a 4-ft thick, greenish-gray to light-olive gray dolomite and a 1.6-ft thick, light- to dark-gray limestone (color is dependant on amount of solid hydrocarbon) with prominent wavy or crinkled laminae. Bass and Northrop (1950, 1963) collected fossils from the South Canyon Creek Member that were of Permian age and suggested the wavy structure indicated an algal origin. The upper and lower members of the State Bridge Formation are dominantly pale-red and grayish-red siltstone with minor claystone and sandstone. The only exposure of the State Bridge Formation within the quadrangle is in an exposure in a roadcut in the canyon of Threemile Creek. At this location, the formation is either very thin (less than about 50-ft thick) or is partially removed by an unrecognized fault. The South Canyon Creek Dolomite Member was not observed at this locality.

The contact with the overlying Chinle is unconformable (Freeman, 1971a), but it is often difficult to accurately locate unless the Gartra Member of the Chinle is present. The top of the upper member of the State Bridge coincides with the base of the Gartra Member or with the base of the Mottled Member if the Gartra is absent. There usually is a distinct color change from the orange-red color of the Mottled Member of the Chinle to the brick-red and gray-red colors of the upper State Bridge. According to Bryant (1979) parallel oscillation ripple marks are diagnostic of the State Bridge Formation. The formation abruptly thickens south and east of the Glenwood Springs-El Jebel area (Freeman, 1971a, b). The State Bridge Formation was probably deposited chiefly in a fluvio-lacustrine environment that was dominated by lacustrine processes; however, the South Canyon Creek Member suggests a short-lived encroachment of an environment favorable for carbonate deposition.

PIPm

Maroon Formation (Lower Permian and Pennsylvanian) — Mainly red beds of sandstone, conglomerate, mudstone, siltstone, and claystone with minor, thin beds of gray limestone. At the top of the Maroon Formation is the Schoolhouse Member (Johnson and others, 1990), which previously was called the Schoolhouse Tongue of the Weber Sandstone (Bass and Northrop, 1963; Stewart and others, 1972b). Conglomerate beds in the Maroon Formation contain subangular to rounded pebble- and cobble-sized clasts of quartz, feldspar, and granitic rock fragments. The unit commonly is arkosic and very micaceous. The Schoolhouse Member consists of light-gray to greenish-black, grayish-red, and pale-reddish-brown, fine-grained, feldspathic sandstone and conglomeratic sandstone that contain locally abundant interstitial and grain coatings of solid hydrocarbon. Marcasite nodules are occasionally present in the middle of Schoolhouse Member. Total thickness of the formation is about 3,000 to 4,000 ft, including the 150- to 175-ft thick Schoolhouse Member.

Red beds of the Maroon Formation crop out in the southwestern part of the quadrangle and are particularly well exposed on the valley walls of the Roaring Fork River. Exposures are generally poor near Lookout Mountain. The Schoolhouse Member is typically poorly exposed in the quadrangle, except in a roadcut along Threemile Creek where it is partially exposed. The contact with the overlying State Bridge Formation is sharp; it is placed where the light-colored beds of the Schoolhouse Member are overlain by the red beds of the State Bridge. Johnson and others (1988) suggested the contact is an angular unconformity. The Maroon Formation was deposited in fluvial and perhaps eolian environments in the Central Colorado Trough between the ancestral Front Range and Uncompahgre Highlands.

IPe

Eagle Valley Formation (Middle Pennsylvanian) — Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, 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 dominantly evaporitic rocks of the Eagle Valley Evaporite. The unit includes rock types of both formations. Thickness is variable, ranging from about 500 to 1,000 ft. The formation is generally poorly exposed, but appears to be conformable and intertonguing with the overlying Maroon Formation and underlying Eagle Valley Evaporite. The contact with Maroon Formation is placed at the top of the uppermost evaporite bed or light-colored clastic bed below the thick sequence of red beds. The Eagle Valley Formation was deposited in the Eagle Basin on the margin of an evaporite basin at the distal end of a coalescing alluvial fan complex and in a submarine environment within the evaporite basin.

IPee

Eagle Valley Evaporite (Middle Pennsylvanian) — Sequence of evaporitic rocks consisting of massive to laminated gypsum, anhydrite, halite, and beds of light-colored mudstone and fine-grained sandstone, thin limestone and dolomite, and black shale. The Eagle Valley Evaporite may include eolian deposits similar to those reported 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. The formation is generally poorly exposed except in recent alluvial cuts, man-made exposures, and stacks, which are unique chimney-like landforms that are locally well developed west of Roaring Fork River. Stacks are typically composed of yellowish-brown, calcareous sandstone breccia and sandy limestone breccia cemented by orangish-yellow to greenish-yellow-brown calcareous siltstone, sandstone, and claystone.

Total thickness of the Eagle Valley Evaporite ranges from about 1,200 to perhaps as much as 9,000 ft (Mallory, 1971) where it is tectonically thickened along the axis of the Cattle Creek Anticline. Presence of a thick halite sequence near the mouth of Cattle Creek on the adjacent Cattle Creek quadrangle was reported by Mallory (1966) on the basis of the Shannon Oil Company Rose No. 1 well, which encountered 60 ft of alluvial gravel, 2,065 ft of gypsum, anhydrite, and siltstone, and 935 ft of predominantly halite (unpublished lithologic log by American Stratigraphic Company). Drilling stopped in halite; therefore the total thickness of the halite and the formation is unknown. The well was spudded near the axis of the Cattle Creek Anticline, a Laramide structure that has been modifed by salt flowage and diapirism during the Neogene.

The contact with the overlying Eagle Valley Formation is both conformable and intertonguing, and it is placed at 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 that formed as the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1987) recognized multiple transgressive-regressive sedimentary cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment rather than in a sabkha.

IPeu

Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian) — Includes the Eagle Valley Formation and Eagle Valley Evaporite on the south wall of Glenwood Canyon where heavy forest cover and a thick veneer of surficial deposits obscure the contact between units. Thickness is highly variable, but averages about 2,000 ft.

IPb

Belden Formation (Lower Pennsylvanian) — Predominantly gray to black, calcareous shale and fossiliferous gray limestone with minor beds of fine- to medium-grained, micaceous sandstone, micaceous siltstone, and a few beds of faintly cross-bedded arkose. The Belden Formation contains thin beds of gray to brown and black chert in the very lowermost part of unit. It may contain discontinuous and localized beds of evaporite which can occur anywhere in the formation. The upper portions of the unit include intertonguing beds of coarse-grained clastic rocks that are thought to be equivalent to the Minturn Formation. These intertonguing beds of lithic wacke and subarkose near the top of the Belden Formation are well exposed to the northeast in the Dotsero quadrangle (Streufert and others, 1997). Sediments of the Belden Formation were deposited in a low-energy marine environment at a distance from their source over a widespread area in the Central Colorado Trough between the Ancestral Uncompahgre and Front Range Highlands. Strata equivalent to the Minturn Formation were most likely deposited in a series of coalescing alluvial fans, the distal ends of which intertongue with rocks of the Belden Formation. The unit is approximately 500 to 750-ft thick across the map area.

Ml

Leadville Limestone (Mississippian)—Light- to medium-gray, bluish-gray, massive, coarsely to finely crystalline, fossiliferous micritic, limestone and dolomite. The lower one-third of the Leadville Limestone contains lenses and nodules of dark-gray to black chert as much as 0.3-ft thick. The upper half of the formation contains coarse-grained oölites. Carbonate veins with disseminated silt-sized quartz grains are common. The top of the unit contains collapse breccias, filled solution cavities, and a red to reddish-purple claystone regolith (elsewhere mapped as the Molas Formation), all of which formed on a paleokarst surface. The Leadville Limestone is very fossiliferous, with abundant crinoid and brachiopod fragments. It forms a prominent cliff and is frequently the caprock of outcrops within Glenwood Canyon and its tributary canyons. The upper contact is irregular and unconformable with the overlying Belden Formation. The unit is about 200-ft thick across the study area. It formed in a marine environment in the sub-littoral zone by chemical precipitation and through the accumulation of biogenic and oölitic sediment.

Dc

Chaffee Group (Upper Devonian)—Sequence composed of green shale, quartzite, dolomite, limestone, and dolomitic sandstone. It consists of three named formations which from top to bottom are the Gilman Sandstone, Dyer Dolomite, and Parting Formation. Total thickness of the Chaffee Group in Glenwood Canyon is 252.5 ft (Soule, 1992).

The **Gilman Sandstone** consists of tan to yellow, laminated, fine- to very fine-grained quartz arenite and dedolomitic limestone. It is variable in lithology and thickness across the study area. On the southeast flank of the White River Uplift the Gilman is predominantly a 16-ft thick calcareous sandstone. It becomes an oxidized dolomite (dedolomite) with thickness less than 1 ft near Glenwood Springs. The sandstone phase consists of round to subround quartz grains which are well sorted. Laminae are generally less than 1 inch in thickness and consist of zones of fine sand which locally display weak planar-tabular cross-bedding and minor load structures. Some laminae contain discontinuous lenses of quartz arenite with visible relict casts of carbonate rhombohedron. Limestone beds in the Gilman consist of a greater than 99 percent pure calcite-bearing dedolomitic limestone with minor hematite and quartz. Contact with the overlying Mississippian Leadville Limestone is unconformable. Tweto and Lovering (1977) suggest a water reworked, eolian origin for the Gilman Sandstone near Gilman. Most likely it was deposited in a changing environment of very shallow water and periodic subaerial exposure in the supratidal (tidal flat) zone.

The **Dyer Dolomite** is divided into two members on the White River Plateau, an upper Coffee Pot Member and a lower Broken Rib Member. The Coffee Pot Member consists of crystalline, micritic dolomite, dolomitic gray shale, and micritic limestone. It is somewhat sandy, especially near the top, and is fossiliferous in places. The Coffee Pot Member is characterized by abundant rip-up clasts, intraformational breccia, and bioturbated bedding (Soule, 1992). Together with the Gilman Sandstone it forms blocky slopes beneath the prominent cliff of overlying Leadville Limestone in canyon outcrops. It was deposited predominantly in the uppermost intertidal to supratidal (tidal flat) zones in a changing environment of periodic subaerial exposure with influxes of shallow marine conditions. The Broken Rib Member consists of gray, nodular, crystalline limestone. The Dyer Dolomite is abundantly fossiliferous, dominantly brachiopods (Bass and Northrop, 1963). It forms a very distinctive “knobbly-weathering” gray ledge above blocky slopes of the underlying Parting Formation in canyon outcrops. The Dyer Dolomite formed in a shallow marine environment in the sub-littoral zone.

The **Parting Formation** is variable in lithology across study area. In Glenwood Canyon it consists of white to buff, well-cemented orthoquartzite with minor feldspar and rock fragments, micaceous green shale with discontinuous lenses of orthoquartzite, and sandy micritic dolomite. The formation contains limestone breccia and sandy, green shale on the north end of the quadrangle in the vicinity of Windy Point. Thicknesses of orthoquartzite beds are consistent across study area, ranging from 0.5 to 1.0 ft. Other beds show much greater variation in thickness. The Parting Formation forms a blocky slope with distinct ledges above the prominent cliffs of the underlying Manitou Formation. Bass and Northrop (1963) collected fish fossils from the Parting in Glenwood Canyon. It formed in a shallow marine environment.

MDr **Mississippian and Devonian rocks, undivided (Mississippian and Upper Devonian) —** Includes rocks of the Leadville Limestone and Chaffee Group where it is not practicable to separate formations due to poor outcrop exposure, inaccessibility, or poorly defined marker horizons. Thickness of the combined unit is about 450 ft.

Om **Manitou Formation (Lower Ordovician) —** Consists predominantly of medium-bedded brown dolomite at the top, with thin beds of gray flat-pebble limestone interbedded with greenish-gray calcareous shale, sandstone, and brown-weathering limestone and dolomite in the lower portions. In Glenwood Canyon the unit is 155.8-ft thick according to Bass and Northrop (1963) and 167.3-ft thick as measured by Soule (1992).

The upper or **Tie Gulch Member** consists of massive, micritic, brown and orange-weathering, crystalline, somewhat siliceous dolomite and minor limestone. It becomes somewhat sandy near the top. The Tie Gulch Member forms a consistent 50- to 90-ft thick, brown- to orange-colored cliff which rises distinctly above a gentler slope produced on the lower Manitou and Dotsero Formations in Glenwood, No Name, and Grizzly Canyons. Some beds are glauconitic although considerably less so than the underlying beds of the Dead Horse Conglomerate Member. No fossils are known to occur in the Tie Gulch Member. Contact with the overlying Devonian Chaffee Group is unconformable, occurring at a thin shale bed which may be the remains of a paleosol (Soule, 1992). Strong dolomitization and a lack of marine fossils suggest that sediments of the Tie Gulch Member accumulated in the upper intertidal and/or lowermost supratidal (tidal flat) environments.

The lower or **Dead Horse Conglomerate Member** consists mostly of thin-bedded, gray, flat-pebble limestone conglomerate, thin-bedded limestone, shaly limestone, and two beds of massive dolomitic orthoquartzite. It is somewhat glauconitic, especially in the bottom portion. A diverse Lower Ordovician fossil fauna was collected from the member by Bass and Northrop (1963) in Glenwood Canyon. The base of the member generally forms a continuous slope with the underlying rocks of the Dotsero Formation. In Glenwood, No Name, and Grizzly Canyons, the upper portions of the member frequently form an unbroken cliff that includes the overlying rocks of the Tie Gulch Member, rendering close inspection of the upper contact difficult. The Dead Horse Conglomerate Member most likely was deposited under fluctuating conditions and varying water depths in the intertidal and shallow marine environments.

Ꞓd **Dotsero Formation (Upper Cambrian) —** Includes four units, which in descending order are the Clinetop Bed, Glenwood Canyon Member, Red Cliff Member, and Sheep Mountain Member (Myrow and others, 2003). The uppermost unit is a 5-ft thick sequence of matrix-supported limestone-pebble conglomerate with abundant rip-up clasts and an overlying bed of stromatolitic limestone with well-preserved algal-head crinkle structure that is now called the **Clinetop Bed** (Myrow and others, 2003). The **Glenwood Canyon Member** consists of approximately 50 ft of thin-bedded dolostone, dolomitic sandstone, conglomeratic limestone, coarse-grained fossiliferous limestone, and dolomitic shale. Dolomitic beds in the Glenwood Canyon Member are glauconitic, giving the beds a greenish hue. Worm tracks and worm burrow (fucoids) are common, especially in the middle third of the member.

The **Red Cliff Member** is composed of approximately 22 ft of sandy dolostone, flat-pebble conglomerate, and dolomitic shale. It is locally glauconitic and/or bioturbated. Although it is a distinct member east of the quadrangle, the contact between the Red Cliff Member and overlying Glenwood Canyon Member is much less distinct within the quadrangle (Myrow and others, 2003). The basal unit of the Dotsero Formation is the **Sheep Mountain Member**, which rests on the white quartz-rich Sawatch Formation. The member consists of 5 to 6 ft of light-brown, very fine- to medium-grained, glauconitic, well-sorted sandstone and local dolomitic flat-pebble conglomerate.

The Dotsero Formation generally forms a vegetated slope above the prominent cliffs of the Sawatch Formation. However, beds within it can form cliffs, especially in the deeper portions of Glenwood, No Name, and Grizzly Canyons. The entire formation is about 80 ft thick. Variation in lithologies and sedimentary structures in the formation indicate a period of widely fluctuating depositional patterns ranging from near-shore shallow marine through intertidal to supratidal (tidal flat) environments.

€s

Sawatch Formation (Upper Cambrian) — White and buff to gray-orange, brown-weathering, vitreous quartz arenite in beds from 1 to 3-ft thick. Locally, the base of the Sawatch Formation contains beds of arkosic quartz-pebble conglomerate that rest unconformably on highly weathered Precambrian rocks. Basal hematite-stained, planar to tabular cross-bedded sandstone interbedded with quartz arenite is also present in the map area. The middle part of the formation includes beds of massive, brown, sandy dolomite, and white dedolomitic quartzite. Fossils are extremely rare to non-existent in this formation. Total thickness of the formation is about 500 ft. Primary sedimentary structures are poorly preserved in the Sawatch Formation. The formation most likely was deposited in a beach environment or in shallow water of the littoral zone, and it consists of sediment eroded off a highland in the vicinity of the Front Range (Tweto and Lovering, 1977).

O€r

Ordovician and Cambrian rocks, undivided (Upper Cambrian and Lower Ordovician) — Includes rocks of the Sawatch Formation, Dotsero Formation, and Manitou Formation where it is not practicable to separate these rocks due to poor exposure, inaccessibility, or poorly defined marker horizons. The combined unit is about 745 ft in thickness.

Xp

Pegmatite (Paleoproterozoic) — Two varieties of pegmatite were observed in the quadrangle. Both types are included in this unit. The most abundant variety, pink pegmatite, is a coarse- to very coarse-grained rock composed of potassium feldspar, quartz, and plagioclase, with variable amounts of muscovite and biotite. Pink pegmatite is widespread and especially abundant as concordant tabular bodies within the Grizzly Creek Shear Zone. The second variety, white pegmatite, consists mainly of subequal proportions of quartz and white plagioclase, with 0.5–1.0 inch-wide books of muscovite and garnet crystals ranging in diameter from 0.04–0.4 inches. Biotite, tourmaline, and specular hematite are rare accessory minerals, and potassium feldspar may be locally present. Outcrops of white pegmatite exist in the upper parts of the No Name and Grizzly Creek drainages.

Xmg

Megacrystic granite (Paleoproterozoic) — Megacrystic granite is characterized by a distinctly bimodal grain size. A coarse-grained salt-and-pepper matrix is composed 0.2–1.0-inch-long anhedral crystals of gray quartz, white plagioclase, and gray-pink orthoclase, with abundant black biotite that constitutes up to 20 percent of the matrix. In the southwestern part of its outcrop extent, the unit is granodiorite in composition. Blocky tabular phenocrysts of pink orthoclase about 2–4 inches long account for up to 20 percent of the volume of the rock. Locally, alignment of the phenocrysts defines a NW-striking magmatic foliation. Evidence for solid state deformation is apparent near the Grizzly Creek Shear zone where phenocrysts are stretched and drawn out into irregularly shaped augen. Near the shear zone, orthoclase is highly altered into a fine-grained micaceous aggregate. Megacrystic granite from the quadrangle yielded a preliminary $^{207}Pb/^{206}Pb$ age of 1,741 ± 10 Ma (unpublished data; sample J06-GC2). The granite shows discordant, intrusive relationships into the older mica schist and gneiss unit.

Xfg

Fine-grained granodiorite (Paleoproterozoic) — Dark-pink to gray, fine- to medium-grained, equigranular granodiorite and granite. Primary constituents are anhedra of plagioclase, microcline, and perthite, and variably strained anhedra of quartz. Accessory minerals include interstitial biotite and hornblende. The granite is variably foliated with a prominent sub-solidus fabric developed adjacent to the Grizzly Creek Shear Zone. The unit occurs in the hanging wall of the Grizzly Creek Shear Zone in the canyon of No Name Creek. A preliminary $^{207}Pb/^{206}Pb$ age of 1,743 ± 8 Ma was obtained from a relatively undeformed sample of the fine-grained granite (unpublished data; sample J06-GC1). A sample of foliated fine-grained granite yielded discordant ages of 1,935-1,760 Ma (unpublished data), which is interpreted to be the ages of inherited zircons. These ages suggest the fine-grained granite is essentially coeval with the megacrystic granite (unit Xmg). The fine-grained granite locally shows discordant, intrusive relationships into the older mica schist and gneiss unit.

Xbg

Biotite granite (Paleoproterozoic) — Gray- and white-speckled, medium-grained granite. Primary constituents are anhedra of sodium-rich plagioclase, microcline, perthite, and quartz. Accessory minerals include interstitial biotite and hornblende. Trace minerals are magnetite, apatite, sphene, epidote, chlorite, and zircon. Mafic xenoliths up to 1 ft in diameter are common in the granite. The biotite granite crops out near the mouth of Grizzly Creek in the footwall of the Grizzly Creek Shear Zone. It is well-jointed and contains numerous thin, unmapped, dikes and sills of white to pink pegmatite.

Xg

Granite of Mitchell Creek (Paleoproterozoic) — Dominantly light-red to pink, fine- to medium-grained, equigranular, foliated granite and quartz monzonite. Anhedra of microcline, microperthite, plagioclase, and severely strained, irregular-shaped anhedra of quartz are the primary constituents. Quartz also occurs as chains of small blebs within microshears. Biotite, commonly replaced by chlorite, and muscovite are accessory minerals. The muscovite chiefly occurs in the microshears. Trace minerals include magnetite, hematite, leucoxene, and apatite. A preliminary $^{207}Pb/^{206}Pb$ age of 1,763 ± 9 Ma was obtained for a sample of the granite of Mitchell Creek (unpublished data; sample J06-GC4), making it the oldest granitoid rock in the Glenwood Springs quadrangle.

Xgn

Mica schist and gneiss (Paleoproterozoic) — A heterogeneous unit composed of a variety of supracrustal metamorphic rocks. Mica schist and gneiss are the predominant Precambrian rock types in most of the quadrangle. In the Mitchell Creek drainage quartzofeldspathic gneiss, amphibolite, and calc-silicate rocks also are abundant. The mica schist and gneiss is a dark-gray to black, moderately to well-foliated, biotite-muscovite schist or gneiss composed primarily of fine-grained quartz, potassium feldspar, plagioclase, and as much as 35 percent biotite and muscovite. Biotite is locally partially replaced by chlorite. Garnet is locally present, and sillimanite is increasingly abundant to the north. In some localities the gneiss is coarse grained and contains distinct 1-inch-diameter aggregates of white muscovite. Elongated quartz and feldspar leucosomes and migmatitic layers of granitic gneiss in bands ranging from approximately 0.8–39 inches long are locally abundant. White and pink pegmatite and aplite zones are common within the gneiss and schist unit and can locally comprise much of the unit, especially outside the shear zone where pegmatite was not mapped in detail. The mica schist and gneiss unit is intruded by all of the granitic and pegmatitic units of the map area and is, thus, the oldest map unit in the Glenwood Springs quadrangle. The inferred age of the mica schist and gneiss unit is greater than 1,740 Ma.

Xu

Paleoproterozoic rocks, undivided — Shown only on cross section.

Geologic Setting

The rocks and surficial deposits of the Glenwood Springs quadrangle record a long and diverse geologic history. The rocks are moderately to well exposed in the walls of the deep valleys and canyons and less well exposed elsewhere in the quadrangle. The oldest exposed rocks (units Xgn, Xg, Xbg, Xfg, Xmg, and Xp) date back to the Paleoproterozoic and are apparently related to arc magmatism and sedimentation in arc-related basins along the southern edge of the Archean Wyoming craton (Reed and others, 1987). A major Precambrian shear zone, the Grizzly Creek Shear Zone, deforms these older rocks but not the overlying Phanerozoic rocks (Allen and Shaw, 2007).

A spectacular nonconformity exposed on the walls of Glenwood Canyon separates the Early Proterozoic igneous and metamorphic rocks from overlying lower Paleozoic sediments. Over a billion years of geologic time is represented by this erosion surface. Purple to dark-gray regolith locally present in the Proterozoic rocks beneath the nonconformity suggest that these older rocks were strongly weathered prior to deposition of the overlying lower Paleozoic sediments.

A sequence of Cambrian through Mississippian sediments above the nonconformity (includes strata of the Upper Cambrian Sawatch Formation through Mississippian Leadville Limestone) was episodically deposited in a shelf sequence environment. Disconformities within the Cambrian through Mississippian sequence represent more geologic time than do the preserved strata (Ross and Tweto, 1980). A long period of extended subaerial exposure occurred between deposition of the Leadville Limestone and overlying Lower Pennsylvanian Belden Formation. An extensive karst topography that included sinkholes, caverns, and limestone towers developed on the top of the Leadville Limestone during this time interval. A brightly colored regolith, the Molas Formation, formed on the karst topography and filled many of the sinkholes. Although the Molas is generally too thin or discontinuous in the quadrangle to be mapped at a scale of 1:24,000, it is sometimes well exposed, as for example on the northwest side of the No Name exit on Interstate 70.

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, 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; DeVoto, 1980). The Glenwood Springs quadrangle, which is within the Eagle Basin part of the Central Colorado Trough, received several thousand feet of sediment stripped from the uplifts.

Carbonaceous marine shales, thin limestones, and minor gypsum within the Belden Shale were the initial fill deposited in the Eagle basin in the quadrangle. Thick evaporitic sediments of the Eagle Valley Evaporite, including halite and gypsum, accumulated over the Belden. Highly soluable evaporite minerals like halite are not present in outcrops, but have been encountered in oil test holes. Red beds of sandstone, conglomerate, and siltstone of the Maroon Formation were deposited in fluvial and fan environments that prograded into and over the evaporitic sequence. An interval of interbedded red beds and evaporitic strata that separates the Eagle Valley Evaporite from the Maroon Formation is mapped as the Eagle Valley Formation. 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 repeatedly transgressed and regressed across the area. The Dakota Sandstone, Mancos Shale, and Mesaverde Group were deposited at this time.

Tectonism and igneous activity associated with the Laramide orogeny initiated near the end of the Cretaceous and continued into the Eocene. The White River Uplift, a broad domal structure whose southern flank is in the northern part of the quadrangle, and the Grand Hogback monocline, which trends northwest-southeast across the southwest corner of the quadrangle, formed late during the Laramide orogeny (Tweto, 1975). To the west of the mapped area, strata of the Paleocene and early Eocene Wasatch Formation are deformed by the Grand Hogback Monocline as much as are older strata. The middle Eocene Green River Formation is tilted slightly by the White River Uplift (Tweto, 1975), and the sandstones within this formation coarsen as they approach the uplift (Donnell, 1961). This evidence suggests the White River Uplift and Grand Hogback Monocline were active chiefly in the Eocene.

The Grizzly Creek Fault, one of the many Laramide faults in the quadrangle, formed within the Precambrian-age Grizzly Creek Shear Zone (Allen and Shaw, 2007), at least in areas where the shear zone is exposed. The intrusive rocks of unit Ti may be Laramide in age, although they could be younger.

Sometime after the Laramide orogeny, perhaps initially during late Eocene time (Scott, 1975) and possibly later modified by one or more subsequent periods of erosion (Kirkham, Kunk, and others, 2001; Steven, 2002), a broad angular unconformity was cut across the region. Early and middle Miocene basaltic rocks were erupted onto this low-relief erosion surface in the quadrangle. Erosional remnants of these volcanic flows are widely distributed across the southern half of the quadrangle; they may have originally extended over much and perhaps all of the quadrangle.

During the Miocene, the Colorado River and its tributaries began to downcut through the low-relief erosion surface, creating younger and topographically lower erosion surfaces inset into the regional late Eocene-early Miocene erosion surface (Larson and others, 1975; Kirkham, Kunk, and others, 2001; Kunk and others, 2002). This incision triggered flow and dissolution of halite and gypsum that led to widespread collapse of the ground surface in the region (Kirkham, Streufert, and others, 2001, 2002; Lidke and others, 2002; Scott and others, 2002). The northern margin of the Carbondale Collapse Center runs generally east-west through the middle of the quadrangle; the southern half of the quadrangle lies within the collapsed area.

Miocene basaltic lavas, which were originally erupted onto the low-relief subhorizontal erosion surface, provide critical evidence of the collapse that constrains the timing, rate, lateral extent, and amount of vertical collapse. For example, the 22.56 ± 0.13 Ma flows at the northwest end of Spring Valley are about 4,000-ft lower in elevation than the nearest age-equivalent flows on the White River Plateau. Over 1,400 ft of vertical collapse separates the 9.72 ± 0.05 Ma flow on Lookout Mountain (sample GS96-1) from a 9.78 ± 0.23 Ma flow at the north end of Spring Valley (sample K97-10-8B). The 7.77 ± 0.05 Ma basaltic rocks that crop out west of the north end of Spring Valley have collapsed nearly 2,000 ft relative to correlative flows that cap the mesa on the south rim of Glenwood Canyon north of Consolidated Reservoir (Kirkham, Streufert, and Cappa, 2008; Streufert, Kirkham, and others, 2008).

The structure responsible for Spring Valley is depicted as a half graben on the geologic map, but it may be a pull-apart structure related to evaporite tectonism (Kirkham, Streufert, and others, 2002). Volcanic ash encountered from about 250- to 300-ft below the ground surface in a test well in Spring Valley about 0.25-mi east of the mapped area (Robin VerSchneider, 2001, personal commun.) was identified as the Lava Creek B ash (A.M. Sarna-Wojcicki, 2002, written commun.), which was dated at 639 ka by Lanphere and others (2002). Based on the depth and age of the ash, the sedimentation rate in the valley is very high, especially considering that much of the sediment overlying the ash is clay and silt deposited in a lacustrine environment. If Spring Valley is a pull-apart structure, then evaporite flow may be the primary mechanism responsible for creating the Spring Valley structure. The block of rock that underlies Los Amigos Mesa (the basalt-capped rolling surface west of Spring Valley) protrudes about 0.5 mi into the Roaring Fork River valley. This block may be moving or rafting towards the Roaring Fork River, as underlying evaporite flows westward (Kirkham, Streufert, and others, 2002). Basaltic flows within the narrow graben northwest of Spring Valley are strongly tilted and may be overturned (Hudson and others, 2002); this style of deformation fits well with the pull-apart model. Remnants of flows between Lookout Mountain and the narrow graben are faulted and locally very fractured and strongly weathered, probably a result of undergoing evaporite collapse.

As evaporite dissolved and/or flowed out from beneath the Grand Hogback Monocline along the western side of the quadrangle, the monocline underwent movement in a direction opposite to its Laramide movement; in other words, the monocline relaxed or partially unfolded. Miocene flows that rested on the low-relief erosion surface cut across the monocline are now tilted eastward into the collapse area and broken by numerous flexural-slip faults that are down-dropped to the west (Murray, 1969; Unruh and others, 1993; Kirkham, Streufert, and others, 2001, 2002). A few northeast-trending faults also cut the basaltic rocks that overlie the Grand Hogback Monocline; a scarp in Quaternary deposits coincides with one of these faults.

The Cattle Creek Anticline is a valley-centered, Laramide-age anticline along the Roaring Fork River valley that was modified by evaporite flow during the late Cenozoic (Mallory, 1966; Perry and others, 2002). Evaporite diapirism is responsible for at least 100 ft of post-middle Quaternary uplift near the northern end of the anticline, as evidence by the upwarped Pleistocene deposits beneath the folded Bershenyi terrace south of Cardiff.

The dissolved halite and gypsum that are responsible for the collapse 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 Center every year. Yampa hot spring, which provides the water for the hot springs pool in Glenwood, discharges about 260 tons of dissolved halite and gypsum to the Colorado River daily (Barrett and Pearl, 1976). Many other hot springs in the area also discharge water that is enriched in dissolved evaporite minerals. These high salt concentrations are strong evidence that the evaporite dissolution and collapse is active.

Effects of Pleistocene glaciation are apparent in the valleys of the Colorado and Roaring Fork Rivers and in Dry Possum Creek and Mitchell Creek in the northwest corner of the quadrangle. Till and glacio-fluvio deposits underlie lateral, terminal, and end moraines formed by glaciers shed southward off the ice that capped the White River Plateau. Sequences of terraces underlain by coarse-grained glacial outwash are well preserved in the Roaring Fork River valley and in the Colorado River valley below Glenwood Canyon. Absolute age control was obtained for a low-lying younger terrace deposit (unit Qty) near the rest area along Interstate 70 in west Glenwood Springs. Peat interbedded with tufa that overlies the terrace alluvium yielded a conventional ^{14}C date of 12,410 ± 60 years BP (D. Trimble, 1995, written commun.).

CORRELATION AND AGE OF BASALTIC ROCKS

When the Glenwood Springs quadrangle was initially mapped by the CGS during 1993 and 1994, ten samples of basaltic rock were collected in the quadrangle and analyzed for major elements (Appendix A). One sample (GL100) was dated using $^{40}Ar/^{39}Ar$ methods (Larry Snee, 1995, written commun.). Locations of these samples are shown on the accompanying geologic map.

Early during the collaborative CGS–USGS investigation of evaporite tectonism in the region, it was recognized that a thorough understanding of the late Cenozoic volcanic stratigraphy was needed to better characterize evaporite-related deformation. By tracing dated and correlated volcanic flows across the region, the lateral extent, amount of vertical deformation, and timing and rates of collapse could be assessed. To accomplish this goal, an extensive effort involving $^{40}Ar/^{39}Ar$ age dating of 133 samples (Kunk and others, 2002) and major-, minor-, and trace-element geochemical analysis of 220 volcanic rocks in the region (Unruh and others, 2001) was undertaken. This data, when combined with the geologic framework established by quadrangle mapping, enabled Budahn and others (2002) to identify 46 distinct compositional groups of volcanic rocks. These compositional groups were erupted during signicant pulses of volcanic activity spread across the region during the time intervals from 24 to 22 Ma, 16 to 13 Ma, and 11 to 9 Ma. Smaller, more widely spaced eruptions occurred in the region about 7.8–7.7 Ma, 4 Ma, 3 Ma, 1.3 Ma, and 4 ka (Kunk and others, 2002).

Fourteen samples of basaltic rocks were collected in the Glenwood Springs quadrangle for $^{40}Ar/^{39}Ar$ dating and geochemical analysis as part of the collaborative CGS–USGS investigation. Sample locations are shown on the accompanying geologic map. Five of the compositional groups identified by Budahn and others (2002) were recognized in the Glenwood Springs quadrangle (**Table 1**).

The oldest volcanic rocks in the quadrangle are the early Miocene group 10a flows, which have a preferred age of 22.56 ± 0.13 Ma (Table 1). Rocks of this group are exposed in a road cut at the northwest end of Spring Valley (GL100, K97-10-8C) and within the narrow graben further northwest (KH95-12).

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

Sample Number	Map Unit	Compositional Group	Preferred Age (Ma)
K97-10-8B	Tb	1b	9.78 ± 0.23
KH95-8	Tb	1b	
KH95-9	Tb	1b	
KH95-11	Tb	1b	
GS96-1	Tb	2b	9.72 ± 0.05
GL165B	Tb	2b	
GL207	Tb	2b	
GL25	Tb	4a	
KH95-43	Tb	4a	
K97-10-8D	Tb	5b	7.77 ± 0.05
GL306	Tb	5b	
KH95-15	Tb	5b	
K97-10-8C	Tb	10a	22.56 ± 0.13
GL100*	Tb	10a	22.56 ± 0.13
KH95-12	Tb	10a	

* Sample GL100 was collected from the same outcrop as sample K97-10-8C. An age of 22.4 ± 0.3 Ma was reported for this sample in Kirkham and others (1997), based on L. Snee, written commun. (1995). Kunk and others (2002) assigned an apparent age of 22.04 ± 1.3 Ma and a preferred age 22.56 ± 0.13 Ma to the sample).

Late Miocene basaltic rocks apparently are the most widespread volcanic rocks in the quadrangle. Group 1b rocks crop out northwest of Spring Valley, both within the narrow graben (K97-10-8B, KH-8, KH-9) and on the west side of it (KH-11). One of the group 1b rocks within the quadrangle (K97-10-8B) yielded an age of 9.78 ± 0.23 Ma. Eruption of group 1b rocks apparently spanned more than a million years from about 9.75 to 10.84

Ma, based on dated samples from outside the quadrangle (Kunk and others, 2002).

Basaltic flows from near the top of Lookout Mountain (GS96-1, GL165B) and immediately north of the mouth of Red Canyon (GL207) are included in compositional group 2b. An $^{40}Ar/^{39}Ar$ age of 9.72 ± 0.05 Ma (Kunk and others, 2002) was obtained from a group 2b flow on the south side of Lookout Mountain (GS96-1). Correlative rocks crop out on the east valley wall of the Roaring Fork River about 1 mile south of the mouth of Red Canyon, where they underlie a channel-like body of fluvial gravels that is as much as 75-ft thick (Kirkham and others, 1996). Kunk and others (2002) reported that group 2b rocks in the region range from about 9.68 to 10.70 Ma, a time interval which nearly matches that of group 1a rocks.

Group 4a rocks crop out in the southwest part of the quadrangle where flexural-slip faults associated with relaxation of the Grand Hogback Monocline cut the late Miocene basalt cap. Two samples of group 4a rocks were collected from a single tilted fault block within the quadrangle (samples GL25, KH95-43). Stratigraphic relations suggest the group 4a rocks are ~10 Ma.

The youngest volcanic rocks in the quadrangle are the 7.77 ± 0.05 Ma group 5b flows in Los Amigos Mesa west of the north end of Spring Valley (samples K97-10-8D, GL306, KH95-15). These flows are correlative to ones on the western end of Little Grand Mesa (Budahn and others, 2002).

GEOLOGIC HAZARDS AND CONSTRAINTS

A variety of geologic hazards and constraints affect the Glenwood Springs quadrangle, and they have been the subject of numerous investigations (e.g. Lincoln-Devore, 1976, 1978; Soule and Stover, 1985; Mejia-Navarro, 1995; White, 2002). The town of Glenwood Springs has been hit by debris flows on several occasions during summer thunderstorms (Mears, 1977; Smith, 1986; Mejia-Navarro, 1995). Areas mapped as younger debris-flow deposits (unit Qdfy) are highly prone to future debris flows, mud flows, and flooding; areas mapped as intermediate debris-flow deposits (unit Qdfm) have lower potential for these hazards. Low-lying areas mapped as stream-channel, flood-plain, and low-terrace deposits (unit Qa) and as alluvium and colluvium, undivided (unit Qac) are subject to flooding.

White (2002) developed a hazard derivative map based on prior CGS geologic mapping that depicts collapsible soils in the quadrangle. The hydrocompaction potential of fine-grained sheetwash deposits (unit Qsw), colluvium (unit Qc), alluvium and colluvium, undivided (unit Qac), and loess (unit Qlo) was classified as moderate to high. These deposits, along with lacustrine deposits (unit Ql) and older debris-flow deposits (unit Qdfo), also were considered to have moderate to high potential for settlement and piping.

Recent landslides in the quadrangle (unit Qlsr) have occurred in the Mancos Shale, Maroon Formation, and surficial deposits derived from the Mancos and Maroon, or they have involved reactivation of existing landslide deposits. Other landslides in the quadrangle (unit Qls) are associated with these map units and with the Eagle Valley Evaporite, Eagle Valley Formation, Belden Formation, Morrison Formation, Miocene basaltic rocks, and, to a lesser extent, Proterozoic gneiss.

Sinkholes, which pose significant hazards, may occur in areas where the Eagle Valley Evaporite is present at or near the surface (Mock, 2002; White, 2002). Modern rates of ground movement related to evaporite collapse, diapirism, and slip on bedding plane faults associated with relaxation or unfolding of the Grand Hogback Monocline are poorly constrained. If these rates are sufficiently high to pose hazards, then these types of deformation should be considered in engineering design, particularly where differential movement is possible.

The Eagle Valley Evaporite and surficial deposits eroded from it can be corrosive. Sulfate in the Mancos Shale and its associated surficial deposits may be problematic for metal and concrete. The Mancos Shale and Morrison Formation, as well as surficial deposits derived from them, locally contain expansive clays that can cause shrink-swell problems. Heaving bedrock is possible in areas where the Mancos Shale and perhaps the Morrison Formation crop out within the Grand Hogback Monocline.

There is moderate to high potential for rockfall below cliffs of well indurated bedrock throughout the quadrangle, especially in areas mapped as talus (unit Qt). Proterozoic crystalline rocks and lower and middle Paleozoic rocks in Glenwood Canyon and in steep-walled tributary valleys pose severe rockfall hazards. Very large, sudden rock topples and/or rock slides occurred in the past in No Name Creek. Formations such as the Dakota Sandstone, Morrison Formation, Entrada Sandstone, Maroon Formation, and Eagle Valley Formation can pose rockfall hazards where cliffy ledges crop out on moderate to steep slopes. Even 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 Glenwood Springs area 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 in the future.

Economic Geology

Mineral commodities with possible economic potential in the quadrangle include sand and gravel, high-calcium limestone, geothermal resources, and to a lesser degree, base metals. Many of the surficial deposits have sand and gravel potential, including units Qa, Qty, Qtm, Qto, Qtt, Qtg, Qdfy, Qac, Qaco, Qdfo, and Qm. Limestone has been quarried in the quadrangle from three principal locations, all of which are less than one mile from the city of Glenwood Springs. One of these limestone quarries retains an active permit status even though there has been no mining in recent years (Colorado Division of Minerals and Geology, 2008, http://mining.state. co). One small occurrence of oxidized lead-zinc ore was evaluated in 1944 by the United States Bureau of Mines under the War Minerals Program. This property is located near Windy Point on the north end of the quadrangle.

The Mississippian Leadville Limestone crops out extensively on the White River Plateau and has been suggested as a source of high-calcium limestone. CF & I Steel Corporation, Pueblo, has identified an area near Willow Peak on the adjacent Broken Rib Creek quadrangle that has been proven by core drilling to contain a sizeable resource of metallurgical limestone (Wark, 1980). Specific quality parameters pertaining to limestone feedstock for steel making applications (high calcium content-over 97 percent $CaCO_3$ and low silica content-less than 1 percent SiO_2) are frequently attainable in the Leadville Limestone, particularly in its upper part where dolomitization and chert-bearing zones are less prevalent.

Zones of high-calcium limestone may also exist in the Devonian age Chaffee Group. Any area within the quadrangle where the Leadville Limestone or other high-calcium rocks occur without appreciable overburden may be a target area for limestone development.

All of the Proterozoic units, as well as Tertiary basalt, are potential sources of aggregate and riprap. The Sawatch Formation is a potential source of aggregate. Gypsum and perhaps halite within the Eagle Valley Evaporite may be economic resources.

Lead and zinc minerals with minor copper and silver have been identified within the quadrangle near Windy Point (Strong Mine). The deposit was assayed at 24 percent zinc, 8.7 percent lead, 0.17 percent copper, and 0.81 troy ounces of silver per short ton (Heyl, 1964). The minerals occur in small but rich "pods" within a fissure vein which strikes N. 50° E. and dips 44° NW. The mineralization is hosted in carbonate rocks of the Devonian Chaffee Group and the Mississippian Leadville Limestone. The ore consists of a mixture of lead and zinc minerals that are generally oxidized. At the time of the initial assessment of this deposit in 1944 by the U.S. Bureau of Mines, the ore was observed to occur only above a caved adit and in two small open cuts. When this site was visited in 1994 for this mapping project no ore was apparent in one recently driven adit (20-ft long) nor was any of the described mineralization still observable in surface exposures. This suggests a very discontinuous nature for these occurrences and, at best, a minor resource for this site. Other areas of lead-zinc-silver mineralization may occur in the quadrangle, however, none was observed during the course of field mapping. Other deposits similiar to those at Windy Point, if they do exist, are expected to be small and most likely sub-economic.

There are several thermal springs within the quadrangle; most are associated with the Leadville Limestone and other carbonate rocks. Several hot springs are either used for commercial recreational purposes or for heating. Thermal springs near the city of Glenwood Springs are characterized by their high salinity, 18,000 to 22,000 ppm of sodium, temperatures ranging from 44° to 52°C, and flow rates of up to 5,000 liters per minute (Cappa and Hemborg, 1995).

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APPENDIX A

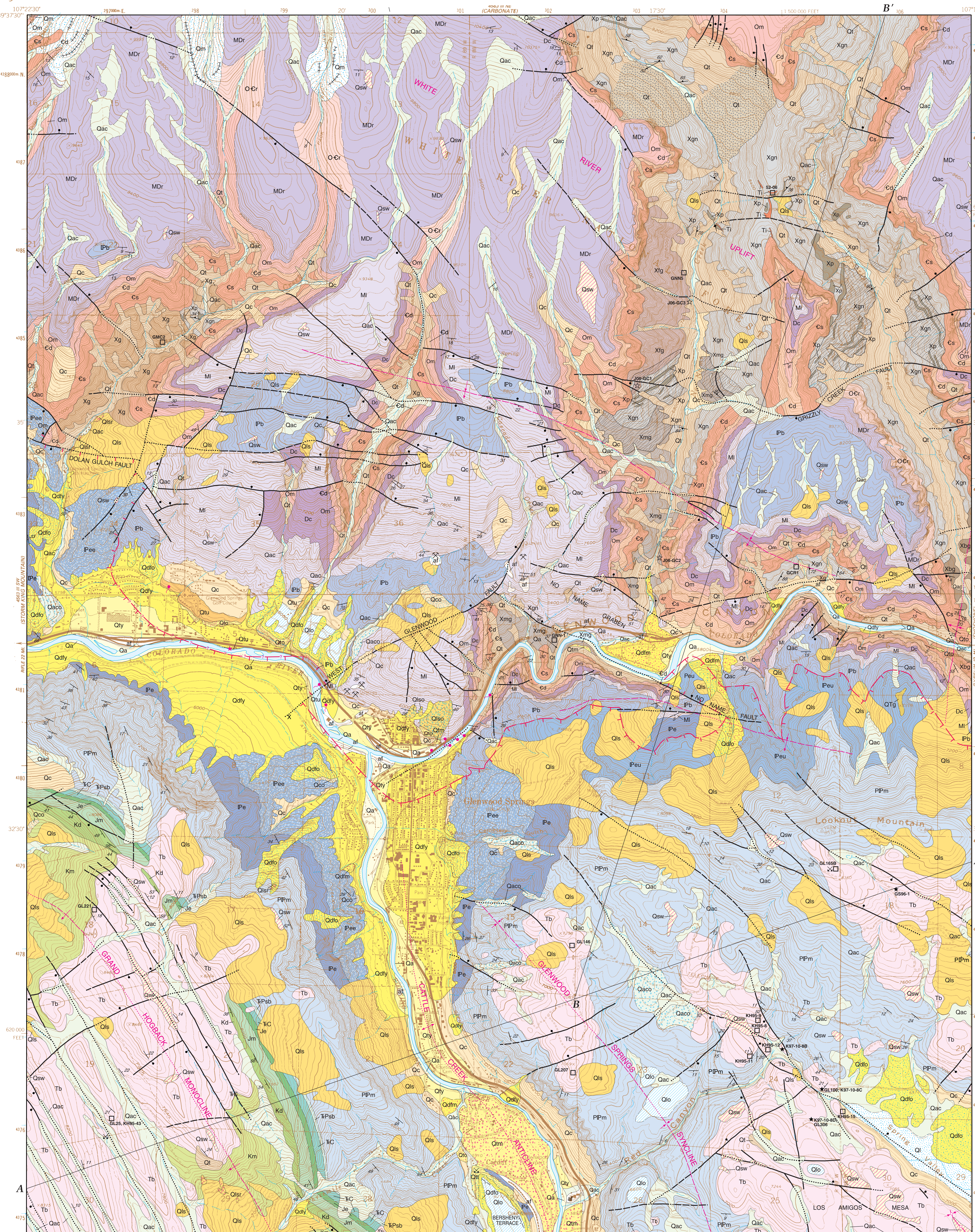
Appendix A. Major-element whole-rock analyses of the Glenwood Springs quadrangle. Sample locations are listed in the lower table and are shown on the accompanying geologic map. (Polyconic projection NAD27)

	Weight Percent												
Sample ID	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**Fe_2O_3**	**MnO**	**Cr_2O_3**	**P_2O_5**	**TiO_2**	**LOI***	**Total**
GL25†	51.1	14.9	7.69	6.69	2.92	2.10	10.30	0.14	0.03	0.55	1.570	1.85	99.8
GL100†	47.0	14.0	8.83	6.53	3.15	1.42	13.40	0.16	0.02	1.05	2.550	0.25	98.4
GL146†	47.3	14.4	7.40	8.35	2.92	2.05	11.40	0.15	0.03	0.67	1.770	1.95	98.4
GL165B†	49.5	15.1	8.11	6.76	2.96	1.23	11.80	0.15	0.03	0.46	1.520	1.70	99.3
GL207§	51.52	15.10	7.76	6.78	2.92	1.43	11.03	0.14	—	0.49	1.63	1.15	99.95
GL221†	49.2	15.7	7.72	7.05	2.70	1.26	12.00	0.16	0.03	0.45	1.520	2.20	100.0
GL306†	50.2	15.2	7.17	6.62	3.12	2.31	11.10	0.15	0.03	0.66	1.810	0.75	99.1
GCR-1†	64.5	15.5	1.32	2.87	2.84	3.19	6.79	0.06	0.03	0.16	0.670	1.70	99.6
GMC-2†	73.7	13.0	1.12	0.47	3.10	4.44	2.89	0.02	0.04	0.05	0.288	0.50	99.6
GNN-1†	62.8	15.6	3.51	2.22	3.35	2.71	6.48	0.08	0.01	0.42	0.945	1.10	99.2
GNN-5†	65.1	15.8	3.17	2.58	3.78	2.34	4.76	0.07	0.01	0.24	0.508	0.80	99.2
GS96-1§	50.04	14.89	7.82	7.84	2.81	1.36	12.79	0.16	—	0.49	1.51	0.40	100.4
KH95-8§	52.05	15.49	7.93	6.91	3.06	1.09	11.48	0.16	—	0.33	1.43	0.14	100.07
KH95-9§	52.06	15.45	7.92	6.98	3.07	1.08	11.37	0.17	—	0.33	1.43	0.21	100.06
KH95-11§	51.72	15.45	8.04	6.84	3.03	1.02	11.50	0.15	—	0.33	1.42	0.60	100.21
KH95-12§	48.29	14.74	9.17	5.28	3.21	1.33	13.09	0.15	—	1.11	2.57	0.60	99.54
KH95-15§	48.75	15.78	7.74	7.02	2.99	2.05	10.15	0.15	—	0.70	1.82	0.56	98.63
KH95-43§	51.43	15.03	7.97	6.60	3.03	2.06	9.87	0.13	—	0.59	1.60	1.50	99.81
K97-10-8B§	51.65	15.40	7.97	6.37	2.98	1.12	11.52	0.15	—	0.31	1.43	0.63	99.54
K97-10-8C§	47.59	14.28	9.14	6.24	3.19	1.40	13.35	0.16	—	1.14	2.64	-0.12	99.01
K97-10-8D§	49.94	15.39	7.17	6.32	3.07	2.37	11.09	0.16	—	0.71	1.86	0.73	98.81
52-06#	64.50	16.25	0.63	0.98	4.25	5.05	5.11	0.05	—	0.35	0.76	1.17	97.93

*Loss On Ignition
†Analysis by XRAL Laboratories, Denver, Colo.
§Analysis by the U.S. Geological Survey (Unruh and others, 2001)
#Analysis by ALS Chemex, Sparks, NV and Vancouver, Canada.

Appendix A, continued

Sample ID	Map Unit	Latitude	Longitude
GL25	Tb	39.5118°N	107.3638°W
GL100	Tb	39.5149°N	107.2695°W
GL146	Tb	39.5296°N	107.3030°W
GL165B	Tb	39.5376°N	107.2685°W
GL207	Tb	39.5164°N	107.3030°W
GL221	Tb	39.5335°N	107.3661°W
GL306	Tb	39.5117°N	107.2711°W
GCR-1	Xgn	39.5685°N	107.2731°W
GMC-2	Xg	39.5916°N	107.3570°W
GNN-1	Xmg	39.5610°N	107.3054°W
GNN-5	Xfg	39.5984°N	107.2885°W
GS96-1	Tb	39.5352°N	107.2600°W
KH95-8	Tb	39.5209°N	107.2783°W
KH95-9	Tb	39.5219°N	107.2782°W
KH95-11	Tb	39.5182°N	107.2792°W
KH95-12	Tb	39.5189°N	107.2769°W
KH95-15	Tb	39.5126°N	107.2669°W
KH95-43	Tb	39.5118°N	107.3638°W
K97-10-8B	Tb	39.5190°N	107.2749°W
K97-10-8C	Tb	39.5149°N	107.2695°W
K97-10-8D	Tb	39.5117°N	107.2711°W
52-06	Ti	39.6068°N	107.2763°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

UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24,000

QUADRANGLE LOCATION

Geology mapped in 1993, 1994, 1996, 2005, and 2006; assisted by Peter Stelling in 1994, by Matt Grizzell, Rafaello Sacerdoti, and Vince Matthews in 2002, and by Ian Ware, Jamie Skeen, and Stephanie Mumma in 2006; Digital cartography by Cheryl Brchan and Larry Scott

CONDENSED DESCRIPTION OF MAP UNITS

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

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — Artificial fill (latest Holocene)

ALLUVIAL DEPOSITS

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix up to about 15 ft above modern rivers

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Gravelly sand, sandy silt, and clayey silt deposited on gentle hillslopes, in small basins, and in stream valleys

Qty — **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix. May include fine-grained overbank deposits. Underlies terraces about 19–56 ft above modern rivers

Qtm — **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally similar to younger terrace alluvium. Underlies terraces about 58–95 ft above modern rivers

Qto — **Older terrace alluvium (late middle Pleistocene)**—Deposits texturally similar to younger terrace alluvium. Underlies terraces about 110–160 ft above modern rivers

Qtt — **Oldest terrace alluvium (middle Pleistocene)**—Deposits texturally similar to younger terrace alluvium. Underlies a terrace west of Glenwood Springs airport about 220–360 ft above the Roaring Fork River

QTg — **High-level gravel (early Pleistocene or Pliocene)**—Includes a single, very poorly exposed deposit of rounded river gravel about 1,500 ft above the Colorado River near the north quarter-corner of sec. 7, T. 6 S., R. 88 W.

MASS-WASTING DEPOSITS

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

Qc — **Colluvium (Holocene and late Pleistocene)**—Matrix- and clast-supported, pebble to boulder gravel in a sandy silt matrix. Locally fine grained

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from bedrock outcrops and transported by rockfalls, rockslides, rock avalanches, and rock topples. Deposits marked by triangular pattern in No Name Creek indicate two very large, rapid rotational rockslides or rock topples

Qls — **Landslide deposits (Holocene and Pleistocene)**—Similar in texture to recent landslide deposits (Qlsr). Ranges in age from recently active landslides to long-inactive Pleistocene landslides

Qco — **Older colluvium (Pleistocene)**—Highly variable deposits texturally similar to colluvium (Qc), but generally not subject to future deposition

Qlso — **Older landslide deposits (Pleistocene and late Pliocene?)**—Landslide deposits dissected by erosion and lacking distinctive landslide morphology. Similar in texture to recent landslide deposits (Qlsr)

ALLUVIAL AND MASS-WASTING DEPOSITS

Qdfy — **Younger debris-flow deposits (Holocene)**—Poorly sorted to moderately well-sorted matrix- and clast-supported, pebble, boulder, and cobble gravel in a sandy silt or silty sand matrix. Distal fan areas are finer grained. Deposited on active fans

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

Qdfm — **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similiar in texture, lithology, and depositional environment to younger debris-flow deposits (Qdfy). Geomorphic character of original depositional surfaces are commonly recognizable, but the surfaces are 10 ft or more above active debris-flow channels

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally similar to alluvium and colluvium, undivided (Qac), that underlie terraces and hillslopes above the floor of tributary valleys

Qdfo — **Older debris-flow deposits (late, middle, and early? Pleis-tocene)**—Remnants of long-inactive debris fans found on ridge lines, mesas, and valley floors 40–320 ft above adjacent streams. Similar in texture to younger debris-flow deposits (Qdfy)

GLACIAL DEPOSITS

Qm — **Morainal deposits (late and/or middle? Pleistocene)**—Deposits of gravel, sand, silt, and minor clay deposited in lateral, end, and ground moraines

LACUSTRINE DEPOSITS

Ql — **Lacustrine deposits**—Stratified deposits of medium- to dark-gray and reddish-brown, organic-rich, silty clay and silt, medium-red-brown, well-sorted sand, and volcanic ash deposited in Spring Valley

EOLIAN DEPOSITS

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

SINTER DEPOSITS

Qtu — **Tufa (Holocene and Pleistocene?)**—Low density, porous calcium carbonate deposits precipitated from mineral-charged spring water. A conventional radiocarbon age of 12,410 ± 60 ^{14}C years BP was obtained from peat interbedded with tufa that overlies younger terrace alluvium near Funston (D. Trimble, 1995, written commun.)

UNDIFFERENTIATED DEPOSITS

Q — **Undifferentiated surficial deposits (Quaternary)**—Shown only on cross sections

BEDROCK

Tb — **Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and trachybasalt interbedded with fluvial and lacustrine sediments. Includes flows in compositional groups 1b, 2b, 4a, 5b, and 10a of Unruh and others (2001) and Budahn and others (2002). $^{40}Ar/^{39}Ar$ age dates range from 7.77 ± 0.05 Ma to 22.56 ± 0.13 Ma (Kunk and others, 2002)

Ti — **Porphyritic intrusion (Tertiary?)**—Brown to red-brown, fine-grained, intrusive porphyry with white plagioclase phenocrysts

Kmv — **Mesaverde Group (Upper Cretaceous)**—Shown only on cross section A–A'

Km — **Mancos Shale (Upper Cretaceous)**—Includes in ascending order: siliceous, dark-gray fissile shale possibly correlative to the Mowry Shale; interbedded calcareous, yellow-brown sandstone interbedded with dark-gray fissile shale (Juan Lopez member?); a calcareous shale zone equivalent to the Niobrara Formation, and a dominantly light- to dark-gray, sometimes bentonitic, fissile shale

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

Jm — **Morrison Formation (Upper Jurassic)**—Pale-green and maroon mudstone and shale and gray limestone. Thin beds of silty sandstone in lower part

Je — **Entrada Sandstone (Upper Jurassic)**—Light-gray to light-orange, cross-bedded sandstone. Medium to very fine grained and well sorted

ŦRc — **Chinle Formation (Upper Triassic)**—Thin, even bedded, 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

ŦRPsb — **State Bridge Formation (Lower Triassic? and Permian)**—Includes upper and lower members composed of pale-red, grayish-red, reddish-brown, and greenish-gray, micaceous siltstone, clayey siltstone, and minor sandstone that are separated by the South Canyon Creek Member, a prominent, thin bed of sandy dolomite and sandy limestone

PIPm — **Maroon Formation (Permian and Pennsylvanian)**—Mainly reddish-brown sandstone, conglomerate, mudstone, siltstone, and claystone with minor, thin beds of gray limestone. Includes Schoolhouse Member at top of formation

IPe — **Eagle Valley Formation (Middle Pennsylvanian)**—Intertonguing sequence of Maroon Formation and Eagle Valley Evaporite

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

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

IPb — **Belden Formation (Lower Pennsylvanian)**—Medium-gray to black, calcareous shale and fossiliferous limestone with interbeds of fine-grained micaceous sandstone, gritstone, coaly shale, and gypsum

Ml — **Leadville Limestone (Mississippian)**—Gray to bluish-gray, coarse to finely crystalline limestone and dolomite. Abundant chert nodules in lower part of formation

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

MDr — **Mississippian/Devonian rocks-undivided (Mississippian and Upper Devonian)**

Om — **Manitou Formation (Lower Ordovician)**—Flat-pebble limestone conglomerate, brown and tan crystalline dolomite, and greenish-gray calcareous shale

Ꞓd — **Dotsero Formation (Upper Cambrian)**—Thin-bedded, brown to tan sandy dolomite and dolomitic sandstone with abundant glauconite, and pinkish-light-gray to light-gray algal limestone

Ꞓs — **Sawatch Formation (Upper Cambrian)**—White to buff, massive, medium-grained quartz arenite and arkosic quartz-pebble conglomerate. Includes dolomitic units in the middle part of the formation

OꞒr — **Ordovician and Cambrian rocks, undivided (Upper Cambrian-Lower Ordovician)**

PRECAMBRIAN ROCKS

Xp — **Pegmatite (Paleoproterozoic)**—Includes coarse- to very coarse-grained pink pegmatite composed chiefly of potassium feldspar, quartz, and plagioclase, and white pegmatite consisting of quartz, white plagioclase, muscovite, and garnet

Xmg — **Megacrystic granite (Paleoproterozoic)**—Has distinctly bimodal grain size with coarse-grained salt-and-pepper matrix composed of quartz, plagioclase, orthoclase, and biotite, and blocky tabular phenocrysts of orthoclase as much as 4 inches long. Preliminary $^{207}Pb/^{206}Pb$ age of 1,741 ± 10 Ma (unpublished data; sample J06-GC2)

Xfg — **Fine-grained granodiorite (Paleoproterozoic)**—Dark-pink to gray, fine- to medium-grained, equigranular granodiorite and granite with plagioclase, microcline, perthite, and quartz. Preliminary $^{207}Pb/^{206}Pb$ age of 1,743 ± 8 Ma (unpublished data; sample J06-GC1)

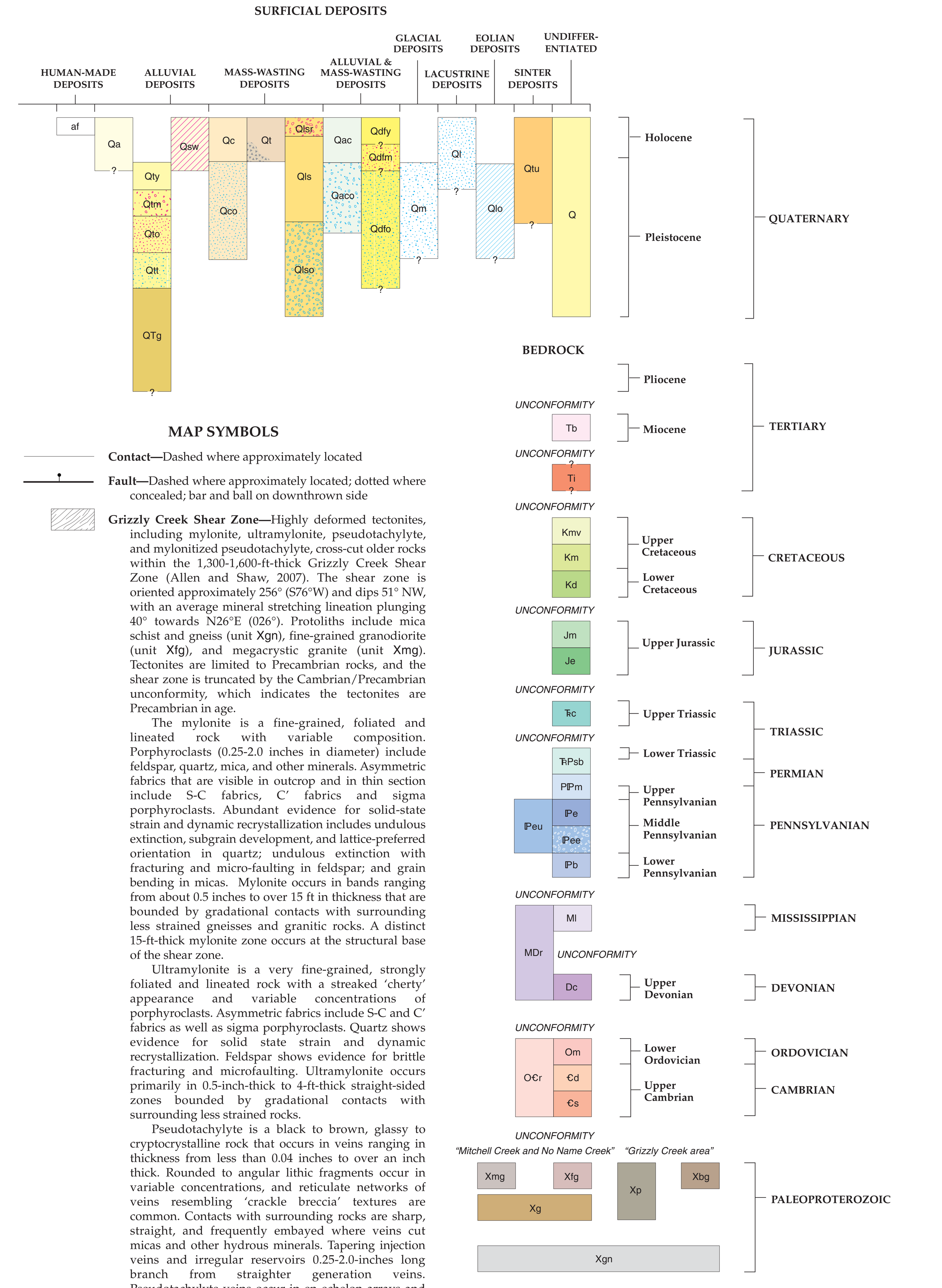
Xbg — **Biotite granite (Paleoproterozoic)**—Gray- and white-speckled, medium-grained granite consisting of sodium-rich plagioclase, microcline, perthite, quartz, and biotite

Xg — **Granite of Mitchell Creek (Paleoproterozoic)**—Light-red to pink, fine- to medium-grained, equigranular, foliated granite and quartz monzonite. Preliminary $^{207}Pb/^{206}Pb$ age of 1,763 ± 9 Ma (unpublished data; sample J06-GC4)

Xgn — **Mica schist and gneiss (Paleoproterozoic)**—Heterogeneous unit composed of various moderately to well-foliated schist and gneiss with quartz, potassium feldspar, plagioclase, biotite, and muscovite

Xu — **Paleoproterozoic rocks, undivided**—Shown only on cross sections

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side

Grizzly Creek Shear Zone—Highly deformed tectonites, including mylonite, ultramylonite, pseudotachylyte, and mylonitized pseudotachylyte, cross-cut older rocks within the 1,300-1,600-ft-thick Grizzly Creek Shear Zone (Allen and Shaw, 2007). The shear zone is oriented approximately 256° (S76°W) and dips 51° NW, with an average mineral stretching lineation plunging 40° towards N26°E (026°). Protoliths include mica schist and gneiss (unit Xgn), fine-grained granodiorite (unit Xfg), and megacrystic granite (unit Xmg). Tectonites are limited to Precambrian rocks, and the shear zone is truncated by the Cambrian/Precambrian unconformity, which indicates the tectonites are Precambrian in age.

The mylonite is a fine-grained, foliated and lineated rock with variable composition. Porphyroclasts (0.25-2.0 inches in diameter) include feldspar, quartz, mica, and other minerals. Asymmetric fabrics that are visible in outcrop and in thin section include S-C fabrics, C′ fabrics and sigma porphyroclasts. Abundant evidence for solid-state strain and dynamic recrystallization includes undulous extinction, subgrain development, and lattice-preferred orientation in quartz; undulous extinction with fracturing and micro-faulting in feldspar; and grain bending in micas. Mylonite occurs in bands ranging from about 0.5 inches to over 15 ft in thickness that are bounded by gradational contacts with surrounding less strained gneisses and granitic rocks. A distinct 15-ft-thick mylonite zone occurs at the structural base of the shear zone.

Ultramylonite is a very fine-grained, strongly foliated and lineated rock with a streaked 'cherty' appearance and variable concentrations of porphyroclasts. Asymmetric fabrics include S-C and C′ fabrics as well as sigma porphyroclasts. Quartz shows evidence for solid state strain and dynamic recrystallization. Feldspar shows evidence for brittle fracturing and microfaulting. Ultramylonite occurs primarily in 0.5-inch-thick to 4-ft-thick straight-sided zones bounded by gradational contacts with surrounding less strained rocks.

Pseudotachylyte is a black to brown, glassy to cryptocrystalline rock that occurs in veins ranging in thickness from less than 0.04 inches to over an inch thick. Rounded to angular lithic fragments occur in variable concentrations, and reticulate networks of veins resembling 'crackle breccia' textures are common. Contacts with surrounding rocks are sharp, straight, and frequently embayed where veins cut micas and other hydrous minerals. Tapering injection veins and irregular reservoirs 0.25-2.0-inches long branch from straighter generation veins. Pseudotachylyte veins occur in en echelon arrays and swarms within the shear zone. Mylonitized pseudotachylyte veins exhibit internal foliation and/or distorted contacts indicative of plastic deformation subsequent to vein formation.

Fold—Showing trace of axial plane, and direction of plunge where known. Dashed where approximately located; dotted where concealed

Anticline—Showing crestal trace

Syncline—Showing trough trace

Synclinal sag related to flowage or dissolution of underlying evaporitic rocks—Showing trough line

Monocline—Showing traces of upper and lower fold axes; arrows indicate direction of dip; longer arrow indicates flatter dip; dashed where approximately located; dotted where concealed

Monocline—Showing approximate trace of vertical plane placed about equidistant from anticlinal and synclinal fold axes

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

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

23 **Inclined**

Vertical

Inclined—Showing approximate attitude of terrace surface; dip between 0° and 30°

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

7 **Inclined**

Vertical

37 **Axial trace of small antiforms in metamorphic rocks**

62 **Lineation of porphyroblasts**

Moraine crest—Crest of lateral and end moraines

Thermal spring

Gravel pit

Quarry

Location of radiocarbon sample—Radiometrically dated using the ^{14}C method

GL146 **Location and identification number of geochemical rock sample (see Table 1 and/or Appendix A in booklet; from Unruh and others, 2001; Budahn and others, 2002)**

GL-100 **Location and identification number of rock sample with geochemical analysis and $^{40}Ar/^{39}Ar$ age date (see Table 1 and Appendix A in booklet; Unruh and others, 2001; Budahn and others; 2002 Kunk and others, 2002)**

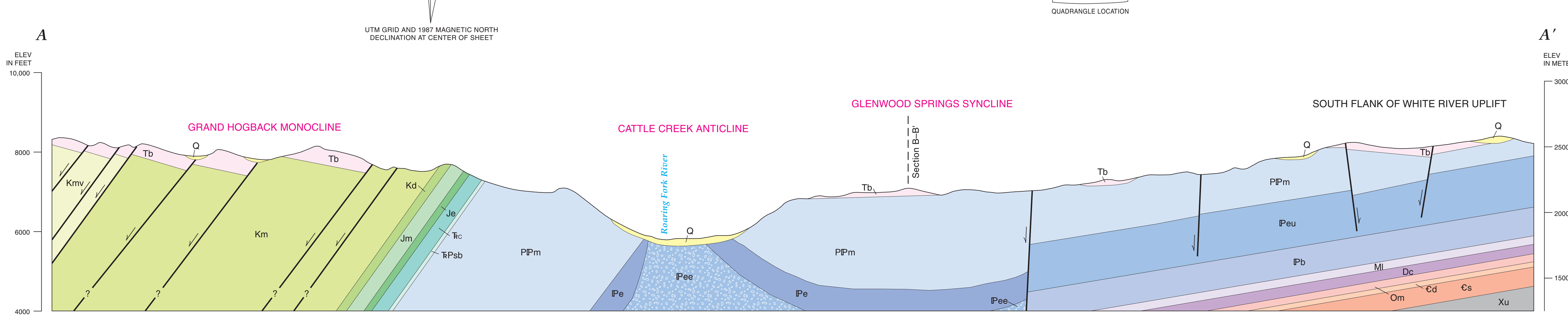
J06-GC1 **Location and identification number of rock sample with preliminary unpublished $^{207}Pb/^{206}Pb$ age date**

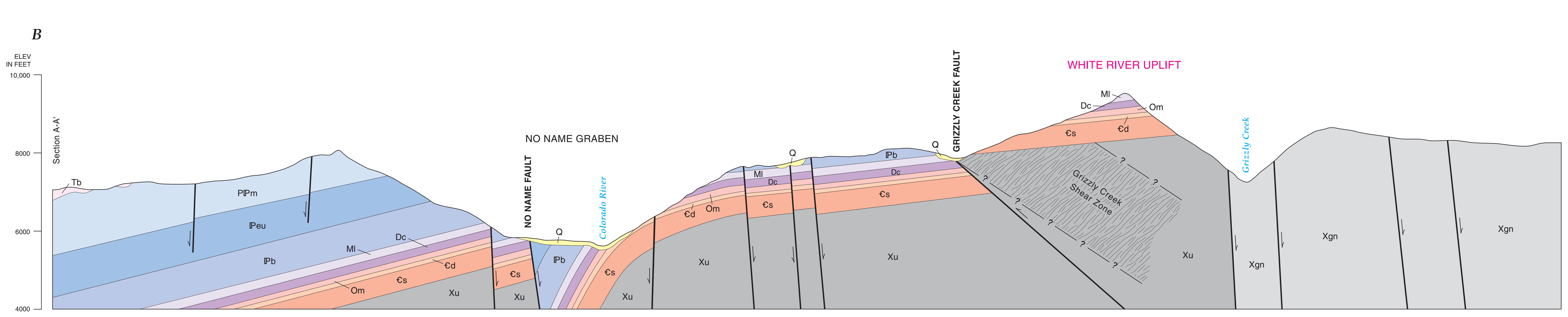
Sinkhole in surficial deposits

A——A′ **Alignment of cross section**

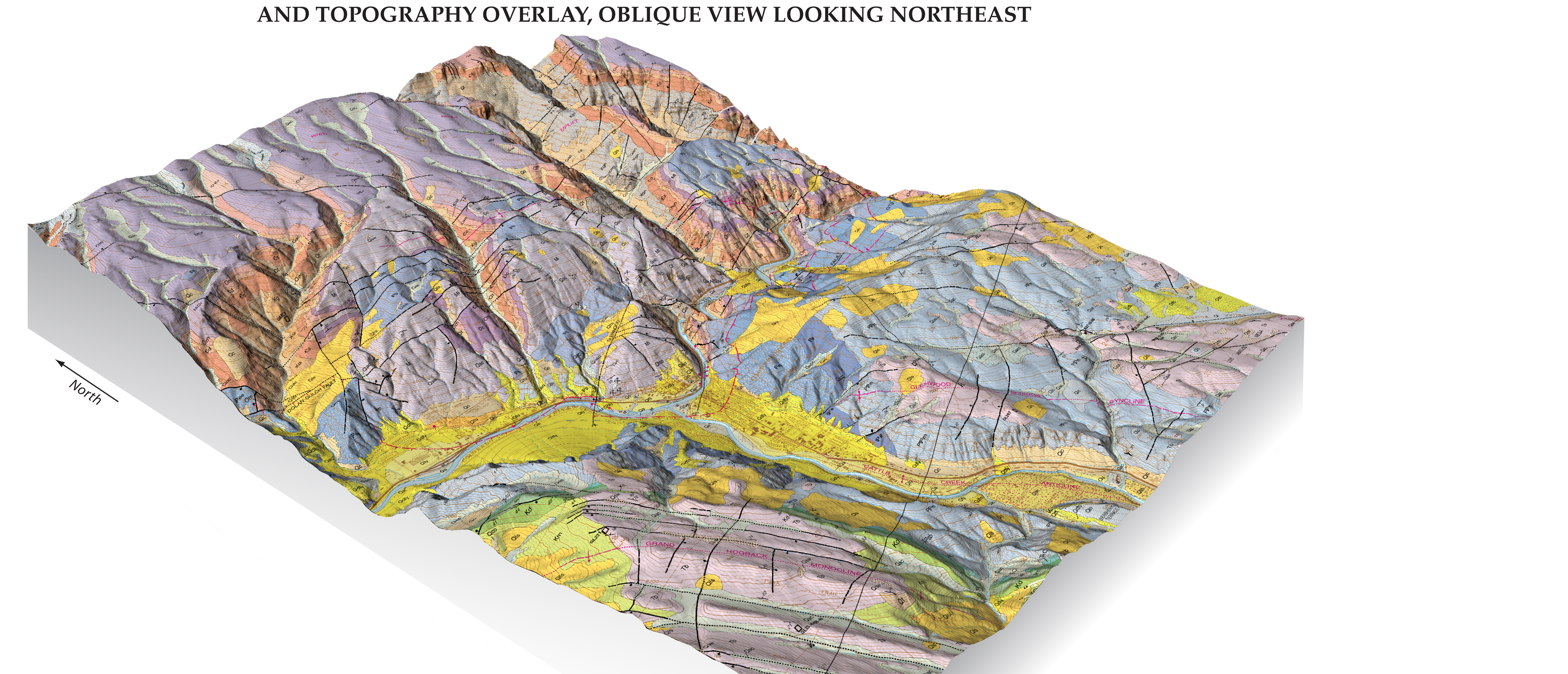
ACKNOWLEDGEMENT

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





SHADED-RELIEF MAP OF THE GLENWOOD SPRINGS QUADRANGLE WITH GEOLOGY AND TOPOGRAPHY OVERLAY, OBLIQUE VIEW LOOKING NORTHEAST



GEOLOGIC MAP OF THE GLENWOOD SPRINGS QUADRANGLE, GARFIELD COUNTY, COLORADO

By Robert M. Kirkham, Randall K. Streufert, James A. Cappa, Colin A. Shaw, Joseph L. Allen, and James V. Jones

2008

Bill Ritter Jr., Governor
State of Colorado

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Vincent Matthews
State Geologist and Director
Colorado Geological Survey