USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE STORM KING MOUNTAIN QUADRANGLE, GARFIELD COUNTY, COLORADO

By

Bruce Bryant, Ralph R. Shroba, Anne E. Harding, and Kyle E. Murray

2002

Pamphlet to accompany
MISCELLANEOUS FIELD STUDIES MAP
MF–2389

DESCRIPTION OF MAP UNITS

INTRODUCTION

Surficial deposits shown on the map are estimated to be at least 1 m thick. Fractional map symbols (for example, Qlo/Qto) are used where loess (Qlo) mantles older surficial deposits and the underlying deposits have been identified. Thin, discontinuous colluvial deposits, residual material on bedrock, and some of the small artificial fills were not mapped. Areas underlain by the Wasatch Formation, the Mancos Shale, and the Eagle Valley Formation, especially, have small unmapped colluvial deposits. Also not mapped are four elongate areas above mined coal beds on the north side of the Grand Hogback, near Coal Ridge and Horse Mountain, where the ground surface is highly oxidized, fractured, and prone to subsidence (Stover and Soule, 1985).

Divisions of Pleistocene time correspond to those of Richmond and Fullerton (1986). Age assignments for surficial deposits are based chiefly on the degree of modification of original surface morphology, height above stream level, and degree of soil development. Age assignments for units Qtt, QTd, and Tgy are inferred chiefly by three long-term rates of incision of dated basalt flows near Glenwood Canyon by the Colorado River and its tributaries within 60 km of the map area. They are 0.24 m/k.y. in the past 0.6 m.y. by Rock Creek for the Rock Creek flow near the town of McCoy, Colo., (Larson and others, 1975), 0.29 m/k.y. in the past 1.4 m.y. by the Roaring Fork River for the flows at Triangle Peak between Basalt and Aspen, Colo., and 0.24 m/ k.y. in the past 3 m.y. by the Colorado River for the Gobbler Knob flow about 14 km east of Glenwood Springs, Colo., (Streufert and others, 1997; Kirkham and others, in press; Kunk and others, 2001; Kunk and others, in press). Tentative correlations of units Qfp, Qto, and Qtt with other alluvial units are based chiefly on the height of the alluvial units above stream level and the geomorphic relations of the alluvial unit to moraines of known or inferred ages.

Soil-horizon designations are those of the Soil Survey Staff (1975), Guthrie and Witty (1982), and Birkeland (1999). Most of the surficial deposits are calcareous and contain different amounts of primary and secondary calcium carbonate; stages of secondary calcium carbonate morphology (referred to as stages I through IV Bk or K horizons in this report) are those of Gile and others (1966). Grain sizes given for the surficial deposits are based on visual estimates and follow the modified Wentworth scale (American Geological Institute, 1982). In descriptions of surficial map units, the term “clast” refers to the fraction greater than 2 mm in diameter, whereas the term “matrix” refers to particles less than 2 mm in size. Dry matrix colors of the surficial deposits in the map area were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). The colors of the surficial deposits in the map area correspond to those of the sediments and (or) bedrock from which they were derived. Surficial deposits derived from non-red sediments and bedrock are commonly light brownish gray (2.5Y 6/2), pale yellow (2.5Y 7/4), light gray (10YR 7/2), very pale brown (10YR 7/3, 8/3, 7/4, and 8/4), pale brown (10YR 6/3), light yellowish brown (10YR 6/4), light brown (7.5YR 6/4), and pink (7.5YR 7/4). Those derived from red sediments and bedrock are commonly light reddish brown (5YR 6/4 and 2.5YR 6/4), reddish brown (5YR 5/4 and 2.5YR 5/4), reddish yellow (5YR 6/6), light red (2.5YR 6/6), and red (2.5YR 5/6). Colors of bedrock units are according to Goddard and others (1948).

In this report the term “colluvium” includes mass-wasting (gravity-driven) deposits as well as sheetwash deposits. The term “piping” refers to subsurface erosion chiefly along desiccation joints by percolating water, which commonly removes silt to medium sand-size material and produces tabular and circular subsurface conduits that are a few centimeters to as much as a few meters in diameter. As used in this report the term “hydrocompaction” refers to any water-induced decrease in volume detected at or near the ground surface that is produced by a decrease in void space resulting from a more compact arrangement of particles and (or) the dissolution and collapse of rock fragments or matrix material. The term “expansive soils” includes both pedogenic soil and surficial deposits that expand when wet and shrink when dry. Measurements in this report are in metric units except for the total depth of drill holes from drilling records that are reported on the map in feet. A conversion table is provided for those more familiar with English units (table 1). A review of the divisions of geologic time used in this report is also provided (table 2).

Table 1. Factors for conversion of metric units to English units to two significant figures

Multiply	By	To obtain
centimeters (cm)	0.39	inches (in.)
meters (m)	3.3	feet (ft)
kilometers (km)	0.62	miles (mi)
kilograms per cubic meter (kg/m^3)	0.062	pounds per cubic foot (lb/ft^3)

Table 2. Definitions of divisions of geologic time used in this report (Palmer and Geissman, 1999)

ERA	Period	Epoch	Age (years)
CENOZOIC	Quaternary	Holocene	0 to 10 thousand
		Pleistocene	10 thousand to 1.8 million
	Tertiary	Pliocene	1.8 to 5 million
		Miocene	5 to 24 million
		Oligocene	24 to 34 million
		Eocene	34 to 55 million
		Paleocene	55 to 66 million
MESOZOIC	Cretaceous		65 to 144 million
	Jurassic		144 to 206 million
	Triassic		206 to 248 million
PALEOZOIC	Permian		248 to 290 million
	Pennsylvanian		290 to 323 million
	Mississippian		323 to 354 million
	Devonian		354 to 417 million
	Silurian		417 to 443 million
	Ordovician		443 to 490 million
	Cambrian		490 to 543 million
LATE PROTEROZOIC			543 to 900 million
MIDDLE PROTEROZOIC			900 to 1,600 million
EARLY PROTEROZOIC			1,600 to 2,500 million

SURFICIAL UNITS

Artificial-fill deposits—Earth and rock fragments placed in the channel and flood plain of the Colorado River, mine dumps, and trash and other material in landfills

af **Artificial fill (latest Holocene)**—Compacted and uncompacted fill material composed mostly of silt, sand, rock fragments, and, locally, trash. Mapped in the channel and flood plain of the Colorado River, beneath segments of Interstate 70 and the nearby tracks of the Denver and Rio Grande Western Railroad, and in the Glenwood Springs landfill and coal mine dumps. Unit locally includes small areas of flood-plain and stream-channel deposits (Qfp), younger fan alluvium and debris-flow deposits (Qfy), younger terrace alluvium, undivided colluvium (Qc), and undivided alluvium and colluvium (Qac). The Glenwood Springs landfill, west of South Canyon Creek, contains organic and inorganic trash. The inorganic portion probably consists chiefly of plastic, metal, wood, and concrete. The configuration of the landfill shown on the map is constantly changing, due to continued filling. The configuration of the landfill is that of the summer of 1995. Thickness is generally less than 10 m

Alluvial deposits—Silt, sand, and gravel in flood plains, stream channels, and terraces along the Colorado River and Canyon Creek

Qfp **Flood-plain and stream-channel deposits (Holocene and late Pleistocene?)**—Chiefly clast-supported, slightly bouldery, pebble and cobble gravel with a sand matrix that is locally overlain by gravelly sand to sandy silt. Poorly to moderately well sorted and poorly to well bedded. Clasts are commonly subangular to rounded; their lithologies reflect those of the bedrock in the upstream areas. Unit occurs along the Colorado River and along Canyon Creek upstream of the till (Qti) that forms the terminal moraines near the junction of Canyon Creek and East Canyon Creek. Deposits along Canyon Creek may contain more sand and silt than those along the Colorado River. Unit locally includes younger fan alluvium and debris-flow deposits (Qfy), low terrace deposits that are commonly less than 5 m above modern stream level, and sheetwash deposits (Qsw), and locally may include some organic-rich deposits upstream of the moraines. Upper part of unit may be a complex of cut-and-fill deposits of Holocene and late Pleistocene(?) age. Lower part of unit is probably equivalent, at least in part, to the younger terrace alluvium. Unit is tentatively correlated with deposits in terrace T8 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo. Low-lying areas are prone to periodic flooding. Thickness along the Colorado River is greater than 15 m near the western boundary of the map area (Colorado Highway Department, unpub. data); maximum thickness in the map area along the Colorado River may be about 20 m; maximum thickness along Canyon Creek may be 25 m or more

Qty **Younger terrace alluvium (late Pleistocene)**—Not mapped separately. Stream alluvium that underlies terrace remnants that are about 12 m above the Colorado River. Unit consists mostly of a poorly sorted, clast-supported, slightly bouldery, cobbly, pebble gravel with a sand matrix. Unit is overlain by about 1–3 m of loess (Qlo) and locally by unmapped younger fan deposits (Qfy). This alluvium is probably equivalent in part to outwash of the Pinedale glaciation, which is about 12–35 ka (Richmond, 1986, chart 1A), and is equivalent to unit Qty mapped in the New Castle (Scott and Shroba, 1997), Silt (Shroba and Scott, 2001), and Rifle (Shroba and Scott, 1997) 7.5-minute quadrangles west of the map area. These terrace remnants are tentatively correlated with deposits in terraces T7 and T6 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo., and with deposits in terraces A and B of Bryant (1979) farther upstream between Woody Creek and Aspen, Colo.

Qto **Older terrace alluvium (late middle Pleistocene)**—Stream alluvium that underlies terrace remnants 40–50 m above the Colorado River. Unit mostly is a poorly to moderately well sorted, clast-supported, bouldery, pebble and cobble gravel and cobbly pebble gravel with a sand matrix that is locally overlain by about 5–9 m of sand and pebbly sand that probably contains thin beds and lenses of pebble gravel. Some of the sandy alluvium in the upper part of the unit was probably contributed by tributary streams. Locally thin beds of sandy pebble gravel near the base of the unit are weakly cemented by fine-grained calcium carbonate. Clasts are chiefly subrounded to rounded sandstone, gneiss, quartzite, basalt, granodiorite(?), limestone, and dolomite deposited by the Colorado River and by Canyon Creek near its confluence with the Colorado. Alluvium along the Colorado River upstream of Canyon Creek contains abundant basalt boulders, some of which are as long as 2 m. Unit is locally mantled by 2.5–4 m of loess (Qlo) and by older fan alluvium and debris-flow deposits (Qfo). The morphologic development of the soil that is formed in the top of the unit, and locally in the lower of two loess sheets that locally mantle the unit in the adjacent New Castle 7.5-minute quadrangle (Scott and Shroba, 1997), suggests that unit Qto is of Bull Lake age (Hall and Shroba, 1993; Nelson and Shroba, 1998) and may be about 140–150 ka (Pierce and others, 1976; Pierce, 1979) or about 130–300 ka (late middle Pleistocene; Richmond, 1986, chart 1A). Unit Qto is equivalent to unit Qto mapped in the New Castle (Scott and Shroba, 1997), Silt (Shroba and Scott, 2001), and Rifle (Shroba and Scott, 1997) 7.5-minute quadrangles west of the map area. Unit Qto is tentatively correlated with deposits in terraces T5 and T4 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits in terrace C of Bryant (1979) farther upstream between Woody Creek and Aspen. Exposed thickness is 18 m; maximum thickness is possibly about 40 m

Qtt **Oldest terrace alluvium (middle and early Pleistocene)**—Stream alluvium that underlies small terrace remnants that are about 65, 90, 195, and 225 m above the Colorado River mostly downstream of its confluence with Canyon Creek. Unit is mostly a poorly sorted, clast-supported, slightly bouldery, pebble- and cobble-gravel with a sand matrix. It locally consists of thin (10–40 cm) lenses and beds of sandy silt, silty sand, and sandy pebble gravel. Unit locally grades upward into about 0.5 m of moderately well sorted, clast-supported, pebble gravel with a sand matrix that is overlain by about 0.5–1 m of slightly pebbly sand. Clasts are mostly subrounded to rounded and are derived from a variety of sedimentary, igneous, and metamorphic rocks in the upstream areas. Many pebbles and cobbles of biotite-bearing rocks in the upper part of the unit are weathered to gruss. A stage III K soil horizon is locally present in the top of the unit. Unit is mantled by 2–4 m of loess (Qlo) and locally by about 5–10 m of sandstone-rich older fan alluvium and debris-flow deposits (Qfo), which is overlain by loess. The loess mantle locally consists of two or more sheets. The age of the 90-m-terrace deposits relative to those of other terrace deposits at similar heights along major streams within 50 km of the map area that contain or are overlain by Lava Creek B volcanic ash (about 640 ka; Lanphere and others, 2002) is uncertain, due to the dissolution and flowage of subsurface evaporite deposits (Kirkham and others, 2001). Unit Qtt is equivalent to unit Qtt mapped at similar heights above the Colorado River in the New Castle (Scott and Shroba, 1997), Silt (Shroba and Scott, 2001), and Rifle (Shroba and Scott, 1997) 7.5-minute quadrangles west of the map area. Unit Qtt is tentatively correlated with deposits in terraces T3 and T2 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, and with deposits in terrace D of Bryant (1979) farther upstream between Woody Creek and Aspen. Exposed thickness is 6–9 m; maximum thickness is possibly about 25 m

Alluvial and colluvial deposits—Clay, silt, sand, and gravel in flood plains; in fans on flood plains and terraces; in pediment deposits on a gently sloping surface cut on bedrock; and in sheets of pebbly silty sand that locally mantles valley bottoms and the adjacent valley sides and hill slopes

Qfy **Younger fan alluvium and debris-flow deposits (Holocene and latest Pleistocene)**—Mostly poorly to very poorly sorted, poorly stratified, clast- and matrix-supported, slightly bouldery, pebble and cobble gravel with a silty sand matrix, and locally pebbly and cobbly silty sand that contains thin (10–40 cm) beds and lenses of sand, pebble gravel, and cobbly pebble gravel. Deposits derived from the upper and lower members of the Mancos Shale (Kmu, Kml) have a clayey silt matrix that is sticky when wet and has prominent shrinkage cracks when dry. Some of these deposits may contain expansive clays and may have high shrink-swell potential. Unit locally contains boulders as long as 2 m; some of the larger boulders were probably deposited by debris flows. Unit is nonbedded to poorly bedded; beds are commonly less than 1 m thick. Clasts are commonly angular to subangular sandstone north of the Colorado River and angular to subangular sandstone, angular to subrounded basalt, and locally angular to subangular shale and siltstone south of the Colorado River. Unit is slightly incised by shallow channels and was deposited chiefly by small intermittent streams and debris flows that are graded to the flood plains of modern streams (Qfp) and to the tops of terraces that are underlain by younger terrace alluvium. Locally includes minor, unmapped, undivided alluvium and colluvium (Qac) and sheetwash deposits (Qsw). Beds of silty sand are prone to piping and gullying. Surface is locally subject to flooding and debris-flow deposition. Exposed thickness is 3–20 m; maximum thickness is probably about 25 m

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Chiefly undivided flood-plain and stream-channel deposits (Qfp), younger fan and debris-flow deposits (Qfy), younger debris-flow deposits (Qdy), and sheetwash deposits (Qsw). Some of these deposits probably grade laterally and vertically into each other. The alluvial deposits typically consist of interbedded sand, pebbly sand, and pebble gravel and range from thin-bedded (0.5–15 cm), clayey, silty sand to thick-bedded (>1 m), poorly sorted, clast- and matrix-supported, slightly bouldery, pebble and cobble gravel with a sand matrix. Sheetwash deposits are typically pebbly sand to clayey silt. Alluvial deposits form flood plains, low terraces, and small fans along small perennial streams and some of the larger intermittent streams that are tributary to the Colorado River. Sheetwash deposits locally mantle the valley bottoms and the adjacent valley sides and hill slopes. Low-lying areas are prone to periodic flooding and debris-flow deposition. Deposits derived from the upper and lower members of the Mancos Shale (Kmu, Kml) commonly contain more silt and clay than those derived from other bedrock units. Deposits that are composed of well-sorted and silty sand are prone to piping and gullying. Some of the deposits derived from the Mancos may contain expansive clays and have high shrink-swell potential. Exposed thickness of the alluvial deposits is 1–9 m; maximum thickness probably about 12 m. Exposed thickness of the colluvial deposits is 1–2 m; maximum thickness is probably about 5 m. The post-glacial sediments, which accumulated above the lateral moraine that dams the south end of the valley of Bearwallow Creek, may be as much as 90 m thick and may include some lacustrine deposits

Qfo **Older fan alluvium and debris-flow deposits (late? and middle? Pleistocene)**—Mostly poorly to very poorly sorted, clast- and matrix-supported, slightly bouldery, pebble and cobble gravel with a silty sand matrix, sandy pebble gravel, pebbly sand, and locally pebbly and cobbly silty sand. Clasts are chiefly angular to subangular sandstone and locally shale and siltstone. Nonbedded to poorly bedded; commonly contains discontinuous beds and lenses. Unit has a slightly dissected surface that is mantled by about 1–3 m of loess

(Qlo). Deposited by small intermittent streams graded to tops of terrace remnants composed of older terrace alluvium (Qto) and oldest terrace alluvium (Qtt) along the Colorado River. Locally includes sheetwash deposits (Qsw). Exposed thickness is 1–8 m; maximum thickness is possibly about 25 m

Qp **Pediment deposit (middle Pleistocene)**—Gravelly alluvium and debris-flow deposit that overlies a gently sloping surface cut on the upper member of the Mancos Shale (Kmu) north of the Colorado River at the western boundary of the map area. Mostly poorly sorted, clast-supported, nonbouldery to bouldery, cobbly pebble gravel with a sandy silt matrix, and thin beds and lenses of poorly sorted, clast- and matrix-supported, cobbly sandy pebble gravel to pebbly silty sand. Clasts are chiefly angular to subangular sandstone. Some of the sandstone boulders in the debris-flow deposits are as long as 2 m. Unit is mantled by 2–4 m of loess (Qlo). The lower limit of the pediment deposits is about 85 m above the Colorado River. The pediment deposits appear to be graded to a terrace remnant of the oldest terrace alluvium (Qtt) that is about 65 m above the Colorado River in the adjacent New Castle 7.5-minute quadrangle (Scott and Shroba, 1997). Exposed thickness is 3 m; maximum thickness is possibly about 15 m

Tgy **Younger Neogene gravel (Pliocene or Miocene)**—Two deposits about 800 and 900 m above the Colorado River. North of the river on Storm King Mountain, the unit consists of round to subround boulders of Leadville Limestone (Ml) as much as 1.5 m in diameter and minor pebbles and cobbles of gray dolomite, pinkish-yellow chert, angular sandstone of the Maroon Formation, white chert, calcareous sandstone, yellowish gray dolomite, and conglomerate in a matrix of silty sand. The conglomerate resembles that in the conglomerate of Canyon Creek (Tcc) on the north ridge of Storm King Mountain. The clasts in the younger gravel (Tgy) indicate a source to the north. South of the Colorado River on Horse Mountain, the unit consists of angular boulders of basalt as much as 4 m long, rounded smaller boulders and cobbles of basalt, and a few cobbles of sandstone in a sandy, silty, and clayey matrix. Clast composition indicates a source to the south. The northern area of younger gravel (Tgy) is similar in composition and may be somewhat similar in age to the gravel (Tg) in the adjacent New Castle 7.5-minute quadrangle, which is about 700–760 m above the Colorado River (Scott and Shroba, 1997). Estimated maximum thickness is 15 m

Colluvial deposits—Clay, silt, sand, and gravel on valley sides and hill slopes that were mobilized, transported, and deposited by gravity and sheet erosion

Qc **Colluvium, undivided (Holocene and late Pleistocene)**—Mostly clast-supported, pebble, cobble, and boulder gravel with a silty sand matrix, and gravelly, silty sand to clayey silt. Deposits derived from the upper and lower members of the Mancos Shale (Kmu, Kml) commonly contain more silt and clay than those derived from the other bedrock units. Typically unsorted to poorly sorted and unstratified to poorly stratified. Clasts are typically angular to subrounded; their lithologic composition reflects that of the bedrock and (or) the surficial deposits from which the colluvium was derived. Basalt boulders are locally as much as 3 m in diameter. The unit locally includes creep, younger debris-flow (Qdy), sheetwash (Qsw), landslide (Qls), talus (Qta), and undivided alluvium and colluvium (Qac) deposits that are too small to map separately or that lack distinctive surface morphology and could not be distinguished in the field or on aerial photographs. Some of the deposits derived from shale in the Mancos Shale, claystone in the Morrison Formation (Jm), and shale in the Mesaverde Group may contain expansive clays and have high shrink-swell potential. Deposits derived from the Eagle Valley Evaporite (IPee) are prone to hydrocompaction and subsidence owing to the dissolution of gypsum, anhydrite, and possibly halite. These minerals are damaging to untreated concrete and uncoated steel. Exposed thickness is 2–4 m; maximum thickness is about 5 m

Qdy **Younger debris-flow deposits (Holocene? and late? Pleistocene)**—Lobate and fan-shaped masses of debris and bouldery levees with well-preserved surface morphology that were deposited by sediment-charged flows. Unit is poorly exposed, but it appears to consist mostly of very poorly sorted and very poorly stratified boulders to granules supported in a matrix of silty sand, and locally includes poorly sorted, clast-supported, bouldery, cobbly pebble gravel with a silty sand matrix in levees and lenticular beds. The clasts on the deposits are mostly subangular to subrounded sandstone. Some of the clasts are as long as 1 m. The top of the younger debris-flow deposit in the northwestern part of the quadrangle is irregular and is less than 5 m above stream level. Unit probably locally includes minor steam-flow deposits. Low-lying areas of the map unit that are adjacent to stream channels are prone to periodic flooding and debris-flow deposition. Maximum thickness is possibly 25 m

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Mostly pebbly, silty sand and sandy silt that are derived chiefly from weathered bedrock and loess (Qlo) by sheet erosion.

Common on gentle to moderate slopes in areas underlain by the Wasatch Formation. Unit locally includes small deposits of loess (Qlo) and undivided alluvium and colluvium (Qac) in and along minor drainageways, and may locally include creep-derived colluvium (Qc) and younger fan (Qfy) deposits and small outcrops of the Wasatch Formation that are too small to map separately. Low-lying areas of the unit are prone to periodic sheet flooding. Exposed thickness is 2–5 m; maximum thickness is probably about 10 m

Qls **Landslide deposits (Holocene and Pleistocene?)**—Chiefly unsorted and unstratified rock debris that is commonly characterized by lobate form and hummocky topography. Many of the landslides are complex (Varnes, 1978) and commonly formed on unstable slopes that are underlain by the Eagle Valley Formation (IPe), Maroon Formation (PIPm), Mancos Shale (Kmu, Kml), Iles Formation (Ki), Williams Fork Formation (Kw), and Wasatch Formation (Twu, Twl, TKu) in the eastern part of the map area. The younger deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. Unit includes debris-slide, rock-slide, debris-slump, rock-slump, slump-earth-flow, earth-flow, and debris-flow deposits (Varnes, 1978; Cruden and Varnes, 1996). The sizes and lithologies of the clasts and the grain-size distributions of the matrices of these deposits reflect those of the displaced bedrock units and surficial deposits. Landslide deposits are prone to continued movement or reactivation due to natural as well as human-induced processes. Deposits derived from the Mancos Shale and the Wasatch Formation are clay rich. Deposits derived from the Leadville Limestone (Ml), basalt (Tb), the Maroon Formation (Pms, PIPm, IPml), the Dakota Sandstone (Kd), the Williams Fork Formation (Kw), and the Iles Formation (Ki) may contain blocks of rock as long as 5 m. Unit locally includes unmapped sheetwash (Qsw) and creep-derived colluvium (Qc) deposits that are too small to map. Mancos-derived clay in landslide deposits may be expansive and have high shrink-swell potential. Deposits derived from the Eagle Valley Evaporite (IPee) are prone to hydrocompaction and subsidence owing to the dissolution of gypsum and anhydrite. These minerals are damaging to untreated concrete and uncoated steel. Exposed thickness is 2–5 m; maximum thickness is possibly 50 m

Qta **Talus deposits (Holocene and late Pleistocene)**—Chiefly crudely sorted and stratified, angular, bouldery to pebbly rubble on steep slopes produced chiefly by rockfall from outcrops of Proterozoic to Mississippian bedrock in the northern part of the map area and from outcrops of Dakota Sandstone (Kd) in the southern part of the area. The matrix is mostly sand and silt; some of it may be of eolian origin. Upper part of unit locally lacks matrix. Unit includes minor colluvial deposits (Qc). Small talus deposits in the valleys of Canyon, East Canyon, and Possum Creeks were not mapped. Maximum thickness is possibly about 30 m

Qdo **Older debris-flow deposits (middle? and early? Pleistocene)**—Mostly debris-flow deposits and minor amounts of other colluvium deposits and stream-channel and fan alluvium that commonly overlie gently sloping surfaces on Mancos Shale on the north flank of the Grand Hogback and on the drainage divide between Paradise and South Canyon Creeks in the southern part of the map area. The debris-flow deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of slightly clayey, silty sand to slightly sandy silty clay, and locally include lenticular beds of poorly sorted, clast-supported bouldery, cobbly pebble gravel with a silty sand matrix. Clasts are commonly randomly oriented and angular to subangular. Clasts in deposits north of the Colorado River are mainly sandstone. Clasts in deposits on the north flank of the Grand Hogback are mainly sandstone as long as 3 m. Some of the eastern deposits on the north flank of the Grand Hogback also contain basalt boulders, some as long as 4 m that were probably derived in part from younger Neogene gravel (Tgy) on Horse Mountain. Some of the deposits on the north flank of the Grand Hogback are cut by gullies as much as 70 m deep, and debris-flow-mantled ridges there are locally as much as 30 m above the general level of the adjacent debris-flow deposits in unit Qdo. The deposits on the north flank of the Grand Hogback are probably locally mantled by loess (Qlo), and by younger debris-flow deposits (Qdy) and other colluvial deposits (Qc) on their steep upper parts. The lower extent of the debris-flow deposits on the north flank of the Grand Hogback is about 80–120 m above the Colorado River. The lower parts of these deposits have been incised as much as 80 m. The debris-flow deposits on the drainage divide between Paradise and South Canyon Creeks are about 140–180 m above South Canyon Creek. Exposed thickness is 7 m; maximum thickness is possibly about 30 m

QTd **Oldest debris-flow deposits (early Pleistocene? or Pliocene?)**—Mostly debris-flow deposits and probably a minor amount of other colluvial deposits and stream alluvium commonly on drainage divides and high surfaces along the Colorado River and South Canyon Creek in the northwestern, central, and southeastern parts of the map area. The debris-flow deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of slightly clayey, silty sand to slightly sandy, silty clay and locally may include lenses of poorly sorted, clast-supported gravel. Clasts are commonly randomly oriented and are angular to subangular. Clasts in the deposit north of the Colorado River (secs. 21 and 28, T. 5 S., R. 90 W.) are mainly sandstone of the Maroon Formation. Clasts in the two deposits along South Canyon Creek (secs. 3 and 13–14, T. 6 S., R. 90 W.) are mainly rounded sandstone pebbles and cobbles and boulders as long as 3 m and basalt boulders as long as 3 m. Clasts in the elongate deposit on the drainage divide between South Canyon Creek and Alkali Creek (secs. 15, 22, and 27, T. 6 S., R. 90 W.) are mainly subangular basalt boulders as long as 3 m and rounded pebbles and cobbles of quartzite, sandstone, basalt, and rare pegmatite. This deposit probably accumulated on the floor of a former valley. The deposits are about 290–440 m above the Colorado River and about 260–380 m above South Canyon Creek. Exposed thickness is 10 m; maximum thickness is about 15 m

Glacial deposits—Mostly ice-deposited silt, sand, and gravel in moraines and ground moraine near and above the junction of Canyon Creek and East Canyon Creek and in the upper part of the Possum Creek drainage

Qti **Till (late and middle? Pleistocene)**—Stony deposits that typically form steep-sided bouldery and hummocky lateral and end moraines and ground moraine in the valleys of Canyon Creek, East Canyon Creek, Possum Creek, and Dry Possum Creek near the northeastern corner of the map area. Unit is mostly unstratified, unsorted, matrix-supported and locally clast-supported deposits composed of boulders to granules in a matrix of slightly silty, poorly sorted sand. Clasts are mostly angular to rounded and include gneissic granite, biotite-quartz-feldspar gneiss, mica schist, amphibolite, dolomite, limestone, quartzite, sandstone, and siliceous limestone. Boulders of Precambrian rocks on the moraines are as long as 7 m. Closed depressions surrounded by low ridges are common on the terminal moraines. The closed depressions are probably partly filled by unmapped loess (Qlo) or loess-derived sheetwash deposits (Qsw). Unit is locally overlain by younger fan deposits (Qfy), loess (Qlo), sheetwash deposits (Qsw), landslide deposits (Qls), and talus deposits (Qta); and it may locally include deposits of stratified drift. Terminal moraines in the valley of Canyon Creek are well preserved and are narrowly breached by stream erosion, whereas those in the valley of East Canyon Creek were modified or removed by stream erosion and landsliding. The lower limit of glaciation is at an altitude of about 5,900 ft along Canyon Creek. Much of the unit is probably of Pinedale age (about 12–35 ka, Richmond, 1986, chart 1A); although some of the outermost glacial deposits near the junctions of Canyon and Bearwallow Creeks and East Canyon and Possum Creeks are probably of Bull Lake age (about 140–150 ka; Pierce and others, 1976, and Pierce, 1979, or about 130–300 ka; Richmond, 1986, chart 1A) and some of them may be of pre-Bull Lake age. Exposed thickness 1–10 m; maximum thickness is possibly about 150 m in the large lateral moraine on the west side of Canyon Creek

Eolian deposits—Wind-deposited sand, silt, and clay that mantles level to gently sloping surfaces

Qlo **Loess (late and middle? Pleistocene)**—Wind-deposited, nonstratified, friable when dry, slightly plastic to plastic when wet, calcareous (6–18 percent calcium carbonate), slightly clayey, sandy silt. The grain-size distribution of the carbonate-free fraction of unweathered loess in and near the map area commonly consists of 22–46 percent sand (2–0.05 mm), 43–62 percent silt (0.05–0.002 mm), and 15–18 percent clay (<0.002 mm). About 55–75 percent of the unweathered loess is composed of very fine sand (0.01–0.05 mm) plus coarse silt (0.05–0.02 mm). Median grain size ranges from 0.03 to 0.05 mm (Shroba, 1994). Unit is prone to sheet erosion, gullying, and hydrocompaction due to several factors, including its low dry density (about 1,440 kg/m^3), grain size, sorting, and weakly developed vertical desiccation cracks. Locally includes loess-derived sheetwash (Qsw) and creep-derived colluvium (Qc) deposits that are too small to show on the map. Deposited during five or more episodes of eolian activity (Shroba, 1994). Deposition may have continued into Holocene time. Possible sources for the loess include flood-plain deposits of the Colorado River and its major tributaries; sparsely vegetated outcrops of Tertiary siltstone and mudstone in the Piceance Basin west of the map area (Tweto, 1979); and large areas of exposed sandstone in the Canyonlands region in southeastern Utah (Whitney and Andrews, 1983). However, the relatively high content of very fine sand and coarse silt and the relatively high coarse silt/total silt ratios (about 0.7) of the unweathered loess suggest: (1) a relatively short distance of eolian transport and (2) the flood plain of the Colorado River, which aggraded primarily during glacial times in response to glacial and periglacial activity upstream, is the likely source of much of the loess (Shroba, 1994).

The mapped distribution of loess is approximate, because it lacks distinct topographic expression. Loess is mapped separately only in two areas along the west edge of the map. Unit commonly mantles level to gently sloping surficial deposits that are as old or older than the younger terrace alluvium. Younger terrace alluvium is mantled by one loess sheet. Older terrace alluvium (Qto) is locally mantled by two loess sheets. Pediment deposits (Qp) and the oldest terrace alluvium (Qtt) are locally mantled by two or more loess sheets. The soil that is formed in the upper loess sheet on the older terrace alluvium commonly consists of the following sequence of horizons: an organic-enriched A horizon about 20 cm thick; a cambic B horizon about 10–20 cm thick; a weak to moderate prismatic, argillic B horizon about 20–40 cm thick; and a stage I Bk horizon greater than 75 cm thick. The soil that is formed in the lower loess sheet on the older terrace alluvium contains more clay and calcium carbonate than the soil in the upper loess sheet and commonly consists of the following horizons: a cambic B horizon about 20 cm thick; a moderate to strong prismatic, argillic B horizon about 55–75 cm thick that contains weak stage I–II calcium carbonate; a weak stage III K horizon about 40 cm thick; and a stage I–II Bk horizon about 30 to greater than 60 cm thick. Where the upper loess sheet is composed of very sandy silt, the soil formed in it has a weakly developed, nonprismatic argillic B-horizon that is about 35 cm thick. If the upper and lower loess sheets on the older terrace alluvium correlate with loess units A and B, respectively, that are on and adjacent to the eastern Snake River Plain in eastern Idaho, then (1) the uppermost loess sheet in the map area accumulated between about 10–70 ka and is of late Pleistocene age and (2) the underlying loess sheet accumulated during an interval that ended shortly after 140–150 ka and is partly or entirely of latest middle Pleistocene age (Pierce and others, 1982). Exposed thickness is 2–4 m; maximum thickness is possibly about 5 m

Qlo/Qty **Loess on younger terrace alluvium (Pleistocene)**

Qlo/Qto **Loess on older terrace alluvium (Pleistocene)**

Qlo/Qtt **Loess on oldest terrace alluvium (Pleistocene)**

Qlo/Qp **Loess on pediment deposits (Pleistocene)**

Qlo/Qfo **Loess on older fan alluvium and debris-flow deposits (Pleistocene)**

BEDROCK UNITS

Tcc **Conglomerate of Canyon Creek (Pliocene or Miocene)**—Light-brown, white, and very pale gray, poorly to moderately well sorted, clast-supported and locally matrix-supported, locally bouldery cobble and pebble conglomerate containing a few lenses of pale-red, medium- to coarse-grained sandstone and pebbly sandstone. Angular to round clasts are mostly 2–6 cm in diameter, but some are as much as 1 m in diameter. In many outcrops the clasts are sandstone and limestone from the Maroon and Eagle Valley Formations; in some outcrops, especially near the intersections of secs. 14, 15, 22, and 23, T. 5 S., R. 90 W., many of the clasts are limestone, dolomite, sandstone, and quartzite from the Cambrian through Mississippian units. A few outcrops have a few clasts of Proterozoic gneissic granite. Throughout the unit the texture is relatively uniform. The conglomerate is interpreted to have been deposited close to its source by streams with high gradients. The conglomerate on the north ridge of Storm King Mountain is slightly better sorted and contains fewer cobbles than the conglomerate near Canyon Creek. Unit was informally named by Bass and Northrop (1963) for outcrops along Canyon Creek in the Storm King Mountain quadrangle and was subsequently mapped partly as Browns Park Formation (Miocene) and partly as Eagle Valley Formation (Pennsylvanian) by Tweto and others (1978). Maximum thickness is about 240 m

Tb **Basalt and trachybasalt (Miocene)**—Four to six flows of olivine basaltic rock crop out near the southeastern corner of the map area. Flow tops are vesicular, and the thickest vesicular zone is on the top flow. The basaltic rock consists of euhedral to subhedral olivine phenocrysts as much as 1 mm long variably altered to brown iddingsite, laths of plagioclase (An 55–60), as much as 0.5 mm long, interstitial monoclinic pyroxene (generally 0.1–0.2 mm in diameter, but as much as 0.4 mm long), opaque mineral, and alteration products from interstitial glass and mafic minerals. Recent mapping (Kirkham and others, 1997, 1996; Carroll and others, 1996) has shown that these flows were not derived from Sunlight Peak about 8 km to the south, as Bass and Northrop (1963) suggested, and their source remains unknown. Larson and others (1975) mapped the basaltic rocks at Sunlight Peak and in this map area as part of their group 2 (14–9 Ma), and the lowest exposed flow in the Sunlight Peak center about 9 km S. 5° E from the southeast corner of the Storm King Mountain quadrangle has an $^{40}Ar/^{39}Ar$ whole-rock correlation age of 10.14±0.26 Ma (Kunk and Snee, 1998; Kunk and others, in press). According to chemical analyses, a flow about 1 km south-southeast of the southeast corner of the Storm King Mountain quadrangle is a basalt (Kirkham and others, 1996), and a sample from 1 km east of the southern part of the quadrangle is a trachybasalt (Kirkham and others, 1997). Maximum thickness is about 50 m

Tgo **Older gravel (Miocene)**—Basaltic rock-rich bouldery gravel containing basaltic boulders as much as 2.5 m in diameter and rounded pebbles and cobbles of white quartzite from the Dakota Sandstone and less common small pebbles and granules of chert. A single small deposit near the southeastern corner of the map area (eastern part of sec. 25, T. 6 S., R. 90 W.). Overlain by 9.7–10.5 Ma basaltic flows to the south in the Center Mountain 7.5-minute quadrangle (Carroll and others, 1996). Maximum thickness is about 25 m

Wasatch Formation (lower Eocene and Paleocene)

Twu **Upper member (lower Eocene and Paleocene)**—Gray, light-gray, brownish-gray, grayish-red, pale-red, pale-reddish-brown, and greenish-gray siltstone and claystone and yellowish-gray, very light gray, yellowish-gray, gray, light-greenish-gray, and pale-olive-gray, fine- to medium-grained, cross-bedded sandstone. Fossil plant fragments are locally preserved in the sandstone. Some sandstone beds form outcrop-scale, lens-shaped channels cut into the siltstone and claystone. Siltstone and claystone beds are poorly exposed but constitute much more than one-half of the formation. Clayey soils are widespread on the Wasatch, and it is subject to landsliding. Base mapped at the first occurrence of pebble conglomerate. Incomplete section in map area is about 1,500 m thick

Twl **Lower member (Paleocene)**—Pale-yellowish-brown, pale-red, very light gray, light-brownish-gray, grayish-pink, greenish-gray, and light-greenish-gray sandstone and pebble conglomerate and gray, grayish-red, and blackish-red claystone and siltstone. Locally contains two beds of coal and clayey coal as much as 0.5 m thick near the base. Pebble conglomerate occurs as stream-channel deposits in the sandstone and contains well-rounded pebbles of chert and porphyritic igneous rock, which contains phenocrysts of biotite and plagioclase 1–2 mm in diameter in an aphanitic matrix. The igneous pebbles are hypabyssal intrusive or extrusive volcanic rock of Late Cretaceous or Paleocene age probably fed by plutons of that age that are exposed in the Sawatch range to the east (Tweto, 1979). Unit is about 200 m thick

Ks **Sandstone, siltstone, claystone, and conglomerate (Upper Cretaceous)**—Yellowish-gray, fine- to coarse-grained sandstone locally containing chert and quartzite pebbles as much as 3 cm in diameter. Contains less resistant beds, which are generally not exposed, but are probably siltstone or claystone. Unit has a well-defined lower contact with, and is less resistant to erosion than, the Williams Fork Formation, and has a well-defined upper contact with the conglomerate rich in Late Cretaceous or Paleocene igneous rocks at the base of the Wasatch Formation. Rocks similar to those in this unit have been mapped as Ohio Creek Conglomerate by many workers (for example, Tweto and others, 1978), but detailed study and dating of palynomorphs show that many of the rocks previously called Ohio Creek at localities about 90 km west of the Storm King Mountain quadrangle represent a weathered zone at the top of the Hunter Canyon or Mesaverde Formation. This zone was designated the Ohio Creek Member of the Hunter Canyon or Mesaverde Formation by Johnson and May (1980). The upper part of the Williams Fork Formation in the Storm King Mountain quadrangle is equivalent to the Hunter Canyon or Mesaverde Formation at the localities studied by Johnson and May (1980). According to R. Farley Fleming (Volgox Inc., written commun, 1998), a sample of clayey coal collected west of South Canyon Creek from about 20 m below the base of the Wasatch Formation contains abundant well-preserved pollen, including numerous specimens of three species that are restricted to the Cretaceous and no species that are restricted to the Tertiary. The occurrence of *Aquilapollenites reticulatus* in the assemblage indicates a Maastrichtian age. Since the unit is not a weathered zone at the top of the Williams Fork Formation and has a distinctly greater proportion of siltstone and claystone than the Williams Fork, the term Ohio Creek is not used for these rocks here. Unit is 100–200 m thick

TKu **Undivided unit (Paleocene? to Upper Cretaceous)**—Contains lower part of upper member of the Wasatch Formation (Twu), lower member of the Wasatch Formation (Twl), and sandstone, siltstone, claystone, and conglomerate unit (Ks). Unit was mapped where access was denied on the south flank of the Grand Hogback

Mesaverde Group (Upper Cretaceous)

Kw **Williams Fork Formation**—Sandstone, siltstone, mudstone, shale, coal, and clinker. Upper part contains yellowish-gray, very light yellowish gray, very light gray, and white cross-bedded sandstones filling channels and occurring as sheets that generally form massive outcrops with internal stratification. Lower part has similar sandstones and thinly laminated, parallel-bedded sandstone. Some of the siltstone and shale beds contain marine fossils. Clinker consists of moderate-reddish-orange to pale-reddish-brown hornfels produced by thermal metamorphism of mudstone, siltstone, and sandstone adjacent to burnt coal seams. Near the base of the formation a clinker zone as much as 10 m thick that was derived from the Wheeler coal (shown by the line labeled **wc** on the geologic map) is traceable across the quadrangle except in the easternmost part. At South Canyon Creek the Wheeler coal (Gale, 1910) is 83 m above the base of the formation (Gill and Freeman, 1978). In 1996, the Wheeler coal was burning 700 m west and 500 m east of South Canyon Creek. Thickness is about 1,100–1,200 m

wc **Wheeler coal bed**—Thickness 1–6 m

Iles Formation—Shale, sandstone, and siltstone. Thickness about 325 m at South Canyon Creek (Gill and Freeman, 1978)

Ki **Main member**—Sandstone, shale, and siltstone. Includes Rollins Sandstone Member (Warner, 1964; Collins, 1976) at the top of the formation. Rollins is very light gray, fine-grained, thin-bedded to thick-bedded sandstone. Contains some beds of siltstone and carbonaceous shale and mudstone. Maximum thickness about 20 m.

In many places, even on steep slopes, main member does not crop out and may be thin or absent. Top of the formation is inferred where Rollins not found. Siltstone, shale, and fine-grained sandstone grade downward into dark-gray shale 165–180 m thick that locally contains grayish-orange-weathering, brownish-gray to gray limestone concretions similar in appearance to those in the underlying Mancos Shale. Thickness 170–200 m

Kic **Cozzette and Corcoran Sandstone Members**—Unit composed of an upper sandstone, a shale interval, and a lower sandstone. The upper sandstone, the Cozzette Sandstone Member (Young, 1955; Warner, 1964; Collins, 1976), is a very light gray, white, and very pale yellowish gray, thin and even-bedded to thick-bedded, fine-grained sandstone, which is 11 m thick in the eastern part of the quadrangle and 13 m in the western part. A dark-gray shale, 55 m thick in the eastern part of the quadrangle and 35 m in the western part, separates the two sandstone members. The lower sandstone, the Corcoran Sandstone Member, is a yellowish-gray-weathering, thin and even-bedded to thick-bedded, fine-grained sandstone and shaley sandstone, which is 28 m thick in the eastern part of the quadrangle and 40 m in the western part

Mancos Shale (Upper Cretaceous)—Shale and minor limestone and sandstone. About 1,450 m thick

Kmu **Upper member**—Light-gray- to medium-gray-weathering, dark-gray shale containing light-olive-gray, grayish-orange, and dark-yellowish-orange-weathering, medium-light-gray limestone concretions averaging 10 cm in diameter but as much as 1.5 m in diameter. The concretions are more numerous in the upper part of the member. Unit contains beds of dark-yellowish-orange-weathering, light-gray bentonite, which are 1–20 cm thick. Thin-bedded, fine-grained sandstone beds are as much as 2 m thick near contact with the overlying Corcoran Sandstone Member of the Iles Formation. Lower part of the member contains some beds of calcareous shale that form a transition to the underlying Niobrara Member. Lower and middle parts are well exposed in secs. 2 and 3, T. 6 S., R. 90 W.; upper part is poorly exposed. Thickness is about 1,250 m

Kmn **Niobrara Member**—Light-gray- and yellowish-gray-weathering, gray limestone, shaly limestone, and calcareous shale. Unit is generally thin bedded, but limestone beds at and near the base are as much as 1 m thick. The base of the member forms a sharp contact below the lowest limestone bed; the top of the member forms a gradational contact with the overlying upper member of the Mancos Shale and is here mapped at the most obvious change from predominantly calcareous limestone and shaley limestone to shale and calcareous shale. Unit is well exposed in roadcut along U.S. Highway 6 in the central part of sec. 34, T. 5 S., R. 90 W. and in gullies in the SW1/4 of adjacent sec. 35. Unit is 40–80 m thick

Kml **Lower member**—Predominantly dark gray shale. Upper 25 m is dark-gray shale and silty shale containing a few 1- to 6-cm-thick bentonite beds. Underlain by about 30 m of thin-bedded calcareous sandstone, siltstone, and shale and, in the upper part of this interval, a few beds of fossiliferous limestone, which have a fetid odor when broken. These beds probably represent the Juana Lopez Member of the Mancos Shale, which is widespread in the region (Merewether and Cobban, 1986; Molenaar and Cobban, 1991). Top is at sharp contact at base of lowest limestone bed in the Niobrara Member. At the bottom of the member are some beds of fine-grained sandstone in shale in a transition to Dakota Sandstone. Well exposed on either side of the valley of South Canyon Creek in sec. 2, T. 6 S., R. 90 W. and in gullies in southwest corner of sec. 35, T. 5 N., R. 90 W. Thickness is 110–170 m

Kd **Dakota Sandstone (Lower Cretaceous)**—Yellowish-gray-weathering, very light gray to white, well-cemented sandstone. Pebbles of light-gray chert and quartzite as much as 3 cm in diameter locally present at or close to base. Unit is even bedded and medium grained. Locally underlain by cross-bedded, medium-grained, light-gray sandstone and grayish-red siltstone. Many good exposures occur; the most accessible exposure is in South Canyon Creek valley in sec. 2, T. 6 S., R. 90 W. Unit has a sharp lower contact and a gradational upper contact. Thickness is 30–55 m

Jm **Morrison Formation (Upper Jurassic)**—Pale-greenish-gray to grayish-red siltstone, clayey siltstone, and claystone; white, medium-grained sandstone; and local beds of granule to pebble conglomerate containing quartz and chert clasts. Beds of medium-gray limestone in lower part. Sandstone beds in lower Morrison resemble sandstone of the Entrada Sandstone except they contain beds of pale-greenish-gray siltstone and claystone. Upper and lower contacts are sharp. Well exposed on valley walls of South Canyon Creek in sec. 2, T. 6 S., R. 90 W. Stratigraphic section in South Canyon Creek valley was measured by Craig (1959). About 150 m thick

Je **Entrada Sandstone (Middle Jurassic)**—Very light gray to white, medium-grained to very fine grained sandstone. Unit contains scattered round quartz grains; locally a bed 1.5 m thick at top of unit consists mostly of round grains (Craig, 1959). Local high-angle cross bedding, especially at base. The Entrada is well exposed on valley walls of South Canyon Creek in secs. 2, T. 6 S., R 90 W. Thickness is 20–30 m

TRc **Chinle Formation (Upper Triassic)**—Consists of three members that are not mapped separately. Uppermost red siltstone member is composed of pale- to moderate-reddish-brown and moderate-reddish-orange calcareous siltstone, silty limestone, and limestone pebble conglomerate and is 65–85 m thick. Mottled member is pale- to pale-red-purple, sandy to clayey siltstone and silty claystone and is 3–5 m thick. Gartra Member is locally present at the base of the formation as lenses of moderate-reddish-orange sandstone less than 1 m thick. It has sharp upper and lower contacts. Measured section of the Chinle Formation is 69 m thick in the South Canyon Creek valley, sec. 2, T. 6 S., R. 90 W. (Stewart and others, 1972b). Unit is 70–90 m thick

TRPs **State Bridge Formation (Lower Triassic and Permian)**—Consists of three members not mapped separately. Upper member consists of moderate-red, grayish-red, and pale-red siltstone and silty claystone and a few beds of grayish-red, greenish-gray, and light-greenish-gray, fine-grained sandstone that has a minor amount of greenish-gray mottles. Sharp contact with overlying Chinle Formation. Upper member is 17 m thick in South Canyon Creek valley (Stewart and others, 1972a). South Canyon Creek Member is greenish-gray to light-olive-gray dolomite in lower part and light- to dark-gray limestone in upper part. Member weathers yellowish gray to pinkish gray and forms conspicuous ledge between the red beds of the upper and lower members. A poorly preserved and impoverished fauna suggests a Permian age for this member (Bass and Northrop, 1950). Member is 1.7 m thick in South Canyon Creek valley (Stewart and others, 1972a). Lower member consists of grayish-red siltstone and fine-grained sandstone with a minor amount of greenish-gray mottles. Lower 5 m is dark gray to dark greenish gray to light olive gray and has a sharp contact with the underlying Schoolhouse Member of the Maroon Formation. Member is 30 m thick in South Canyon Creek valley (Stewart and others, 1972a). Measured section of the State Bridge Formation in South Canyon Creek valley, sec. 2, T. 6 S., R. 90 W., is 49 m thick (Stewart and others, 1972a)

Maroon Formation (Lower Permian to Middle Pennsylvanian)—Red sandstone, siltstone, and conglomerate, and a few beds of gray limestone. Formation is about 1,150 m thick

Pms **Schoolhouse Member (Lower Permian)**—White to grayish-black and grayish-red and pale-reddish-brown, very fine grained to very coarse grained sandstone and less common pebble to cobble conglomerate. Conglomerate contains pebbles of quartz, feldspar, quartzite, metamorphic rocks, granitic rocks, and limestone as much as 10 cm in diameter. Unit has eolian and fluvial cross bedding. Unit contains various amounts of interstitial and grain-coating solid hydrocarbons. The Schoolhouse Member has a sharp contact with the State Bridge Formation at the top and a gradational contact with main body of the Maroon Formation at the base. Unit is well exposed in sec. 2, T. 6 S., R. 90 W. on the west side of the South Canyon Creek valley, and its thickness is 40–50 m at South Canyon Creek (Johnson and others, 1990; Stewart and others, 1972a) and as much as 60 m elsewhere in the quadrangle

PIPm **Main body (Lower Permian to Middle Pennsylvanian)**—Pale-red, pinkish-gray, light-red, and grayish-red micaceous calcareous sandstone and conglomerate and grayish-red to moderate-red calcareous siltstone and mudstone. Conglomerate beds are most numerous near top of formation and contain rounded pebbles and cobbles of quartz, granite, and fine-grained metamorphic rock. Sedimentary structures include cross bedding and channel fills. Excellent exposures exist in the canyon of the Colorado River and in tributary gullies in the eastern part of the quadrangle. Thickness is about 730–830 m

IPml **Lower member (Middle Pennsylvanian)**—Grayish-red and reddish-brown sandstone and siltstone and a few beds of dark-gray and medium-gray limestone and sandy limestone and light-olive-gray silty limestone as much as 4 m thick, and gypsum and anhydrite as much as 10 m thick. The member grades eastward into very light gray sandstone, dark- to moderate-reddish-brown calcareous mudstone, and light-greenish-gray sandstone of the Eagle Valley Formation (IPe) in the Glenwood Springs 7.5-minute quadrangle (Kikham and others, 1997). Unit is well exposed in sec. 19, T. 5 S., R. 89 W. and has a thickness of 270–335 m

IPe **Eagle Valley Formation (Middle Pennsylvanian)**—Yellowish-gray, pale-yellowish-gray, brownish-gray, pale-red, pale-brown, and grayish-orange, thin-bedded, calcareous and locally micaceous sandstone; pale-grayish-red, pale-reddish-brown, light-brownish-gray, and light-medium-gray siltstone; and yellowish-gray, pale-yellowish-gray, gray, medium-gray, light-medium-gray, pale-orange, light-brownish-gray, and pale-greenish-gray limestone and silty limestone. May contain beds of gypsum and anhydrite that are covered by colluvium derived from the other rock types. Locally contains breccia composed of cemented clasts of calcareous sandstone, probably formed by collapse deformation related to dissolution of underlying evaporite beds. Sandstone locally has small-scale cross beds and channels. The limestone beds are locally fossiliferous, and Bass and Northrop (1963) reported 103 species from the Eagle Valley Formation (mapped as the Paradox Formation by Bass and Northrop). Most of their paleontological data were from the upper 120 m of the formation and indicate a Desmoinesian age. They concluded that the lower part is of Atokan age. The upper part of this unit is fairly well exposed on the valley sides in the central part of the east half of sec. 22, T. 5 S., R. 90 W. and northeast of the center of sec. 15 in the same township. Estimated total thickness of the unit is about 800 m

IPee **Eagle Valley Evaporite (Middle Pennsylvanian)**—White gypsum and anhydrite. Locally contains lenses of massive gray limestone as much as 20 m thick. Unit is well exposed on the east side of the valley of Bearwallow Creek in sec. 14, T. 5 S., R. 90 W. Diaparism probably affects the thickness and configuration of most of the mapped bodies making original stratigraphic thicknesses uncertain. All contacts of units IPe, IPml, and Tcc with IPee are interpreted as intrusive. Map relations in the northwestern part of the quadrangle in and west of the Canyon Creek valley show that the evaporite cuts across bedding in the Eagle Valley Formation

IPb **Belden Formation (Middle and Lower Pennsylvanian)**—Dark-gray, thin-bedded carbonaceous limestone and medium-gray limestone, dark-gray to black carbonaceous shale, white to very light gray shaley limestone, pale-brownish-gray gypsiferous siltstone, calcareous siltstone, and gypsum. Locally the limestone beds are highly fossiliferous, and 248 species have been reported from the Belden in the Glenwood Springs region by Bass and Northrop (1963), who concluded that the lower part is Morrowan and the upper part Atokan. Unit is well exposed only along irrigation ditch on west side of Canyon Creek at north edge of map area in sec. 14, T. 5 S., R. 89 W., where folds make the thickness of the exposed rocks uncertain. A thickness of 213–274 m was mapped in the Glenwood Springs 7.5-minute quadrangle to the east (Kirkham and others, 1997) and 167 m on East Rifle Creek about 15 km northwest of the Storm King Mountain quadrangle (Bass, 1958). No complete stratigraphic section of the Belden is exposed in this quadrangle, but 120 m of the unit were mapped east of Canyon Creek (cross section A–A') where exposures are poor

Ml **Leadville Limestone (Lower Mississippian)**—Massive, gray, oolitic limestone forms the upper part and is exposed in prominent cliffs at the margin of the White River uplift. The lower part is brownish-gray, thin- to medium-bedded limestone and dolomite containing dark-gray chert. The lower part resembles the Coffee Pot Member of the Dyer Dolomite but is separated from it by the Gilman Sandstone, which is locally very thin and poorly exposed. The most accessible exposures of the Leadville are on the west side of Canyon Creek at the north edge of the map area. Unit is about 55 m thick

Dc **Chaffee Group, undivided (Upper Devonian)**—Includes three formations, the Gilman Sandstone at the top, the Dyer Dolomite, and the Parting Formation at the base. The Gilman Sandstone is a yellowish-gray sandstone and dolomitic sandstone and is only 0.3–2 m thick, too thin to map as a separate unit. The Chaffee Group is about 70 m thick

Dcd **Dyer Dolomite**—Light-gray to dark-gray limestone and dolomitic limestone that contains two members that are not mapped separately, the Coffee Pot and Broken Rib Members. Coffee Pot Member is a light-gray to dark-gray, thin-bedded dolomite and dolomitic limestone. Thin laminations are interpreted as stromatolites (Campbell, 1970). Zones of intraformational dolomite breccia occur in the upper part. Member is about 30 m thick (Campbell, 1972). Broken Rib Member consists of gray nodular limestone and dolomitic limestone. This member is thickly bedded and forms a distinctive gray cliff. Rock contains fossils and is rich in fossil fragments. Member is about 20 m thick (Campbell, 1972)

Dcp **Parting Formation**—Yellowish-gray to white, medium- to coarse-grained, locally conglomeratic, locally cross-bedded quartzite, light-green and black, silty, dolomitic, micaceous shale, dolomite, and sandy dolomite. Unit forms a bench above the Manitou Dolomite and below the Dyer Dolomite (Dcd). Member is about 20 m thick (Campbell, 1972)

MDu **Leadville Limestone and Chaffee Group, undivided (Lower Mississippian and Upper Devonian)**—Mapped only in northwest corner of sec. 18, T. 5 S., R. 89 W. and southeast corner sec. 12, T. 5 S, R. 90 W. Combined thickness is about 125 m

O€u **Manitou Dolomite and Dotsero Formation, undivided (Lower Ordovician and Upper Cambrian)**—Combined thickness is about 70 m

Manitou Dolomite (Lower Ordovician)—Not mapped separately. Consists of two members, the Tie Gulch Dolomite Member and the underlying Dead Horse Conglomerate Member. Total thickness about 40 m. Tie Gulch Dolomite Member is thin- to medium-bedded, light- to medium-brown, fine- to medium-grained dolomite in even beds; locally contains yellow chert stringers and thin beds of flat-pebble conglomerate. Tie Gulch Member is about 15 m thick (Campbell, 1972). Dead Horse Conglomerate Member consists of thin beds of gray flat-pebble limestone conglomerate, greenish-gray calcareous shale, sandstone, and brown-weathering limestone and dolomite. Glauconite is present in the lower part but almost absent in the upper part. Dead Horse Member is about 25 m thick (Campbell, 1972)

€d **Dotsero Formation (Upper Cambrian)**—Thinly bedded, yellowish-gray to gray sandy dolomite, dolomitic sandstone, green dolomitic shale, dolomitic conglomerate, and pinkish-gray to very light gray algal limestone, which weathers white to pale purple, in two unmapped members. Formation is about 30 m thick (Campbell, 1972). Clinetop Member consists of stromatolitic limestone and matrix-supported limestone pebble conglomerate. Clinetop is 0.5–1.7 m thick. Underlying Glenwood Canyon Member is composed of thin-bedded dolomite and dolomite or limestone flat-pebble conglomerate and a few beds of greenish-gray shale. Glenwood Canyon is about 29 m thick. Mapped with the Manitou Dolomite as a combined unit (O€u) except a small area in the southwest corner of sec. 7, T. 5 S., R. 89 W.

€s **Sawatch Quartzite (Upper Cambrian)**—Fine-grained quartzite, sandstone, sandy dolomite, dolomite, and thin beds of gray, green, and purple micaceous shale in three unmapped members. Unit has a total thickness of about 160 m (Campbell, 1972). Upper part consists of fine-grained quartzite, dolomitic sandstone, sandy dolomite, and dolomite. Alternate white and light-brown beds of quartzite give that part of the cliffs formed by this unit a distinctive banded aspect. Upper part is 15–45 m thick. Middle part is dolomitic sandstone grading down into dolomite and sandy, glauconitic and micaceous dolomite and is 5–23 m thick. Forms a notch in the cliff formed by the Sawatch Quartzite. Lower part consists of fine-grained to very coarse grained quartzite and feldspathic quartzite and a few beds of sandy dolomite and micaceous shale. Purplish-red feldspathic quartzite and pebble conglomerate are present at the base. Pebbles are quartz and feldspar as much as 6 cm in diameter. Lower part is about 100 m thick

Xg **Granodiorite gneiss (Early Proterozoic)**—Medium-grained, strongly foliated, biotite-hornblende trondhjemite and granodiorite gneiss locally containing 2- to 6-cm-thick veins of pegmatite. Plagioclase with a composition of An 14–23 occurs as anhedral porphyroclasts, which are locally bent or broken and are as much as 5 mm long. Anhedral microcline as much as 1.7 mm in diameter is interstitial to the plagioclase. Anhedral quartz as much as 4 mm in diameter locally fills around the plagioclase grains and is strongly strained and ductilely drawn out. Microcline, quartz, and plagioclase forms a matrix with a grain size of 0.02–0.5 mm. Also present are dark-green hornblende as much as 3.5 mm in diameter but mostly 1.5 mm and smaller, and synkinematic to postkinematic (crystallized at the same time and after the rock was being deformed) biotite as much as 1.4 mm long, locally replacing hornblende. Accessory allanite, sphene, apatite, zircon, and opaque minerals, and secondary carbonate and chlorite, also occur in the rock. Granodiorite gneiss crops out in valley of East Canyon Creek at the north edge of the quadrangle in secs. 7, 8, 17, and 18, T. 5 S., R. 89 W.

Xf **Felsic gneiss (Early Proterozoic)**—Heterogeneous unit composed predominantly of fine-grained biotite-quartz-feldspar gneiss; also includes layers of hornblende gneiss, amphibolite, biotite quartzite, and, rarely, biotite-microcline-magnetite-plagioclase-sillimanite schist. Unit also contains some migmatitic gneissic granite and pegmatite and is exposed in the valley of Possum Creek near the northeastern corner of quadrangle

Xu **Proterozoic rocks, undivided (Early Proterozoic)**—Shown only in cross sections

GEOLOGY

INTRODUCTION

This version of the geology of the Storm King Mountain quadrangle was released in preliminary form in 1998 (Bryant and others, 1998). It superceded one by Fairer and others (1993) that contained incorrect contacts, faults, and rock unit identifications and a lack of structural information. Unfortunately during fieldwork for this revision about 12 percent of the quadrangle, mostly in the southwestern part, was not accessible to us; consequently geologic information for the inaccessible areas was obtained from interpretation of aerial photographs, published reports, and observations from a county road and adjacent areas.

STRATIGRAPHY

Conglomerate of Canyon Creek (Tcc)

The age and origin of the conglomerate of Canyon Creek is the most important stratigraphic problem in the Storm King Mountain quadrangle. The conglomerate is remarkably uniform in texture and structure. No channeling, cross bedding, or graded bedding that might indicate facing direction was found. The conglomerate contains only a few thin beds and lenses of sandstone. Such a uniform texture and structure may have formed during deposition by braided streams having a high gradient and high discharge. Much of the conglomerate contains clasts from nearby Pennsylvanian rocks upon which the unit was deposited. Locally, especially in the central part of its outcrop belt and close to the trend of the Canyon Creek drainage in the White River uplift to the north, there are numerous clasts from the Lower Paleozoic section and a few clasts of Proterozic basement rock. These lower Paleozoic and Proterozoic rock types are exposed in the valley of Canyon Creek, suggesting a source in that drainage for some of the conglomerate and showing that those rock types were exposed at the time the conglomerate of Canyon Creek was deposited. Although the clasts are locally imbricated, we found no places where the imbrication in the conglomerate is developed well enough to allow determination of the direction of stream flow. The conglomerate of Canyon Creek differs from old conglomerates described in the Pennsylvanian and Permian section in the Eagle Basin. Not even the conglomerates deposited near the margins of the Pennsylvanian-Permian basin, such as those east of Vail, Colo., on the east side of the Eagle basin (90 km to the east) or those near Redstone, Colo., or in the Treasure Mountain dome on the west side of the basin (50-65 km south), were deposited as close to their sources as the conglomerate of Canyon Creek. Conglomerate in the Maroon formation in the Storm King Mountain quadrangle markedly contrasts with the conglomerate of Canyon Creek and contains rounded pebbles of quartz, granite, and fine-grained metamorphic rock. No other conglomerates like the conglomerate of Canyon Creek are known in this region.

Waechter and Johnson (1986) placed the southwest side of a late Paleozoic horst beneath the town of Silt, Colo., about 15 km to the west-southwest of Canyon Creek, based on their interpretation of a seismic reflection line. If such a paleohorst were present, the sedimentary facies and thickness of the Maroon Formation or Eagle Valley Formation in the New Castle quadrangle directly northeast of the paleohorst should be affected by its presence, and conglomerates derived from the horst should interfinger with or grade to rocks typical of the Maroon or Eagle Valley Formations. No conglomerates of this type were identified in the Storm King Mountain quadrangle or in the adjacent New Castle quadrangle (Scott and Shroba, 1997). Therefore the geographically restricted and distinctive conglomerate of Canyon Creek cannot be related to the proposed paleohorst.

No conglomerates related to the Laramide orogeny in the region resemble the conglomerate of Canyon Creek. The few conglomerates in the Wasatch Formation in the quadrangle have distant sources in the Sawatch Range to the east or southeast, as indicated by their well-rounded pebbles of volcanic and hypabyssal porphyry. We tentatively conclude, as Bass and Northrop (1963) did, that the conglomerate of Canyon Creek is of Neogene age. It cannot be two units as Tweto and others (1978) suggested, because the conglomerate they mapped as Neogene Browns Park Formation west of Canyon Creek and the conglomerate mapped as Pennsylvanian Eagle Valley Formation east of Canyon Creek form a continuous belt of outcrops that have similar textures, structures, and clast lithologies.

We conclude that the conglomerate of Canyon Creek originated during incision of the region in late Miocene or Pliocene time. A steep-sided, local basin was formed by dissolution or flow of evaporite accompanied by collapse. At the time during which the conglomerate was being deposited, ancestral Canyon Creek had cut down to an altitude of 3,000 m in its upper reaches where Early Proterozoic granitic rocks are exposed (Tweto and others, 1978). Further dissolution or flow of evaporite underlying the conglomerate, combined with diapiric intrusion along its margins, formed the tight syncline exposed in the valley of Canyon Creek.

Lower members of the Wasatch Formation

The members of the Wasatch Formation characteristic of the southern part of the Piceance basin (Donnell, 1969) were not mapped in the Storm King Mountain quadrangle, although they have been mapped in the New Castle quadrangle (Scott and Shroba, 1997) immediately west of our map area. An eastward increase in the number of sandstone beds in the predominantly claystone Shire Member, combined with relatively poor exposures, makes it difficult to differentiate the more clay-rich Shire Member from the more sandy Molina Member. The lower member of the Wasatch (Twl) mapped in the

Storm King Mountain quadrangle is the equivalent of the volcaniclastic-rich unit mapped to the west by Scott and Shroba (1997).

Sandstone, siltstone, claystone, and conglomerate (Ks)

This unit is mapped only in the eastern part of the quadrangle because access for mapping in the remaining outcrop area was denied. Palynomorphs from fossil locality F1 (NE1/4 sec. 22, T. 6 S., R. 90 W.) from near the top of the unit indicate a Cretaceous age. According to R. Farley Fleming (Volgox, Inc., written commun., 1998):

"This assemblage contains abundant, well-preserved pollen and spores. The assemblage also contains abundant cuticular debris and fusinitic debris. Many of the palynomorphs observed are present in Cretaceous and Tertiary rocks. The assemblage contains numerous specimens of three species that are restricted to the Cretaceous and no species that are restricted to the Tertiary. One species (*Aquilapollenites reticulatus*) indicates a Maastrichtian age. This assemblage is Maastrichtian in age. Selected palynomorph taxa observed:

Aquilapollenites reticulatus (Maastrichtian)
Aquilapollenites delicatus (Campanian-Maastrichtian)
Proteacidites retusus
Fraxinoipollenites variabilis
Triporopollenites plektosus
Ulmipollenites sp.
Cupuliferodaepollenites sp.
Liliacidites sp
Pityosporites sp.
Taxodiaceaceapollenites sp.
Cyathidites minor
Laevigatosporites sp."

Rocks along strike to the west in the New Castle quadrangle are mapped as a lower member of the Wasatch Formation (Scott and Shroba, 1997). Field data obtained by R.B. Scott (USGS, oral commun., 1997) suggest that stratigraphic relations between Cretaceous and Tertiary rocks may be more complicated than we can map at this time. Pebbles of volcanic rock believed to be characteristic of the Wasatch Formation occur near the base of the lower unit of the Wasatch Formation in the western part of the New Castle quadrangle and to the west in the Silt quadrangle.

Mesaverde Group

Following Collins (1976) we use the terminology of Hancock and Eby (1930) for the subdivision of the Mesaverde Group. The Rollins Sandstone Member or Trout Creek Sandstone Member (Warner, 1964) forms the top of the Iles Formation, and in many areas this sandstone forms prominent outcrops. However, Murray (1966) could not identify it on aerial photographs between Fourmile Creek 10 km south-southeast of the Storm King Mountain quadrangle to Harvey Gap 5 km west-northwest of the quadrangle. The Rollins Sandstone Member has been traced by detailed mapping from Harvey Gap to the west edge of the Storm King Mountain quadrangle (Scott and Shroba, 1997). The Rollins is covered by Miocene basalt and Quaternary surficial deposits for about 6 km in the southeastern part of the Storm King Mountain quadrangle and the northwestern part of the adjacent Cattle Creek quadrangle, where that horizon is mapped as the Rollins Sandstone Member of the Williams Fork Formation rather than the Iles Formation (Kirkham and others, 1996). The outcrops of the Rollins Sandstone Member in the Storm King Mountain quadrangle are not impressive; in places apparently the Rollins is thin, not exposed, or missing. The best exposures are on the west side of South Canyon Creek in the southeast corner of sec. 10, T. 6 S., R. 90 W. The Rollins Sandstone does not crop out along strike on the ridge east of South Canyon Creek.

Lower member of the Mancos Shale (Kml)

The predominantly shale unit overlying the Dakota Sandstone is here designated the lower member of the Mancos rather than Frontier Sandstone and Mowry Shale, as has been done in some previous studies (Kirkham and others, 1997, 1996; Tweto and others, 1978). Regional correlation studies indicate that the calcareous sandstone beds that constitute a minor proportion of the unit are related to the Juana Lopez Member of the Mancos Shale in northwestern New Mexico (Merewether and Cobban, 1986; Molenaar and Cobban, 1991) rather than to the Frontier Sandstone of eastern Utah, western Wyoming, and southwestern Montana. A few beds resembling the siliceous, fish-scale-bearing shale of the Mowry are in the lower part of the unit. Because of these facts, we decided to follow the nomenclature used by Bryant (1979) west of Aspen and call this unit the lower member of the Mancos Shale.

Lower member of the Maroon Formation (IPml)

The Middle Pennsylvanian deposits in the central Colorado trough, or Eagle Basin, exposed in the Storm King Mountain quadrangle differ from those in the adjacent Glenwood Springs quadrangle (Kirkham and others, 1997). The unit here mapped as the lower member of the Maroon Formation is mapped as the Eagle Valley Formation in the Glenwood Springs quadrangle (Kirkham and others, 1997) because it has more gray calcareous siltstone and sandstone, more limestone, and less coarse-grained sandstone than in the Storm King Mountain quadrangle. In the Glenwood Springs quadrangle, the Eagle Valley Formation consists of the transitional rocks between the Maroon or Minturn Formations and the Eagle Valley Evaporite. It contains more clastic rocks and fewer evaporites than the Eagle Valley Evaporite and less coarse-grained arkose than the Maroon Formation, and it is variegated in shades of red, brown, gray, and yellow. The lower member of the Maroon Formation in the Storm King Mountain quadrangle changes facies eastward into the

Eagle Valley Formation in the Glenwood Springs quadrangle. That change is part of a regional southeastward transition in facies towards an evaporite depocenter in the Cattle Creek quadrangle (Mallory, 1971; Kirkham and others, 1997, 1996).

Eagle Valley Formation (ℙe)

The rocks mapped as Eagle Valley Formation here and to the west (Scott and Shroba, 1997) contain only irregular, lenticular masses of evaporite, which are interpreted to be diapiric intrusions and tectonic lenses derived from nearby beds or from more distant masses below the surface and to the south and are mapped separately. The Eagle Valley Formation in the Storm King Mountain quadrangle strikes into rocks mapped as Eagle Valley Evaporite in the Glenwood Springs quadrangle (Kirkham and others, 1997). The rocks are changing facies towards the evaporite depocenter in the Cattle Creek quadrangle (Mallory, 1971; Kirkham and others, 1997, 1996).

Proterozoic rocks

Although none of the metamorphic rocks or granites exposed in canyons in the White River uplift have been dated isotopically, they are inferred to be of Early Proterozoic age because of studies elsewhere in the region. These studies are summarized in Reed and others (1993). All the rocks of high metamorphic grade in the Precambrian terrane of Colorado, such as those exposed in the White River uplift, have been dated as Early Proterozoic between the ages of 1.668 and 1.792 Ga (billion years). The strongly foliated granodiorite gneiss has a grain size and texture more nearly resembling the granitic rocks dated as 1.76–1.66 Ga (Early Proterozoic) than the granitic rocks dated as 1.47–1.36 Ga (Middle Proterozoic), although the textural differences are not infallible indications of age (Reed and others, 1993). Gneissic granite exposed in the Mitchell Creek valley in the Glenwood Spring quadrangle (Kirkham and others, 1997) 1 km east of the Storm King Mountain quadrangle was sampled for U-Pb zircon dating. This work did not result in a precise date, but the data obtained seem to indicate an age somewhere around 1.7 Ga (D.M. Unruh, USGS, written commun., 2000).

STRUCTURE

The Storm King Mountain quadrangle spans the south margin of the White River uplift and crosses the Grand Hogback monocline into the Piceance basin. Nearly flat lying Cambrian through Mississippian sedimentary rocks capping the White River uplift are bent into gentle south dips and broken by faults at the edge of the uplift in the northeastern part of the quadrangle (cross section B–B'). South of those faults Pennsylvanian rocks dip moderately to steeply south and are overturned locally and folded and faulted. Mesozoic rocks dip moderately to steeply south, and the overlying Tertiary rocks have increasingly gentle dips to the south into the Piceance basin (cross section A–A').

The quadrangle lies astride a zone of evaporite tectonism extending 50 km northwest from the Carbondale collapse center (Kirkham and others, 2001) along the northern part of the belt of Pennsylvanian rocks at the margin of the White River uplift (Scott and others, in press).

In the central and east-central parts of the quadrangle a fold in the Maroon Formation forms a large structural terrace (cross section A–A') on which are superposed numerous discontinuous, gentle to sharp folds and minor faults and a few more continuous ones. On the south flank of Storm King Mountain much of the terrace is covered by old landslide debris and other colluvial deposits, but some of the details of the structure are well exposed in the steep-sided gullies eroded into these deposits, which drain south into the Colorado River. This structural terrace has about the same length as, but is 2 km south of, the conglomerate of Canyon Creek. Perhaps the structural terrace was formed by sagging of part of the Grand Hogback monocline due to withdrawal of underlying evaporite related to dissolution and diapirism that formed the steep-sided local basin in which the conglomerate was deposited.

The conglomerate of Canyon Creek is folded into a tight, asymmetric syncline with a steep south limb and a gentler north limb. The trough of the syncline is concealed by surficial deposits, and east of Canyon Creek the trough is either very sharp or broken by a fault of minor displacement. The trough at the east end of the syncline is moderately well controlled by mapping of float, but at its west end debris from the conglomerate above makes lack of offset along the trough less certain, but apparently there is none. In reconnaissance studies by MacQuown (1945), this conglomerate was shown as being in the Pennsylvanian section, and the syncline was called the Glenwood Springs syncline and connected with a syncline in the Pennsylvanian and Permian rocks southeast of the town of Glenwood Springs. Detailed mapping (Kirkham and others, 1997) shows that the Glenwood Springs syncline dies out east of the town of Glenwood Springs. On the east side of Canyon Creek, beds in the south limb of the syncline dip about parallel with those in the underlying Eagle Valley Evaporite. However, the beds in the Eagle Valley Evaporite are probably overturned, whereas the conglomerate is right side up based on its map pattern. To the south, beds in the Maroon and Eagle Valley Formations certainly are overturned. If the conglomerate was of Pennsylvanian age, an isoclinal anticline in the evaporite south of the syncline would be required, and such an anticline is shown by Tweto and others (1978). Such an anticline in the Pennsylvanian rocks would require that the distinctive conglomerate of Canyon Creek be exposed on its south limb, if the conglomerate is in the Pennsylvanian section. If the conglomerate is Neogene, as we believe is favored by available evidence, near-vertical right-side-up beds lying on near-vertical overturned beds seems an improbable, although a theoretically possible, stratigraphic relationship. We interpret the base of the conglomerate to have been tilted up by diapiric movement of the adjacent evaporite. To the west, the north limb of the syncline of conglomerate dips less steeply and unconformably overlies rocks of the lower member of the Maroon Formation, which strike southwest beneath the conglomerate and are overturned. Also, the conglomerate overlies the western part of the Possum Creek fault and thus is younger than any movement on the underlying part of that fault. The presence of pre-Pennsylvanian rocks in the conglomerate of Canyon Creek argues against faults and folds forming in Pennsylvanian or Permian time as a result of salt tectonics because such deformation is confined to rock of the same age or younger than evaporite horizon.

For the reasons given above we conclude that the age of the conglomerate of Canyon Creek is Neogene. It must have been deposited after ancestral Canyon Creek had cut down into the basement rocks of the White River uplift, which now are at an altitude of 3,000 m in the upper part of the Canyon Creek valley and about 300 m below a surface that truncates the White River uplift and is overlain by 23–10 Ma Miocene basalts (Larson and others, 1975). These relations suggest that the conglomerate is younger than 10 Ma. However, no basaltic clasts were identified in the conglomerate, perhaps because its primary sources were so nearby and the remnants of the basalt were much farther away by the time drainage from the White River uplift had incised enough to reach the level of the Proterozoic basement rocks some 250 m lower than the projected base of the Miocene basaltic rocks that cap the White River uplift. The folding of the syncline at Canyon Creek and the faulting and tilting of the conglomerate on the ridge north of Storm King Mountain must be even younger than the conglomerate and probably occurred in Pliocene or early Quaternary time. Bass and Northrop (1963) suggested that dissolution of evaporite might be the mechanism that accounts for the formation of the syncline. This suggestion is at least partly supported by the fact that much of the eastern and tighter part of the syncline is underlain by evaporite or poorly exposed rocks that may contain considerable evaporite. Diapiric movement of the evaporite, which accompanied dissolution and was concentrated beneath the east and tighter part of the syncline, folded the conglomerate.

Evidence for evaporite diapirism is found north of the syncline in the conglomerate of Canyon Creek. In secs. 14 and 15, T. 5 S., R. 90 W. the Eagle Valley Evaporite cuts through the Eagle Valley Formation in an irregular manner. In sec. 19, T. 5 S., R. 89 W. the evaporite pinches and swells and forms an isolated lens along strike.

A major fault is required along the lower part of Possum Creek to account for the south-dipping rocks of the Maroon Formation that abut near-vertical-dipping Eagle Valley Formation. The same relations continue to the west, but the fault is concealed beneath the conglomerate of Canyon Creek. The downthrown side is to the north toward the White River uplift. Faults with their downthrown sides on the north or uplift side are locally common along the south flank of the White River uplift (MacQuown, 1945; Tweto and others, 1978; Kirkham and others, 1995, 1997). The Possum Creek fault is cut by the Dolan Gulch fault, which has a down-to-the-south sense of displacement (Kirkham and others, 1997) and dies out east of Canyon Creek. We infer that at least some displacement occurred along the Dolan Gulch fault in late Neogene time because it truncates the conglomerate of Canyon Creek, which dips 35° into it on the ridge north of Storm King Mountain. Just north of the Dolan Gulch fault, an unnamed fault forms the edge of the White River uplift (cross section B–B') from the east edge of the quadrangle to East Canyon Creek where it splays out or is replaced by several faults. The unnamed fault intersects the Dolan Gulch fault near its end in the Glenwood Springs quadrangle 1 km east of our map area (Kirkham and others, 1997).

In the valley of Canyon Creek near the north edge of the quadrangle the Eagle Valley Formation lies on lower Paleozoic rocks along a very gently dipping fault. The rocks above and below the fault dip steeply and are broken by high-angle faults (cross section A–A'). On the west side of the valley relations are especially well exposed. A bed in the lower part of the Leadville Limestone, which dips south at about 50°, is dragged into a gently north dipping attitude along the fault plane. To the south this nearly flat fault is unrecogizable in the Eagle Valley Formation, but is interpreted to be gently dipping and cut by a diapiric intrusion of evaporite. Immediately north of the quadrangle, the gently dipping fault cuts steeply south dipping Leadville Limestone and older rocks in the hanging wall. Northward displacement of the upper block is about 400 m. North of the quadrangle several gently east dipping faults with a sense of displacement similar to that of the low-angle fault in the Storm King Mountain quadrangle cut steeply south dipping lower Paleozoic rocks. A series of moderately north dipping normal faults along the margin of the White River uplift was shown along Canyon Creek by MacQuown (1945, cross section A–A') based on reconnaissance work. The gently to moderately dipping normal faults along Canyon Creek may have formed during minor extensional deformation after formation of the White River uplift by compressional forces. This is the only place along the margin of the White River uplift where such low-angle extensional structures are known. Perhaps they imply that extension was locally greater here than elsewhere along the southern margin of the White River uplift. This extension may have been associated with dissolution of evaporite when the depression in which the conglomerate of Canyon Creek was deposited was formed.

Along the east edge of the quadrangle south of the Colorado River, Neogene basalt flows are offset by faults that are parallel or subparallel to bedding planes in the steeply northeast dipping Mancos Shale and Mesaverde Group. How far those faults extend along strike to the west along the Grand Hogback is not known. Coal mines near South Canyon Creek exposed a shear zone parallel to

Table 3. Geologic hazards commonly associated with map units in the Storm King Mountain quadrangle

Erosion				Volume change			Corrosive minerals	Flooding
Mass wasting			Gullying and piping	Hydro-compaction	Expansive materials	Collapse		
Qls	Qc	Qdy	Qac	Qc	Kmu	₱ee	₱e	Qfp
Qac	Qdo	Qfy	Qfy	Qls	Jm	₱e	₱ee	Qsw
Twu	Twl	TKu	Qlo	Qlo	Qfy	Kw	Kmu	Qfy
Ks	Kw	Ki			Qls		Qls	Qac
Kic	Kmu	Kmn			Qac		Qc	
Kml	Kd	Jm			Qc			
Kml	Kd	Jm			Qdo			
P₱m	Pms	₱ml						
₱ee	₱e	₱b						
Ml	Dc	O€u						
€s	Xf	Xg						

bedding in the Wheeler coal zone (Gale, 1910). The area of these faults in the Storm King Mountain quadrangle is part of a larger area in the Center Mountain, Glenwood Springs, and Cattle Creek quadrangles (Carroll and others 1996; Kirkham and others, 1997, 1996) in which 10 Ma basaltic rocks are dropped down towards the Roaring Fork valley along more than 20 faults from an altitude of 3,230 m to 2,320 m. Murray (1969) suggested that these faults were due to tension caused by minor unfolding of the Grand Hogback monocline. Unruh and others (1993) and Kirkham and Widmann (1997) attributed these faults to deformation associated with flowage of evaporite into the Cattle Creek anticline, which is along the Roaring Fork about 5 km east of the Storm King Mountain quadrangle.

An inferred north-trending fault along the bottom of the Canyon Creek valley in the northern part of the quadrangle offsets the syncline in the conglomerate of Canyon Creek and the contacts in the Paleozoic rocks. Apparent right-lateral displacement along the fault is about 300 m at the northern edge of the quadrangle, and it diminishes southward to none about 1 km south of the syncline formed in the conglomerate. Assuming that our interpretation of the age of the conglomerate of Canyon Creek is correct, this fault must have been active in Pliocene or early Quaternary time.

GEOLOGIC HAZARDS

The quadrangle contains a variety of rock types, which have vastly different physical properties. Steep slopes along the Colorado River and its tributaries combined with the structural and physical properties of the rock units promote gravity-driven erosional processes that produce rockfalls, landslides, and debris flows. Rock units rich in clay, such as the Wasatch Formation, Mancos Shale, Iles Formation, Morrison Formation, Eagle Valley Formation, and Belden Shale, are particularly susceptible to the development of landslides and debris flows. Rockfall from the cliffs of lower Paleozoic rock along Canyon, East Canyon, and Possum Creeks and from the Maroon Formation along the gorge of the Colorado River east of Canyon Creek is a potential hazard. Scars produced during the past few decades by failure of steep slopes underlain by landslide, colluvium, and Wasatch Formation are visible in the South Canyon Creek drainage in the southwestern quarter of the map area. Active talus is well developed on slopes below the cliffs of Cambrian through Mississippian rocks on either side of Canyon Creek at the north edge of the map area. Two months after the South Canyon fire on the south flank of Storm King Mountain in July 1994, debris flows were triggered by intense rainfall. They originated on steep slopes underlain by surficial deposits and weathered Maroon Formation (Cannon and others, 1995; Kirkham and others, 2000). Table 3 summarizes the geologic hazards that are prone to occur on or in geologic units in the map area.

Local bentonitic, smectite-rich beds in the Mancos Shale (Kmu) and probably in the Morrison Formation (Jm) are locally overlain by expansive surficial deposits and pedogenic soils. The bentonitic and smectite-rich beds can expand significantly when wet and shrink when dry. These processes tend to damage foundations and other structures. Surficial deposits and the pedogenic soils derived from these units may also have expansive properties. When the smectite-rich zones are steeply dipping, as they are in areas of steeply dipping rock in the Storm King Mountain quadrangle, strongly expansive material may be adjacent to markedly less expansive material. Structures that span these contrasting soils are more likely to be damaged than if they were on uniformly expansive soil, which would be the case if the rocks were flat lying or gently dipping (Noe and Dodson, 1995).

Collapse due to solution of gypsum, anhydrite, and halite in the Eagle Valley Evaporite is another hazard. The clinker zones in the Mesaverde Group rocks may collapse into voids created by burning of the coal and shrinkage of the adjacent shale, siltstone, and sandstone due to thermal metamorphism and melting. These processes reduce porosity and drive out volatiles, such as water. The clinker zones are not wide, but they are extensive laterally. Since the beds dip steeply, significant collapse diminishes within 100 m or less from their stratigraphic bases. Impressive collapse features have formed in the recently burned and currently burning Wheeler coal zone on both sides of South Canyon Creek. Actively burning coal seams are hazardous because they emit gases including carbon monoxide and hydrogen sulfide, and they may locally be very hot at or near the ground surface. During one inspection of the South Canyon coal-seam fire a temperature of 602°C (1,115°F) was measured in melted rock before insulation melted off the thermocouple wire. A year later the rock had cooled to 218°C (425°F) (Rushworth and others, 1989). The ground surface in these areas does not remain hot for many years, but in June 2002 a major forest fire was ignited by the burning coal seam in the South Canyon Creek valley during severe drought conditions, hot weather, and strong winds. Land above former underground coal mines may subside. The subsidence-prone areas are generally elongate parallel to bedding; the hazard decreases away from the mined bed in the direction of dip. Gullying and piping in some of the silty and sandy surficial deposits pose potential hazard as do expansive soils and expansive bedrock. Hydrocompaction locally occurs in silty surficial deposits, such as loess (Qlo) and mass-movement deposits derived from the Eagle Valley Evaporite (IPee) are prone to subsidence caused by the dissolution of gypsum, anhydrite, and possibly halite.

Evaporite deposits in the Eagle Valley Evaporite (IPee) and the Eagle Valley Formation (IPe) contain soluble minerals, such as halite, anhydrite, and gypsum, which when dissolved by water can cause corrosion of untreated concrete and metal.

Flooding is generally restricted to surficial deposits within a few meters of active channels. Many or most of the flood-plain and stream-channel deposits (Qfp) along the Colorado River and in upper Canyon Creek are unsuitable locations for permanent structures, such as homes. Intense rainfall may cause debris flows and sheetfloods on the younger alluvial-fan and debris-flow despots (Qfy). The September 1, 1994 debris flows from the south side of Storm King Mountain covered parts of the younger alluvial-fan and debris-flow deposits adjacent to the drainage channels in the gullies where the debris flows originated (Cannon and others, 1995; Kirkham and others, 2000). Such rainstorms can cause flooding or debris flows in the narrow valley bottoms underlain by undivided alluvium and colluvium (Qac).

RESOURCES

Coal

In the past coal has been an important mineral commodity in the Storm King Mountain quadrangle (Gale, 1910). Coal was mined intermittently from the Williams Fork Formation of the Mesaverde Group mostly in the valley of South Canyon Creek and near the west margin of the quadrangle between 1887 and 1968. About 2 million long tons of high-volatile bituminous coal were produced in the Storm King Mountain quadrangle (Turney and Murray-Williams, 1984; Murray and others, 1977). The mines commonly contained methane gas, and gas-related explosions and fires caused injuries and deaths.

Analyses of coal samples from the Storm King Mountain quadrangle show that they contain 40.7–45.9 percent volatile matter, 46.4–59.3 percent fixed carbon, 3.1–10.3 percent ash, 0.5–0.9 percent sulfur, and 11,920–13,590 Btu/lb (Murray and others, 1977).

Individual coal beds in the Williams Fork Formation are seldom traceable (Collins, 1976), but coal zones are. The lowest coal zone contains the thicker and more continuous coal beds and is here referred to as the Fairfield coal zone after the Fairfield coal group (Collins, 1976). This coal zone is about 42 m above the base of the Williams Fork Formation in the South Canyon Creek valley and is about 50 m thick. Throughout much of the quadrangle a zone of clinker about 85 m above the base of the Williams Fork Formation marks the former position of a coal bed or several closely spaced beds known as the Wheeler coal, which is as much as 6 m thick and was a major producing horizon. About 227 m above the base of the Williams Fork Formation are coals that Collins (1976) called the South Canyon coal group, and are here called the South Canyon zone, which is about 20 m thick in the South Canyon Creek area. Coal beds in this zone are much less persistent than those in the Fairfield coal zone. They are as thick as 4 m and were mined in the South Canyon area and along Coal Ridge. Another zone of coal beds about 342 m above the base of the Williams Fork Formation was called the Coal Ridge coal group by Collins (1976) and here is called the Coal Ridge zone. Coal beds in this zone range widely in extent and thickness over relatively short distances (Collins, 1976). In the South Canyon area two coal beds in this zone are each 1.7 m thick (Collins, 1976). South of the Storm King Mountain quadrangle the base of each of these three coal zones is marked by a traceable sandstone bed (Collins, 1976); in the Storm King Mountain quadrangle those coal and sandstone beds were not mapped. In the upper part of the Williams Fork Formation are scattered coal beds, one of which was worked at the Keystone mine about 2 km southwest of Newcastle, Colo. These beds constitute the Keystone coal zone, and in the Storm King Mountain quadrangle a coal bed in this zone, about 100 m below the top of the Williams Fork Formation and about 1 m thick, was mined in the South Canyon Creek drainage in secs. 15, 22, and 23, T. 6 S., R. 90 W.

Substantial coal resources remain in the quadrangle. Near the surface the coal beds dip steeply and are difficult to mine safely and economically. In the southwestern part of the quadrangle the beds are flat to gently dipping, but they are as much as 2 km below the surface. New mining techniques need to be developed for these resources to be economic, given the present-day relation between supply and demand for coal.

Gas and oil

Gas and lesser amounts of oil have been produced from the Mesaverde Group, Wasatch Formation, and Dakota Sandstone in the Piceance basin. The most productive horizons are the Corcoran and Cozzette Sandstone Members in the Iles Formation, but minor production has also come from the Rollins Sandstone Member and fluvial sandstones in the Williams Fork Formation (Johnson, 1989). Three wells drilled in the southern part of the Storm King Mountain quadrangle had shows of gas in the coals and sandstones in and near the Fairfield coal zone in the lower part of the Mesaverde Group. The closest producing wells are in the Wildcat field about 5 km west of the quadrangle in the Newcastle quadrangle and the Baldy Creek field about 8 km south of the quadrangle in the Center Mountain quadrangle (Smith and others, 1991). The Mesaverde Group and Wasatch Formation, which are gas-producing horizons in this part of the Piceance basin, are either absent from over one-half of the quadrangle or are exposed on the surface updip from potential reservoirs. Information obtained by drilling to date suggests that probability of significant gas production in the quadrangle is low.

Limestone

The chert-free upper half of the Leadville Limestone is locally pure enough (<1% SiO_2) to be a source of metallurgical limestone (Wark, 1980). The Broken Rib Member of the Dyer Dolomite might also qualify as a potential source of metallurgical limestone, but the unit is thinner than the upper half of the Leadville. However, the outcrop area of the Leadville in the quadrangle is high on the margin of the White River Plateau, and access is more difficult than many other areas in the region where the Leadville crops out.

Gypsum

Some beds of fairly pure gypsum as much as 200 m thick are mapped in the Eagle Valley Evaporite. An outcrop area of gypsum as much as 500 m wide in the Bearwallow Creek area probably represents diapiric accumulation rather than stratigraphic thickness. The gypsum deposits are less economical to mine than thicker and more accessible deposits cropping out along major transportation routes in the Eagle River valley near the towns of Eagle and Gypsum or along the Roaring Fork valley southwest of Glenwood Springs.

Sand and gravel

Terrace and flood-plain deposits along the Colorado River constitute a source of sand and gravel rich in clasts of granite, gneiss, and porphyry. They also contain red Maroon Formation sandstones and quartzite from the Dakota and Sawatch Formations. Some of the sand and gravel in the younger fan alluvium and debris-flow deposits (Qfy) have been partly exploited. The quality of those deposits ranges widely because they have a varied clast content related to the rock types in their source areas and various amounts of silt and clay. Flood-plain and stream-channel deposits (Qfp) rich in debris from the Proterozoic rocks at the south margin of the White River uplift are a sand and gravel resource. The largest such deposit in the quadrangle is on Canyon Creek in sec. 13, T. 5 S., R. 89 W.

Riprap and quarry aggregate

The best sources for riprap and quarry aggregate are basalt, Dakota Sandstone, Leadville Limestone, and Proterozoic rocks.

Hot springs

In the lower part of South Canyon three hot springs issue from alluvium overlying Mancos Shale just above the Dakota Sandstone. They have a discharge ranging from 27 to 64 liters (7–17 gallons) per minute, at a temperature of 46°–48°C, and contain about 800 mg/l dissolved solids. The composition of this water contrasts with that from the well-known springs at Glenwood Springs 7 km to the east where dissolved solids are 17,000–20,000 mg/l, probably due to dissolution of Eagle Valley Evaporite. Estimates of the subsurface reservoir temperatures for the springs at South Canyon Creek based on several geothermometers range from 40°C to 130°C (Barrett and Pearl, 1978; Cappa and Hemborg, 1995).

ACKNOWLEDGMENTS

We have benefited by discussions and field conferences with Bob Kirkham, Randy Streufert, Chris Carroll, and Jim Cappa of the Colorado Geological Survey, who have mapped adjacent quadrangles in a cooperative project with the U.S. Geological Survey, and with Bob Scott, who mapped an adjacent quadrangle, gave this report a thorough review, and supervised this project for the U.S. Geological Survey. We thank Bob Kirkham for a helpful review of this report.

We appreciate the cooperation of the landowners who allowed us access to their property

REFERENCES CITED

American Geological Institute, 1982, Grain-size scales used by American geologists, modified Wentworth scale, *in* Data sheets (2nd ed.): Falls Church, Va., American Geological Institute, sheet 17.1.

Barrett, J.K., and Pearl, R.H., 1978, An appraisal of Colorado geothermal resources: Colorado Geological Survey Bulletin 39, 224 p.

Bass, N.W., 1958, Pennsylvanian and Permian rocks in the southern half of the White River uplift, Colorado, *in* Curtis, B.F., ed., Symposium on Pennsylvanian rocks of Colorado and adjacent

areas: Denver, Colo., Rocky Mountain Association of Geologists, p. 91–94.
Bass, N.W., and Northrop, S.A., 1950, South Canyon Creek Dolomite Member, a unit of Phosphoria age in Maroon Formation near Glenwood Springs, Colorado: American Association of Petroleum Geologists Bulletin, v. 34, no. 7, p. 1540–1551.
———1963, Geology of Glenwood Springs quadrangle and vicinity, northwestern Colorado: U.S. Geological Survey Bulletin 1142–J, 74 p.
Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.
Bryant, Bruce, 1979, Geology of the Aspen 15-minute quadrangle, Pitkin and Gunnison Counties, Colorado: U.S. Geological Survey Professional Paper 1073, 146 p.
Bryant, Bruce, Shroba , R.R., and Harding, A.E., 1998, Revised preliminary geologic map of the Storm King Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 98–472, 36 p, scale 1:24,000.
Campbell, J.A., 1970, Stratigraphy of the Chaffee Group (Upper Devonian), west-central Colorado: American Association of Petroleum Geologists Bulletin, v. 54, no. 2, p. 313–325.
———1972, Lower Paleozoic systems, White River plateau, *in* Devoto, R.H., ed., Paleozoic stratigraphy and structural evolution of Colorado: Quarterly of the Colorado School of Mines, v. 67, no. 4, p. 37–62.
Cannon, S.H., Powers, P.S., Pihl, R.A., and Rogers, W.P., 1995, Preliminary evaluation of the fire-related debris flows on Storm King Mountain, Glenwood Springs, Colorado: U.S. Geological Survey Open-File Report 95–508, 38 p.
Cappa, J.A., and Hemborg, T.H., 1995, 1992–1993 low-temperature geothermal assessment program, Colorado: Colorado Geological Survey Open-File Report 95–1, 34 p.
Carroll, C.J., Kirkham, R.M., and Stelling, P.L., 1996, Geologic map of the Center Mountain quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-2, scale 1:24,000.
Collins, Bruce, 1976, Coal deposits of the Carbondale, Grand Hogback, and southern Danforth Hills coal fields: Colorado School of Mines Quarterly, v. 67, no. 1, 138 p.
Craig, L.C., 1959, Measured sections of Morrison and adjacent formations: U.S. Geological Survey Open-File Report.
Cruden, D.M., and Varnes, D.J., 1996, Landslide types and process, *in* Turner, A.K., and Schuster, R.L., eds., Landslides investigation and mitigation: Washington, D.C., National Academy Press, National Research Council, Transportation Research Board Special Report 247, p. 36–75.
Donnell, J.R., 1969, Paleocene and lower Eocene units in the southern part of the Piceance Creek basin: U.S. Geological Survey Bulletin 1274–M, p. M1–M18.
Fairer, G.M., Green, M.W., and Shroba, R.R., 1993, Preliminary geologic map of the Storm King Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 93–320, scale 1:24,000.
Gale, H.S., 1910, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 415, 265 p.
Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347–360.
Gill, J.E., and Freeman, V.L., 1978, Stratigraphic section of the upper Mancos Shale–lower Mesaverde Formation interval along the Grand Hogback between Rifle Gap and North Thompson Creek, Garfield and Pitkin Counties, Colorado: U.S. Geological Survey Open-File Report 78–178, 1 sheet.
Goddard, E.N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p.
Guthrie, R.L., and Witty, J.E., 1982, New designations for soil horizons and layers and the new Soil Survey Manual: Soil Science Society of America Journal, v. 46, p. 443–444.
Hall, R.D., and Shroba, R.R., 1993, Soils developed in the glacial deposits of the type areas of the Pinedale and Bull Lake glaciations, Wind River Range, Wyoming: Arctic and Alpine Research, v. 25, no. 4, p. 368–373.
Hancock, E.T., and Eby, J.B., 1930, Geology and coal resources of the Meeker quadrangle, Moffat and Rio Blanco Counties, Colorado: U.S. Geological Survey Bulletin 812–C, p. 191–242.
Johnson, R.C., 1989, Geologic history and hydrocarbon potential of Late Cretaceous-age, low-permeability reservoirs, Piceance basin, western Colorado: U.S. Geological Survey Bulletin 1787–E, p. E1–E51.
Johnson, R.C., and May, Fred, 1980, A study of the Cretaceous-Tertiary unconformity in the Piceance Creek basin, Colorado—The underlying Ohio Creek Formation (Upper Cretaceous) redefined as a member of the Hunter Canyon or Mesaverde Formation: U.S. Geological Survey Bulletin 1482–B, 27 p.
Johnson, S.Y., Schenk, C.J., Anders, D.L., and Tuttle, M.L., 1990, Sedimentology and petroleum occurrence, Schoolhouse Member, Maroon Formation, Lower Permian, northwestern Colorado: American Association of Petroleum Geologists Bulletin, v. 74, p. 135–150.
Kirkham, R.M., Kunk, M.J., Bryant, Bruce, and Streufert, R.K., in press, Constraints on timing and rates of Late Cenozoic incision by the Colorado River in Glenwood Canyon, Colorado—A preliminary synopsis, *in* Young, R.A., and Spamer, E.E., eds., The Colorado River—Origin and evolution: Grand Canyon, Arizona, Grand Canyon Association Monograph 12.

Kirkham, R.M., Parise, Mario, and Cannon, S.H., 2000, Geology of the 1994 South Canyon fire area and a geomorphic analysis of the September 1, 1994 debris flows, south flank of Storm King Mountain, Glenwood Springs, Colorado: Colorado Geological Survey Special Publication 46, 39 p.

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

Kirkham, R.M., Streufert, R.K., and Cappa, J.A., 1995, Geologic map of the Shoshone quadrangle, Garfield County, Colorado: Colorado Geological Survey Open File Report 95-4, 16 p., scale 1:24,000.

———1997, Geologic map of the Glenwood Springs quadrangle, Garfield County, Colorado: Colorado Geological Survey Map Series 31, 22 p., scale 1:24,000.

Kirkham, R.M., Streufert, R.K., Hemborg, H.T., and Stelling, P.L., 1996, Geologic map of the Cattle Creek quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-1, 16 p., scale 1:24,000.

Kirkham, R.M., and Widmann, B.L., 1997, Geologic map of the Carbondale quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 97-3, 24 p., scale 1:24,000.

Kunk, M.J., Budhan, James, Unruh, Daniel, Stanley, Josette, Kirkham, R.M., Bryant, Bruce, Scott, R.B., and Streufert, R.K., in press, $^{40}Ar/^{39}Ar$ ages of Late Cenozoic volcanic rocks within and around the Carbondale and Eagle collapse areas, Colorado—Constraints on timing of salt tectonism and incision of the Colorado River, *in* Kirkham, R.M., Scott, R.B., and Judson, T.W., eds, Late Cenozoic evaporite tectonism and volcanism in west central Colorado: Geological Society of America Special Paper 366.

Kunk, M.J., and Snee, L.W., 1998, $^{40}Ar/^{39}Ar$ age-spectrum data of Neogene and younger volcanic rocks in west-central Colorado: U.S. Geological Survey Open-File Report 98–243, 112 p.

Kunk, M.J., Winick, J.A., and Stanley, J.O., 2001, $^{40}Ar/^{39}Ar$ age-spectrum and laser-fusion data for Cenozoic volcanic rocks in west central Colorado: U.S. Geological Survey Open-File Report 01–427, 94 p.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., and Obradovich, J.D., 2002, Revised ages for tuffs of the Yellowstone Plateau volcanic field—Assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event: Geological Society of America Bulletin, v. 114, no. 5, p. 559–568.

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

MacQuown, W.C., Jr., 1945, Structure of the White River plateau near Glenwood Springs, Colorado: Geological Society of America Bulletin, v. 56, p. 877–892.

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

Merewether, E.A., and Cobban, W.A., 1986, Biostratigraphic units and tectonism in the mid-Cretaceous foreland of Wyoming, Colorado, and adjoining areas, *in* Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States, part III, middle Rocky Mountains: American Association of Petroleum Geologists Memoir 41, p. 443–467.

Molenaar, C.M., and Cobban, W.A., 1991, Middle Cretaceous stratigraphy on the south and east sides of the Uinta basin, northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787–P, 34 p.

Munsell Color, 1973, Munsell soil color charts: Baltimore, Md., Kollmorgen Corp., Macbeth Division.

Murray, D.K., Fender, H.B., and Jones, D.C., 1977, Coal and methane gas in the southeastern part of the Piceance Creek basin, Colorado, *in* Veal, H.K., ed., Exploration frontiers of the central and southern Rockies: Denver, Colo., Rocky Mountain Association of Geologists, p. 379–405.

Murray, F.N., 1966, Stratigraphy and structural geology of the Grand Hogback monocline, Colorado: Boulder, Colo., University of Colorado Ph.D. thesis, 274 p.

———1969, Flexural slip as indicated by faulted lava flows along the Grand Hogback monocline, Colorado: Journal of Geology, v. 77, p. 333–339.

Nelson, A.R., and Shroba, R.R., 1998, Soil relative dating of moraine and outwash-terrace sequences in the northern part of the upper Arkansas Valley, central Colorado, U.S.A.: Arctic and Alpine Research, v. 30, no. 4, p. 349–361.

Noe, D.C., and Dodson, M.D., 1995, The Dipping Bedrock Overlay District (DBOD); an area of potential heaving bedrock hazards associated with expansive, steeply dipping bedrock in Douglas County, Colorado: Colorado Geological Survey Open-file Report F-95-5, 32 p.

Palmer, A.R., and Geissman, John, compilers, 1999, 1999 geologic time scale: Geological Society of America, 1 sheet.

Pierce, K.L., 1979, History and dynamics of glaciation in the northern Yellowstone National Park area: U.S. Geological Survey Professional Paper 729–F, 90 p.

Pierce, K.L., Fosberg, M.A., Scott, W.E., Lewis, G.C., and Coleman, S.M., 1982, Loess deposits of southeastern Idaho—Age and correlation of the upper two loess units, *in* Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 717–725.

Pierce, K.L., Obradovich, J.D., and Friedman, Irving, 1976, Obsidian hydration dating and correlation of Bull Lake and Pinedale glaciations near West Yellowstone, Montana: Geological Society of America Bulletin, v. 87, no. 5, p. 703–710.

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

Reed, J.C., Jr., Bickford, M.E., and Tweto, Ogden, 1993, Proterozoic accretionary terranes of Colorado and southern Wyoming, *in* Van Schmus, R.R., and Bickford, M.E., eds., Transcontinental provinces, *in* Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds, Precambrian of the conterminous United States, v. C-2, Geology of North America: Geological Society of America Decade of North American Geology, p. 211–228.

Richmond, G.M., 1986, Stratigraphy and correlation of glacial deposits of the Rocky Mountains, the Colorado Plateau, and the ranges of the Great Basin, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v. 5, p. 99–127.

Richmond, G.M., and Fullerton, D.S., 1986, Introduction to Quaternary glaciations in the United States of America, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v. 5, p. 3–10.

Rushworth, Peter, Haefner, B.D., Hynes, J.L., and Streufert, R.K., 1989, Reconnaissance study of coal fires in inactive Colorado coal mines: Colorado Geological Survey Information Series 26, 60 p.

Scott, R.B., Bryant, Bruce, and Perry, W.J., Jr., in press, Late Cenozoic deformation by evaporite tectonism in the Grand Hogback monocline, southwest of the White River uplift, Colorado, *in* Kirkham, R.M., Scott, R.B., and Judson, T.W., eds., Late Cenozoic evaporite tectonism and volcanism in west central Colorado: Geological Society of America Special Paper 366.

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

Shroba, R.R., 1994, Quaternary loess stratigraphy along the Colorado River between Glenwood Springs and Rifle, Colorado—Preliminary findings [abs.]: American Quaternary Association, 13th Biennial Meeting, Minneapolis, Minn., Abstracts, p. 246.

Shroba, R.R., and Scott, R.B., 1997, Revised preliminary geologic map of the Rifle quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 97–852, 21 p., scale 1:24,000.

———2001, Geologic map of the Silt quadrangle, Gardield County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2331, scale 1:24,000.

Smith, J.R., Tremain, C.M., and Brchan, C.A., 1991, Oil and gas fields of Colorado: Colorado Geological Survey Map MS 26, scale 1:500,000.

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

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region with a section on sedimentary geology by R.A. Cadigan: U.S. Geological Survey Professional Paper 691, 195 p.

———1972b, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region with a section on sedimentary petrology by R.A. Cadigan, and a section on conglomerate studies by William Thordaarson, H.F. Albee, and J.H. Stewart: U.S. Geological Survey Professional Paper 690, 336 p.

Stover, B.K., and Soule, J.M., 1985, Surficial geologic map, *in* Surficial geology, geomorphology, and general engineering geology of parts of the Colorado River valley, Roaring Fork valley, and adjacent areas, Garfield County, Colorado: Colorado Geological Survey Open-File Report 85-1, scale 1:50,000.

Streufert, R.K., Kirkham, R.M., Widmann, B.L., and Schroeder, T.S., 1997, Geologic map of the Cottonwood Pass quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 97-4, 14 p., scale 1:24,000.

Turney, J.E., and Murray-Williams, L., 1984, Inactive coal mine data and subsidence information, Grand Hogback region: Colorado Geological Survey unpublished report 25 p.

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

Tweto, Ogden, Moench, R.H., and Reed, J.C., Jr., 1978, Geologic map of the Leadville 1° x 2° quadrangle, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–999, scale 1:250,000.

Unruh, J.R., Wong, I.G., Bott, J.D.J., Silva, W.J., and Lettis, W.R., 1993, Seismotectonic evaluation, Rifle Gap dam, Ruedi dam, Fryingpan-Arkansas project, northwestern Colorado: Unpublished report prepared for the U.S. Bureau of Reclamation, Denver, Colo., by

William Lettis and Associates and Woodward-Clyde Consultants, Oakland, Calif., 154 p.
Varnes, D.J., 1978, Slope movement types and process, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides, analysis, and control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11–33.
Waechter, N.B., and Johnson, W.E., 1986, Pennsylvanian-Permian paleostructure and stratigraphy as interpreted from seismic data in the Piceance basin, northwest Colorado, *in* Stone, D.S., ed., New interpretations of northwest Colorado geology: Denver, Colo., Rocky Mountain Association of Geologists, p. 51–64.
Wark, J.G., 1980, Development of a metallurgical limestone deposit, *in* Schwochow, S.D., ed., Proceedings of the Fifteenth Forum on Geology of Industrial Minerals: Colorado Geological Survey Resource Series 8, p. 53–62.
Warner, D.L., 1964, Mancos-Mesaverde (Upper Cretaceous) intertonguing relations southeast Piceance basin, Colorado: American Association of Petroleum Geologists Bulletin, v. 48, no. 7, p. 1091–1107.
Whitney, J.W., and Andrews, E.D., 1983, Past and present geomorphic activity in the Piceance Creek drainage basin, northwestern Colorado, *in* Gary, J.H., ed., Sixteenth oil shale symposium proceedings: Golden, Colo., Colorado School of Mines Press, p. 566–577.
Young, R.G., 1955, Sedimentary facies and intertonguing in the Upper Cretaceous of the Book Cliffs, Utah-Colorado: Geological Society of America Bulletin, v. 66, p. 177–201.