Geologic Map of the Horse Mountain Quadrangle, Garfield County, Colorado

By William J. Perry, Ralph R. Shroba, Robert B. Scott, and Florian Maldonado

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Introduction

The Horse Mountain 7.5′ quadrangle comprises 57.2 square miles of rugged terrain just north of the Rifle 7.5′ quadrangle and west of the Rifle Falls 7.5′ quadrangle. The quadrangle was first mapped as part of a M.S. thesis by Cary (1960). Cary's mapping was quite generalized, and though he did not differentiate or recognize most surficial geologic units, his portrayal of the bedrock geology was better than that in an Open-File Report of this quadrangle by Fairer and others (1993) who incorrectly located stratigraphic contacts, faults, and folds in bedrock. The present revision is one of a series of geologic maps (Scott and Shroba, 1997; Scott, Shroba, and Egger, 2001, and Shroba and Scott, 1997, 2001) produced by the I-70 Corridor Project. The northern, particularly north-western, part of the quadrangle was difficult to access, and interpretations there are subject to change.

Description of Map Units

The surficial map units on this map are informal allostratigraphic units of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), whereas the bedrock units are lithostratigraphic units. Therefore, subdivisions of time for stratigraphic units use the terms "late" and "early" for surficial units, but use the terms "upper" and "lower" for bedrock units. Surficial deposits shown on the map are estimated to be at least 1 m thick. The fractional map symbol Qlo/Qp is used where loess mantles pediment deposits. This fractional unit is not described herein; instead refer to descriptions of individual units. Thin, discontinuous colluvial deposits, residual material on bedrock, and small deposits of fill material, coal-mine tailings, and talus were not mapped. Areas underlain by the Mancos Shale (Km), Maroon Formation (Pℙm), Eagle Valley Formation (ℙev), and Belden Formation (ℙb) commonly have unmapped colluvial deposits especially in areas of forest vegetation or dense oak brush.

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 gravelly alluvium (Qg) and high-level gravelly alluvium (QTg) are inferred in part on the basis of three long-term rates of incision of dated basalt flows by the Colorado River and its tributaries within 90 km of the map area. These rates are about 0.24 m/k.y. (k.y., thousand years) during the past 0.6 m.y. (m.y., million years) by Rock Creek for the Rock Creek flow near the town of McCoy (Larson and others, 1975), 0.23 m/k.y. during the past 1.35 m.y. by the Roaring Fork River for the flows at Triangle Peak between Basalt and Aspen (Kunk and others, 2002), and 0.24 m/k.y. during the past 3.0 m.y. by the Colorado River for the Gobbler Knob flow about 14 km east of Glenwood Springs (Streufert and others, 1997; Kunk and others, 2002).

Soil-horizon designations are those of the Soil Survey Staff (1975), Guthrie and Whitty (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 III K horizons in this report) are those of Gile and others (1966). Grain sizes given for surficial deposits and bedrock are based on field estimates and follow the modified Wentworth scale (American Geological Institute, 1982). In descriptions of surficial map units, the term "clasts" refers to the fraction greater than 2 mm in diameter, whereas the term "matrix" refers to the particles less than 2 mm in size. Dry matrix colors of the surficial deposits were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). The colors of the surficial deposits correspond to those of the sediments and (or) bedrock from which they were derived. Surficial deposits derived from non-red sediments and bedrock commonly range from light brownish gray (2.5Y 6/2) to light brown (7.5YR 6/4). Those derived from red sediments and bedrock commonly range from light reddish brown (5YR 6/4) to red (2.5YR 5/6). Bedrock colors were determined by comparison with the Geological Society of America Rock-Color Chart (Rock-Color Chart Committee, 1951).

Hyperconcentrated-flow deposits mentioned in this report are deposits that are intermediate in character between stream-flow and debris-flow deposits. In this report, the term "colluvium" includes mass-wasting (gravity-driven) deposits as well as sheetwash deposits. As used in this report the term "hydrocompaction" refers to any water-induced decrease in volume observed or 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. The term "piping" refers to the subsurface erosion of sand and finer material by percolating water resulting in the formation of voids and conduits about a few centimeters to several meters wide.

Metric units are used in this report (except where the nominal total depth of drill holes is reported on the map in feet from drilling records). 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)]

Artificial-fill Deposits

Compacted material composed mostly of rock fragments and finer material

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)
kilograms	2.2	pounds (lb)
kilometers (km)	0.62	miles (mi)
kilograms per cubic meter (kg/m^3)	0.062	pounds per cubic foot

Table 2. Definitions of divisions of geologic time used in this report.

Eon / Era	Period	Epoch	Age (years)
CENOZOIC	Quaternary	Holocene	0 to 10 ka
		Pleistocene	10 ka to 1.65 Ma*
	Tertiary	Pliocene	1.65 to 5 Ma
		Miocene	5 to 24 Ma
		Oligocene	24 to 38 Ma
		Eocene	38 to 55 Ma
		Paleocene	55 to 66 Ma
MESOZOIC	Cretaceous		66 to 138 Ma
	Jurassic		138 to 205 Ma
	Triassic		205 to 240 Ma
PALEOZOIC	Permian		240 to 290 Ma
	Pennsylvanian		290 to 330 Ma
	Mississippian		330 to 360 Ma
	Devonian		360 to 410 Ma
	Silurian		410 to 435 Ma
	Ordovician		435 to 500 Ma
	Cambrian		500 to 570 Ma
PROTEROZOIC			570 to 2,500 Ma

After Hansen (1991); *1.65 Ma from Richmond and Fullerton (1986). Subdivisions of Pleistocene time are informal and are as follows: late Pleistocene is 10-132 ka, middle Pleistocene is 132–788 ka, and early Pleistocene is 788–1,650 ka (Richmond and Fullerton, 1986).

af **Artificial fill (latest Holocene)**—Compacted fill material composed of rock fragments and finer material in a dam at the south end of Rifle Gap Reservoir, and a small earthen dam on Middle Rifle Creek, just north of the State Correctional Institute. Maximum thickness about 35 m

Alluvial Deposits

Silt, sand, and gravel in stream deposits in valley bottoms and on ridges, hillsides, and hilltops along Middle Rifle Creek, West Rifle Creek, Government Creek, and their tributaries

Qg **Gravelly alluvium (late to middle Pleistocene)**—Small deposits of stream alluvium on hillsides and hilltops between 25 and 170 m above Middle Rifle Creek and West Rifle Creek near Rifle Gap Reservoir. Much of the unit is poorly exposed, but it appears to consist mostly of poorly sorted, clast-supported, slightly bouldery, pebble and cobble gravel in a sand matrix. The gravel probably contains lenses and thin beds of pebbly sand, slightly silty sand, and silty clay. Clasts are mostly subangular and subrounded sandstone along with minor amounts of limestone, chert, and rare quartzite. Some of the sandstone boulders are as long as 1.5 m. Unit Qg is locally mantled by about 1 m of loess (Qlo). The 25-m-high deposits are probably equivalent to unit Qtm in the New Castle quadrangle (Scott and Shroba, 1997) and the 60–170-m-high deposits are probably equivalent to unit Qtt in the New Castle and Silt quadrangles (Shroba and Scott, 2001). Exposed thickness is 3–5 m; maximum thickness is possibly about 30 m

QTg **High-level gravelly alluvium (early Pleistocene or late Pliocene)**—Two deposits of valley-fill(?) material, one on Parker Ridge at the head of Harris Gulch, and the other about 2.1–2.8 km southeast, about 425–475 m above Middle Rifle Creek, in the northwestern and north-central parts of the map area, respectively, at elevations above 2,800 m. The unit is poorly exposed, but it appears to consist of beds and lenses of poorly sorted, clast-supported, slightly bouldery, cobble and pebble gravel, sandy pebble gravel, and pebbly sand. The clasts are mostly angular to subrounded limestone along with minor amounts of chert and sandstone and rare quartzite. At the head of Harris Gulch, distinctive subrounded cobbles of Tertiary basalt and Proterozoic metamorphic rocks are also present. Unit QTg may be roughly equivalent in age to unit QTba in the New Castle quadrangle (Scott and Shroba, 1997). Thickness is possibly as much as 10–25 m

Alluvial and Colluvial Deposits

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

Qfy **Young fan-alluvium and debris-flow deposits (Holocene and late Pleistocene?)**—Mostly poorly sorted, clast- and matrix-supported, slightly bouldery, pebble and cobble gravel in a silty to slightly silty sand matrix, and locally pebbly and cobbly silty sand that contains thin (10–65 cm) lenses of sand, pebble gravel, and cobbly pebble gravel. Deposits derived from the Mancos Shale (Km) commonly have a clayey silt matrix that is sticky when it is wet and has prominent shrinkage cracks when dry. Some of these deposits may be expansive and have high shrink-swell potential. Unit Qfy locally contains boulders as long as 2 m; some of the larger boulders were probably deposited by debris flows. Nonbedded to poorly bedded; beds are commonly less than 1 m thick. Clasts are commonly angular to subangular sandstone. Unit Qfy is undissected and was deposited chiefly by small intermittent streams graded to valley bottoms of modern streams. Locally includes valley-fill deposits of intermittent streams, minor sheetwash deposits (Qsw), colluvium (Qc), and probably hyperconcentrated-flow deposits. Surface is locally subject to stream flooding and debris-flow deposition. Although old fan deposits were not identified in the map area, the unit is named young fan alluvium and debris-flow deposits because it is correlative with younger fan deposits (Qfy) mapped in the adjacent New Castle and Rifle Falls quadrangles where older fan deposits (Qfo) are also mapped (Scott and Shroba 1997; Scott, Shroba, and Egger, 2001). Exposed thickness is 1–1.5 m; maximum thickness is possibly about 30 m

Qac **Undivided alluvium and colluvium (Holocene and late Pleistocene?)**—Chiefly undifferentiated alluvial flood-plain and stream-channel deposits, young fan-alluvium and debris-flow deposits (Qfy), sheetwash (Qsw) deposits, and probably hyperconcentrated-flow deposits. Some of these deposits probably grade laterally and vertically into each other. The alluvial deposits typically consist of interbedded clay, sandy silty clay, sandy clayey silt, silty sand, and lenses of pebbly sand, sandy pebble gravel, and pebble and cobble gravel in a sand matrix. Sheetwash deposits are typically pebbly silty sand. Alluvial and colluvial deposits derived from Mancos Shale (Km) commonly contain more silt and clay than those derived from the other bedrock units. Some of the alluvial deposits derived from the Mancos contain numerous thin, buried soil A horizons in the upper part of the unit and may contain expansive clays that have high shrink-swell potential. Unit Qac is prone to gullying and piping, and low-lying areas of the map unit are prone to periodic stream and sheet flooding and debris-flow deposition. Alluvial deposits form flood plains, low terraces, and small alluvial fans along the perennial streams and some of the larger intermittent streams. Sheetwash deposits locally mantle valley bottoms and adjacent valley sides. Exposed thickness of the alluvium is 1–10 m; maximum thickness is possibly about 15 m. Exposed thickness of the colluvium is 1–1.5 m; maximum thickness is possibly about 5 m

Qp **Pediment deposits (middle Pleistocene)**—Gravelly alluvium and debris-flow deposits at three levels that overlie gently sloping surfaces cut on the Shire, Molina, and Atwell Gulch Members of the Wasatch Formation (Tws, Twm, Twa) and the Mancos Shale (Km) near the southern boundary of the map area. Unit Qp is commonly shown on map as loess over pediment deposits (Qlo/Qp); pediment deposits are exposed locally at the edges of the unit. Locally as much as 6 m of relief exists on the pediment (bedrock surface) where it is incised by stream channels (Shroba, 1996). The unit is mostly poorly sorted, clast-supported, bouldery, pebble and cobble gravel in a sandy silt matrix and poorly sorted, cobbly, sandy pebble gravel to pebbly silty sand. Clasts are chiefly angular to subrounded sandstone, but some are limestone. Sheetwash deposits (Qsw) and colluvium (Qc) locally overlie the unit. Nonsorted, bouldery, debris-flow deposits are common in the upper part of the unit. Some of the sandstone boulders are as long as 2 m. A stage III K soil horizon is locally formed in the top of the unit. The unit is dissected and is mantled by about 1–2 m of loess (Qlo). The lower limits of the pediment deposits are about 35, 65, and 100 m above stream level. Low-lying areas of the map unit adjacent to channels of ephemeral streams may be prone to periodic stream flooding and debris-flow deposition. Sheet flooding may occur on gently sloping surfaces away from stream channels. Exposed thickness is 2–5 m; maximum thickness possibly is about 15 m

Colluvial Deposits

Silt, sand, gravel, and angular rock fragments on valley sides and hill slopes that were mobilized, transported, and deposited by gravity and sheet erosion

Qc **Colluvium, undivided (Holocene to middle? Pleistocene)**—Mostly clast-supported, pebble, cobble, and boulder gravel in a silty sand matrix, and gravelly, silty sand, sandy silt, and clayey silt. Deposits derived from the Mancos Shale (Km) commonly contain more silt and clay than those derived from the other bedrock units. Some of the deposits derived from the Mancos Shale and shale in the Morrison Formation (Jm) may contain expansive clays that have high shrink-swell potential. 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 colluvial deposits were derived. Unit Qc locally includes sheetwash (Qsw), creep-derived, debris-flow (Qd), and landslide (Qls) deposits, and probably hyperconcentrated-flow 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. Unit Qc also locally includes thin loess (Qlo) mantles on older gently sloping colluvial deposits, small deposits of alluvium and colluvium (Qac) in and along minor drainageways, and probably small pediment deposits (Qp) on the flanks of the Grand Hogback near the southern boundary of the map area. Exposed thickness is 1–4 m; maximum thickness probably is about 5 m

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Mostly pebbly silty sand that is derived by sheet erosion chiefly from the Mancos Shale (Km), mass-movement deposits (Qcm), and landslide deposits (Qls). Common on gentle to moderate slopes and in depressions caused by landsliding and creep. Low-lying areas of the map unit are prone to periodic sheet flooding. Unit Qsw locally includes small deposits of loess (Qlo) and undivided alluvium and colluvium (Qac) in and along minor drainageways and may locally include landslide (Qls) and creep-derived colluvial (Qc) deposits. Exposed thickness is 1–1.5 m; maximum thickness probably is about 10 m

Landslide deposits (Holocene to middle? Pleistocene)—Chiefly unsorted and unstratified rock debris characterized by hummocky topography. Many of the landslides are complex (Varnes, 1978) and commonly formed on unstable slopes that are underlain by bedrock units that contain expansive clays. Deposits derived from the Mancos Shale (Km) and Morrison Formation (Jm) are rich in clay. Clay derived from the upper part of the Mancos contains expansive clays that locally probably have high shrink-swell potential. Bedrock units prone to sliding in the map area are the Belden Formation (ℙb), Eagle Valley Formation (ℙev), Maroon Formation (Pℙm), State Bridge Formation (ŦRPs), Chinle Formation (ŦRc), Morrison Formation (Jm), Mancos Shale (Km), Corcoran and Cozette Sandstone Members of Iles Formation, undivided (Kicc), shale member of the Iles Formation (Kis), Rollins Sandstone Member of Iles Formation (Kir), Williams Fork Formation of Mesaverde Group (Kwf), and Atwell Gulch Member of the Wasatch Formation (Twa). The map area contains debris-slide, rock-slide, debris-slump, slump-earth-flow, earth-flow, and debris-flow deposits as defined by Varnes (1978). The size and lithology of the clasts and the grain-size distributions of the matrix material in 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. Landslide deposits locally include unmapped sheetwash (Qsw) and creep-derived colluvial (Qc) deposits

Qlsy **Younger landslide deposits (Holocene and late Pleistocene?)**—Active and inactive deposits along Middle Rifle Creek and in the southwestern part of the map area along Government Creek. These deposits have well-preserved hummocky topography. They are bounded upslope by crescentic head-wall scarps and downslope by lobate toes. Exposed thickness is 1–4.5 m; maximum thickness is possibly 20 m

Qlso **Older landslide deposits (late and middle? Pleistocene)**—Inactive, eroded deposits along Middle Rifle Creek and Government Creek in the southern part of the map area. These deposits commonly lack hummocky topography, crescentic headwall scarps, and lobate toes. Exposed thickness is 1–4 m; maximum thickness is possibly 50 m

Qls **Landslide deposits, undivided (Holocene to middle? Pleistocene)**—Younger and older landslides deposits (Qlsy and Qlso; described above) that are mapped as an undivided unit. Exposed thickness is 1–3 m; maximum thickness is possibly 50 m

Qcm **Mass-movement deposits (Holocene to middle? Pleistocene)**—Chiefly chaotically bedded, brecciated, or unstratified debris derived from and overlying Mancos Shale (Km), Dakota Sandstone (Kd), and Morrison Formation (Jm) on southwest-facing dip slopes in the southern part of the map area, including most of the southwest-facing slope of Horse Mountain. Unit Qcm is a complex of landslide, creep, and debris-flow deposits that mostly lack distinctive surface morphology. The unit is locally dissected by southward-flowing intermittent streams. The unit locally includes isolated masses of partly brecciated and partly coherent Morrison Formation (Jm), Dakota Sandstone (Kd), and Mancos Shale (Km), which have slid down low-angle dip slopes on detachment surfaces or zones on or within beds of expansive clay in the lower part of the Morrison Formation (Jm). The size and lithology of the clasts and the grain-size distributions of the matrix material in unit Qcm reflect those of the bedrock units and surficial deposits displaced by mass movement. Shallow depressions locally contain deposits of loess (Qlo) or sheetwash deposits (Qsw) derived in part from loess. Exposed thickness (on the west side of

Harris Gulch) is locally as much as 60 m; maximum thickness is possibly 100 m

Qta **Talus deposits (Holocene and late Pleistocene)**—Chiefly crudely sorted and stratified, angular, bouldery to pebbly rubble on steep slopes produced mainly by rockfall from outcrops of Leadville Limestone (Ml) or resistant older Paleozoic rocks in the northeastern part of the map area. The matrix is mostly sand and silt; some of which may be of eolian origin. The upper part of the unit locally lacks matrix. Unit Qta probably includes minor colluvial deposits (Qc). Maximum thickness is possibly 60 m

Qd **Debris-flow deposits (Holocene to late Pleistocene?)**—Three small, lobate masses of debris, some with bouldery levees that were deposited by sediment-charged flows. Deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of silty sand to slightly sandy silty clay. They 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 are mainly subangular sandstone. Low-lying areas of the map unit that are adjacent to stream channels are prone to periodic stream flooding and debris-flow deposition. Unit Qd probably includes minor stream-flow and hyperconcentrated-flow deposits. Exposed thickness is about 1 m; maximum thickness is possibly 10 m

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 near the map area commonly consists of 22–46% sand (0.05–2 mm), 43–62% silt (0.002–0.05 mm), and 15–18% clay (<0.002 mm). About 55–75% of the unweathered loess is composed of very fine sand (0.01–0.05 mm) plus coarse silt (0.02–0.05 mm). Median grain size ranges from 0.03 to 0.05 mm (Shroba, 1994). The unit is prone to sheet erosion, gullying, piping, 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 some loess-derived sheetwash (Qsw) and creep-derived colluvium (Qc) deposits that are too small to map. Deposited during five or more episodes of eolian activity in the nearby New Castle quadrangle (Scott and Shroba, 1997) to the east. 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 ratio (about 0.7) of coarse silt to total silt in the unweathered loess suggest a relatively short distance of eolian transport; therefore, the flood plain of the nearby 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. Unit Qlo commonly mantles gently sloping pediment deposits (Qp) near the southern boundary of the map area. Exposed thickness is 1–2 m; maximum thickness is possibly 8 m

Eolian Deposits over Alluvial and Colluvial Deposits

Qlo/Qp **Loess over pediment deposits (late and middle? Pleistocene)**—Thin loess deposits, generally less than 10 m thick, on Quaternary pediment deposits

Bedrock Units

Lower Tertiary and pre-Tertiary rocks, which are partly or completely consolidated, are present beneath the above described surficial deposits and are exposed where surficial deposits have been removed

Tw **Wasatch Formation (lower Eocene and Paleocene)**—Formation includes from youngest to oldest the Shire (Tws), the Molina (Twm), and the Atwell Gulch Members (Twa). In the Rifle quadrangle to the south, about 693 m of the formation are exposed (Shroba and Scott, 1997). The youngest member, the informal Doodlebug Gulch member proposed by Shroba and Scott (1997) is not present in the Horse Mountain quadrangle

Tws **Shire Member (Eocene)**—Nonmarine, predominantly multicolored fine-grained clastic deposits of thick claystone, mudstone, and siltstone interbedded with sparse deposits of coarse-grained fluvial sandstone (descriptions modified herein from Shroba and Scott, 1997). The Shire Member was defined and originally described by Donnell (1969). Colors in the fine-grained clastic beds include pale red, moderate pink, light red, pale reddish brown, pale purple, pale red purple, pinkish gray, light gray, medium light gray, light brownish gray, brownish gray, light olive gray, greenish gray, and yellowish gray. Discontinuous, thin (1–15 cm) beds of siltstone of similar colors form less than 1% of the fine-grained clastic deposits. Sandstone, which forms about 3% of the member, is commonly cross-bedded, locally displays channels 0.3–4 m deep and 5– 15 m wide. The base of many of these channel deposits contains coarse sand and conglomerate. Colors of the sandstone beds include yellowish gray, grayish yellow, light gray, and light olive gray. The sandstone is generally medium grained and consists of about 50% quartz grains, 30% feldspar grains, 20% rock fragments, and weathered mafic grains. Based on drill-hole data and map relations in the Rifle quadrangle to the south, the Shire Member is about 1,550 m thick (Shroba and Scott, 1997)

Twm **Molina Member (Eocene)**—Nonmarine, predominantly multicolored fine-grained clastic deposits consisting of thick beds of claystone, mudstone, and siltstone interbedded with abundant thinner bedded, ledge-forming medium-grained sandstone, defined by Donnell (1969) at the south side of Rifle Gap in the northeastern part of the adjacent Rifle quadrangle (Shroba and Scott, 1997). The fine-grained clastic beds are similar to those described above for the Shire Member (Tws). The Molina Member is distinguished from the Shire by the presence of about 20% or more sandstone beds that are more resistant than those of the Shire because of more abundant calcareous cement. These resistant sandstone layers form nearly vertical ribs near the southeast corner of the map area at the southern margin of Rifle Gap. Sandstone of the Molina is very pale orange, grayish orange, yellowish gray, and very light brown. It commonly contains 1–4-cm-long claystone rip-up clasts. The sandstone is very friable, medium to very coarse grained, moderately sorted, and consists of about 65% quartz grains, 25% feldspar grains, and 10% dark-gray rock fragments and mafic mineral grains. Traces of muscovite and biotite are present. Although the sandstone is cross-bedded, cut by channels, and slightly conglomeratic at the base of channel deposits, the sandstone beds of the Molina are more continuous than those of the Shire. Conglomerate clasts are primarily rounded chert pebbles. The lower part of the Molina Member contains very little if any volcanic debris. The Molina ranges from 105 to 160 m thick (Shroba and Scott, 1997).

Twa **Atwell Gulch Member (Paleocene and Eocene)**—Nonmarine unit with (1) a volcaniclastic-rich upper part that consists predominantly of drab-gray to multicolored fine-grained clastic deposits that include thick deposits of claystone, mudstone, and siltstone interbedded with less abundant thinner deposits that include coarse-grained andesitic debris in fluvial sandstone and abundant conglomerate and (2) a lower mostly nonvolcanic part that consists predominantly of gray to brownish-gray fine-grained clastic deposits consisting of thick siltstone, mudstone, and claystone interbedded with less abundant deposits of thinner bedded, coarse-grained conglomeratic sandstone (Shroba and Scott, 1997). The Atwell Gulch Member was defined by Donnell (1969) at the mouth of Rifle Gap, just south of the southeast corner of the quadrangle. The upper, volcaniclastic-rich part of the member contains fine-grained clastic deposits that are commonly greenish gray, light gray, pale purple, pale pink, and reddish brown. About 15–30% of the upper part consists of medium- to coarse-grained and some fine-grained sandstone, conglomeratic in part, in beds that range from 1 to 15 m thick. The sandstone is greenish gray, light olive gray, dark greenish gray, and light gray. Clasts range from poorly sorted to well sorted and are almost exclusively andesitic debris.

They range in grain size from fine sand to cobbles and contain distinct phenocrysts of augite and plagioclase; isolated biotite flakes are common. The upper part of the member commonly displays cross-bedding, channels, and conglomeratic lower parts of channel deposits. The more conglomeratic parts of the unit are slightly more resistant and are moderately cemented with calcium carbonate, whereas the finer grained sandstone is generally very poorly cemented. Locally, soft-sediment slumping has contorted bedding within the sandstone. The mostly nonvolcanic lower part of the member consists chiefly of fine-grained clastic rocks that range from very light gray, light gray, light brownish gray, pale olive, and light olive gray to brownish gray. In the upper layers of the lower part of the member, coarse-grained sandstone deposits make up less than 10% but are more abundant westward and downward. These beds range from 1 to 5 m thick and are brownish gray, pale yellowish brown, grayish green, and very pale orange. These sandstones are poorly to moderately sorted, weakly cemented by calcium carbonate, and typically consist of about 50% quartz, 30% feldspar, 10% muscovite and biotite, and 19% rock fragments and altered mafic minerals (Shroba and Scott, 1997). These sandstone beds commonly contain rounded, matrix-supported, scattered andesitic clasts, the abundance of which decreases downward. Volcaniclasts appear absent near the base; here the vast majority of the clasts are chert and quartzite pebbles and cobbles. The Paleocene Ohio Creek Formation of Tweto and others (1978) and the Ohio Creek Member of the Mesaverde or Hunter Canyon Formation of Johnson and May (1980) appears to be absent in this area according to Shroba and Scott (1997). The Atwell Gulch Member ranges from about 170 to 270 m thick in the adjacent Rifle quadrangle (Shroba and Scott, 1997)

Mesaverde Group (Upper Cretaceous)—Group includes, from top to base, the Williams Fork Formation and the Iles Formation (Ki), described below. About 1,400 m of the group are exposed along East Rifle Creek just east of the quadrangle

Williams Fork Formation—Formation contains coal near the top and is chiefly nonmarine. Bleached and pitted coarse to very coarse grained pebbly sandstone is characteristic of the erosion surface at the upper contact. Bleached zone of torrentially cross-stratified nearly white sandstone is as much as 10 m thick. Pebbles are rounded and are chiefly pale gray to dark gray, and there are some brown-weathered chert clasts as much as 5 cm in diameter, as well as pink metaquartzite clasts as much as 10 cm in diameter. Volcaniclastic sandstone and andesitic clasts typical of the lower Wasatch Formation (Atwell Gulch Member) are absent. Below the upper sandstones, the unit is predominantly fine-grained clastic deposits: mudstone, siltstone, and burnt coal (clinker). Mudstone and siltstone are light olive gray, greenish gray, light brownish gray, and light gray and are poorly exposed between massive to thick-bedded sandstone outcrops. Sandstone bed packets form about 30% of the unit, are 1–50 m thick and contain channel deposits and crossbeds. The base of the formation is defined as the base of the shale unit that overlies the Rollins Sandstone Member of the Iles Formation. Unit Kwfu (upper Williams Fork on the map) denotes the entire Williams Fork unit less the clinker zone (Kwfc). Formation thickness about 1,100 m (Shroba and Scott, 1997)

Kwfu **Upper part**—That part of the Williams Fork Formation above the Cameo-Fairfield clinker zone

Kwfc **Cameo-Fairfield clinker zone**—Prominent orange to red oxidized coal (clinker), carbonaceous shale, and associated mudstone of the nonmarine Cameo-Fairfield coal zone of the lower Williams Fork Formation. Thickness about 100 m

Ki **Iles Formation**—Shown only in cross section *B-B'*. Marine shale and nonmarine to marginal marine sandstone and siltstone, comprised of from top to base the Rollins Sandstone Member, informal Rifle Gap shale unit, and Corcoran and Cozette Sandstone Members, undivided, and separated by an unmapped lower tongue of marine shale. This shale member consists of medium-dark-gray to light-olive-gray fissile shale lithologically similar to the Mancos Shale (Km), described below. The base of the Corcoran Sandstone Member overlies the Mancos Shale. The Iles Formation is about 300 m thick to the east and southeast in the Silt quadrangle (Shroba and Scott, 1997) and appears to be about the same thickness in the Horse Mountain quadrangle

Kir **Rollins Sandstone Member**—Laterally continuous yellowish-gray to very pale orange, fine- to medium-grained well-sorted sandstone. Unit is commonly thin bedded to massive. Clay partings and interbeds separate thinner beds of sandstone. Low-angle cross-stratification common. In adjacent map area (Shroba and Scott, 1997), sandstone locally consists of 70% quartz, 20% feldspar, <10% rock fragments and altered dark mafic minerals, as well as a trace of muscovite. The Rollins Sandstone Member is about 20–40 m thick

Kis **Shale member**—The map unit is an unnamed (informal Rifle Gap) marine shale, a tongue of the Mancos Shale (Km), described below. It is a medium-dark-gray to light-olive-gray fissile shale 10–20 m in thickness

Kicc **Corcoran and Cozette Sandstone Members, undivided**—Two sandstone-dominated intervals separated by a marine shale-dominated interval. These laterally extensive nonmarine to marginal marine sandstone bodies, neither as thick or uniform as the Rollins Sandstone Member, are separated by mudstone and shale which are poorly exposed. The upper sandstone, the Cozzette Sandstone Member, is pale orange to yellowish gray, well sorted, very fine grained, contains minor beds of medium-dark-gray shale, and is about 20 m thick where exposed in the southwestern part of the adjacent Rifle Falls quadrangle. Clasts in the sandstone consist of about 80% quartz, 15% feldspar, 5% dark rock fragments and mafic minerals, and a trace of muscovite (Scott, Shroba, and Egger, 2001). The Cozzette Sandstone Member has thinly laminated, flaggy bedding at the top and thicker bedding toward the base. The monotonous sequence of underlying marine shale is medium dark gray to dark gray and is about 30 m thick in the southwestern part of the adjacent Rifle Falls quadrangle. The lower sandstone, the Corcoran Sandstone Member, has clasts that consist of about 75% quartz, 15% feldspar, 10% dark rock fragments and mafic minerals, and <1% muscovite (Scott, Shroba, and Egger, 2001), which is concentrated along partings in the sandstone. This sandstone is brownish gray to yellowish gray, moderately sorted, fine to very fine grained, contains minor interbeds of medium-gray shale and is about 55 m thick. Associated thin coals of the Corcoran and Cozzette coal zones have been mined in the eastern part of the quadrangle. Total thickness of the member is about 250 m

Km **Mancos Shale (Upper Cretaceous)**—Predominately medium- to dark-gray silty to carbonaceous shale. A thin-bedded (Niobrara Formation equivalent) shaly limestone, with interbedded light-gray calcareous shale, is about 300 m above the base and is about 20-50 m thick. This unit is underlain by about 70–100 m of brown, decalcified, weathered siltstone (probably Juana Lopez Member of Mancos). Both units are abundantly fossiliferous. The siltstone overlies a basal member (Benton Shale equivalent) of highly carbonaceous, very fissile, black shale about 120–150 m thick. Upper and lower contacts of the Mancos Shale and its recognized subunits are conformable. The Mancos is generally a poorly exposed valley-forming unit; thickness is about 1,220 m. In the nearby Arco-North Rifle Unit 1 drill hole (sec 31, T. 45 N., R. 93 W.) in the Rio Blanco 7.5′ quadrangle, the drilled interval of Mancos is 3,000 m thick, tectonically thickened by structural wedging as revealed by seismic line CPB-3 (Fouch and others, 1994, figure T5b). On this seismic line, 4.2 km to the southwest, where the Dakota Sandstone and near-top of Mancos reflectors become parallel, the Mancos is about 1,430 m (4,700 ft) thick, using an interval velocity of 4.33 km/sec (14,200 ft/sec), thicknesses and velocities calculated in English units

Kd **Dakota Sandstone (Lower Cretaceous)**—Predominately medium- to thick-bedded, medium- to fine-grained, light-gray (7.5YR 7/1) to light-brownish-gray (10YR 6/2-3) well-sorted quartz sandstone, pale orange weathered in part. Silica cement makes the Dakota the most resistant unit in the map area, and it forms a prominent narrow hogback. In many localities, the base of the unit is characterized by rounded granules and pebbles of chert and quartzite less than 2 cm in diameter. West of the junction of West Rifle and Middle Rifle Creeks, bright-green mudstone (Cedar Mountain Formation of Young, 1960) similar to the underlying Brushy Basin Member of the Morrison Formation is near the base of the Dakota, interstratified with typical sandstone of the Dakota. Although beds are planar in the upper part of the unit, crossbedding is common toward the base. In the overlying

Mancos Shale, in the Dakota Sandstone, and in the underlying Morrison Formation (Jm), where the dip is less than about 20°, landslides, debris flows, creep, and shallow, highly listric breakaways commonly create a mass movement deposit (Qcm). Thickness, uncorrected for dip, encountered in the Cameron Oil – 1 Bowen drill hole (sec 20, T. 4 S., R. 93 W.) is 27 m. Thickness mapped is 25-40 m

Jm **Morrison Formation (Upper Jurassic)**—Light-greenish-gray to dark-greenish-gray and pale-red-purple to grayish-red-purple siltstone and claystone interbedded with very light gray to medium-gray, medium- to fine-grained sandstone (Scott, Shroba, and Egger, 2001). Locally, pebble and granule conglomerate is present, and light-gray to medium-light-gray limestone beds are present in the lower part of the unit. The base of the Morrison Formation makes a sharp contact with the underlying Entrada Sandstone. The Morrison Formation contains expansive clays which locally have high shrink-swell potential (Noe, 1996). The lower part of the Morrison is the breakaway zone for mass movement deposits (Qcm) on the west side of Harris Gulch as observed in the bulldozer cut in SW ¼ Sec. 5, T. 4 S., R. 93 W. The thickness of the Morrison interval, uncorrected for dip, in the Cameron Oil–1 Bowen drill hole (sec 20, T. 4 S., R. 93 W.) is 189 m. Thickness of the map unit is about 160–180 m (Scott, Shroba, and Egger, 2001)

Jeg **Entrada Sandstone (Middle Jurassic) and Glen Canyon Sandstone (Lower Jurassic), undivided**—Mapped separately in the Rifle Falls quadrangle just to the east (Scott, Shroba, and Egger, 2001). The upper part of the unit (Entrada Sandstone) is a grayish-orange-pink to very light gray, fine- to very fine grained, well-sorted, friable, calcite-cemented quartz sandstone. Large-scale, steep cross-bedding is common, reaching heights as much as 15 m. Rock weathers to smooth, rounded exposures that commonly form small cliffs at the base. Thickness of the Entrada is about 25–35 m. The lower part of the unit (Glen Canyon Sandstone) consists of yellowish-gray and grayish-pink to very light gray, fine- to very fine grained, carbonate cemented, mainly eolian sandstone consisting mostly of well-rounded quartz grains but also includes some feldspar and chert grains. This subunit contains small- to large-scale cross-beds that range from a few tenths of a meter to nearly 10 m in height, smaller than the large-scale (locally 15 m or more in height) cross-beds of the Entrada. Cross-beds include tabular-planar and wedge-planar in the upper part, but the lower part consists of parallel beds that may be of marine origin. Locally, the Glen Canyon subunit forms nearly vertical slabby cliffs whereas the overlying Entrada Sandstone forms steep, smooth, rounded cliffs. Previously, the lower part of the map unit was called Navajo Sandstone (Cary, 1960) but was renamed Glen Canyon by Poole and Stewart (1964). The contact with the underlying Chinle Formation is unconformable. Thickness of the Glen Canyon subunit is about 20 m but thins toward the east and southeast to pinch out east of the New Castle quadrangle (Scott and Shroba, 1997). Thickness of this map interval is about 45–55 m

ꝶPcs **Chinle Formation (Upper Triassic) and State Bridge Formation (Lower Triassic and Permian), undivided**—Shown on cross section *A–A′*; only

ꝶc **Chinle Formation (Upper Triassic)**—Moderate-red, moderate-reddish-orange, and pale-red-purple siltstone and calcareous siltstone. These siltstones probably belong to the red siltstone member of Stewart and others (1972). Contact with underlying State Bridge Formation is difficult to locate because the mottled member and Gartra Member of the Chinle present in the South Canyon Creek valley in the Storm King Mountain quadrangle (Poole and Stewart, 1964) 40 km to the southeast are seldom exposed in the map area. The contact in the map area is based on a subtle color change, typically from moderate reddish orange of the Chinle Formation to grayish red of the State Bridge Formation (ꝶPs). Thickness of the Chinle Formation is about 80–110 m

ꝶPs **State Bridge Formation (Lower Triassic and Permian)**—Predominately nonresistant unit of dull-gray and grayish-red fine- to very fine grained calcareous sandstone, siltstone, and mudstone. The upper member, termed “Moenkopi formation” by Cary (1960) consists of about 30 m of thin-bedded grayish-red calcareous siltstone, generally poorly exposed. This is underlain by about 1 m of sandy to silty dolostone, the South Canyon Creek Dolomite Member of Bass and Northrup (1963), thickness from Cary

(1960). Below the South Canyon Creek Dolomite Member, the basal State Bridge consists of about 25 m of pale-olive to dusky-yellow-weathering, calcareous, very fine grained, silty, medium-gray (N5 to 5Y5/1) to pale-gray (N8) sandstone and sandy limestone. Thickness is about 56 m, as measured by Cary (1960) who mapped the lower 26 m of this unit as "Park City(?) formation"

PPm **Maroon Formation (Lower Permian to Pennsylvanian)**—Predominately redbeds that include grayish-red to pale-gray arkosic sandstone and reddish-brown siltstone, mudstone, and claystone. The petroliferous upper 40 m is a coarse-grained white sandstone containing conglomeratic lenses and reddish-gray conglomeratic lenses near the base. This unit, which is unmapped here, was called the "Schoolhouse tongue of the Weber formation" by Cary (1960) but now is considered to be the Schoolhouse Member of the Maroon Formation (Johnson and others, 1990). The lower part of the Maroon Formation consists of interbedded grayish-red arkosic sandstone and reddish-brown siltstone, mudstone and claystone, with a few thin discontinuous unfossiliferous limestone beds near the base. Thickness of the Maroon is about 450 m. Thickness appears to decrease from about 500 m in the east to about 400 m in the northwestern part of the quadrangle

Pev **Eagle Valley Formation (Middle Pennsylvanian)**—Yellowish-gray, very pale orange, light-olive-gray, greenish-gray to light-greenish-gray, light-gray, dark-greenish-gray, and sparse pale-red calcareous, fine- to coarse-grained, micaceous sandstone, siltstone, and gypsiferous mudstone interbedded with at least one major highly fossiliferous limestone interval (Pevl, described below). A variable thickness of gypsum is present at the surface. The Eagle Valley Formation contains much brecciated limestone, which is tightly folded in part and highly sheared. Total thickness is about 500 m (from DeVoto and others, 1986, fig. 5), and it appears to decrease westward in the quadrangle, but thickness highly variable due to Neogene and possibly older diapirism and flowage as well as solution collapse

Pevl **Limestone interval**—Light-brownish-gray, dark-gray- to medium-gray-weathering, fossiliferous limestone bed within upper part of Eagle Valley Formation along the eastern edge of the map area; minor limestone beds are present but are not mapped. In the western part of the map area, the bed appears to be absent. This unit is about 40 m thick where locally prominent in the NE1/4 of section 19, T. 4 S., R. 92 W.

Pee **Eagle Valley Evaporite (Middle Pennsylvanian)**—Pale-gray to white, coarse-grained gypsum locally containing brecciated clasts of limestone and sandstone; appears to be diapirically injected into the upper part of the Eagle Valley Formation near the confluence of Middle Rifle and Butler Creeks. Original thickness unknown

Pb **Belden Formation (Middle and Lower Pennsylvanian)**—Consists of thin- to medium-bedded, dark-gray, finely crystalline limestone and dolostone, with some interbedded black shale near the base and top. The upper part of the Belden is comprised of about 91 m of interbedded dark-gray limestone, black shale, and thin beds of dark-gray, orange-weathered fine-grained sandstone. Below this is a 1.5-m-thick bed of limestone with abundant dark-bluish-gray finely crystalline coarse sand to fine pebble intraclasts and oolites in light-bluish-gray limestone matrix. These are in roughly equal amounts and constitute more than 75% of the bed (Cary, 1960). The lower part of the Belden consists of about 23 m of dolostone and interbedded black shale (Cary, 1960). Total thickness is about 116 m

Ml **Leadville Limestone (Lower Mississippian)**—Predominately light- to medium-gray massive bioclastic limestone that is oolitic near the top and is hackly weathering with abundant black chert nodules, particularly near the base. Karst pinnacles and sinkholes characterize upper surface of the Leadville, associated locally with a crumbly red-weathered paleosol remnant of the limestone, equivalent to the Molas Formation (Cary, 1960), but this is not continuous or thick enough to be mapped separately. Includes 6–9 m of dense dark-gray limey dolostone beds, which form a series of small scarps below the main Leadville cliff, just above the basal crenulated sandy dolostone (Gilman? Formation) which rests disconformably on the Dyer Dolomite (Cary, 1960). Thickness of the Leadville is about 90 m

Dc **Chafee Group (Upper Devonian)**—Consists of two formations (Campbell, 1970). The Dyer Dolomite at the top is about 34 m thick

(Cary, 1960), and it consists of a fossiliferous medium-gray dolomitic limestone, fine-grained dark-gray dolostone, and some greenish dolostone. The lower 17 m of the Dyer forms the third cliff above Butler Creek and is a massive, dark-gray, knobby-weathered fossiliferous dolomitic limestone (Broken Rib Member). The Dyer is underlain by Parting Formation, which consists of 35 m of fairly well sorted and rounded quartz sandstone, quartzite, and some sandy dolostone and shale; lower part composed of vitreous white quartzite (Cary, 1960). Base of unit is disconformable on Manitou Formation. The Chafee Group is about 70 m thick along Butler Creek

Om **Manitou Formation (Lower Ordovician)**—Consists of two members: the overlying Tie Gulch Dolostone Member, a resistant light-blue-green, fine- to medium-grained, slabby-weathered dolostone interbedded with thin bluish-gray shale and brown sandstone. This member is an approximately 20-m-thick cliff former. The underlying Dead Horse Conglomerate Member consists of thin- to medium-bedded sandy dolostone and gray fissile shale with an occasional bed of edgewise conglomerate. This member is an approximately 14-m-thick slope former. The Manitou Formation is about 34 m thick

O€y **Ordovician and Cambrian rocks, undivided**—This map unit is composed of Manitou Formation at top (described previously); underlain by Dotsero Formation (Upper Cambrian) that consists of two members, an overlying wavy-bedded algal limestone (Clinetop Member) that forms an approximately 1-m-high ledge, underlain by Glenwood Canyon Member about 33 m thick, which is a recessive slope former and consists of thin beds of tannish-gray dolostone, edgewise conglomerate, and dolomitic shale, and Upper Cambrian Sawatch Quartzite at the base. Only about the upper 30 m of Sawatch is exposed on Butler Creek [NE ¼ sec 18]. It is generally thinly interbedded coarse-grained quartzite, with very thin partings of dark-gray silty to sandy dolostone. Estimated total thickness of Sawatch Quartzite is 152 m on Middle Rifle Creek (Cary, 1960). Total thickness of interval is about 230 m

Ꞓgn **Altered medium- to coarse-grained hornblende tonalitic gneiss (Proterozoic)**—Locally poorly foliated, containing moderate-orange-pink feldspar and black to greenish-gray mafic minerals (chlorite and epidote) in samples 97P1 and 97P2 collected from exposures in SW ¼ NE ¼ Sec. 2, T. 4 S., R. 93 W. (Bruce Bryant, written commun., 2000). The first sample was analysed by Naeser and others (2002, tables 2 and 3) as sample WR-7, described as "altered leucocratic tonalite," which yielded an apatite fission-track age of 48.2±4.2 Ma. Plagioclase twinning visible in grains of altered feldspar viewed in thin section. Cary (1960) reports exposures of "granite porphyry with white feldspar phenocrysts as much as 1.5 centimeters in diameter imbedded in a finely crystalline matrix" in prospect pits in the southwest quarter of the same section

Geomorphic Features

The Grand Hogback and Horse Mountain are major geomorphic features in the Horse Mountain quadrangle. The Grand Hogback is a roughly west-northwest-trending ridge that stands about 600 m above adjacent valleys and has elevations as high as 2,636 m. The trend of this ridge curves gradually from N 70° W to N 35° W across the southern margin of the quadrangle, a clockwise bend of 35°, and it is supported by steeply south- and southwest-dipping sandstones of the Upper Cretaceous Mesaverde Group. It is breached near the southeastern corner of the quadrangle by Rifle Gap, a canyon cut by Rifle Creek probably during late Pliocene(?) through Pleistocene or Holocene time. The lowest elevation in the quadrangle is about 1,781 m along Rifle Creek in Rifle Gap. Horse Mountain is a prominent landform and highest feature in the quadrangle. It reaches an altitude of 2,877 m in the northwestern part of the quadrangle. Horse Mountain is separated from the Grand Hogback by the southeast-trending valley of West Rifle Creek, which is cut in shales of the Mancos Shale. Harris Gulch is a southwest-trending valley on the western flank of Horse Mountain. Slopes on either side of Harris Gulch are inclined toward the southwest, subparallel to bedding in the Entrada Sandstone. These slopes are mantled by scattered blocks and masses of bouldery rubble derived from the Dakota Sandstone resting on claystone and clayey sediment derived from the Morrison Formation. The valley of Brush Creek, northeast of Horse Mountain, separates Parker Ridge from Horse Mountain. Elevations along the crest of the ridge are as high as 2,855 m. Parker Ridge is held up by predominantly southwest-dipping sandstones in the lower and middle part of the Maroon Formation. The upper reach of Brush Creek appears to overlie less resistant and poorly exposed mudstones beneath the more resistant sandstones and conglomeratic sandstones in the Schoolhouse Member in the upper part of the Maroon Formation. The position and character of the saddle between the head of the valley of Brush Creek and Harris Gulch suggests stream capture by the principal stream in Harris Gulch.

The deep canyon along the upper reach of Middle Rifle Creek, just northeast of Parker Ridge, exposes Leadville Limestone along much of the canyon's rim, and Cambrian through Devonian sedimentary rocks on its slopes. Proterozoic high-grade metamorphic basement rocks are locally exposed in the canyon (near the center of section 2, T. 4 S., R. 93 W.). Northeast of this canyon lies a gently southward-sloping tableland underlain by a dip slope composed of limestone and siltstone of the Belden Formation and the lower part of the Eagle Valley Formation. The middle and lower reaches of Middle Rifle Creek (east and south of section 12, T. 4 S., R. 93 W.) flow southward across the strike of the Paleozoic and lower Mesozoic rocks. Just north of the confluence of Brush Creek and Middle Rifle Creek, the latter crosses a diapir composed of Eagle Valley Evaporite. Coarsely crystalline gypsum from the diapir flowed southward to the valley floor of lower Brush Creek over Quaternary deposits, between the near-vertical spires composed of sandstone in the lower part of the Maroon Formation, which forms the structural boundary on the southwestern margin of the evaporite.

Stratigraphy of Tertiary and Quaternary Deposits

Members of the Wasatch Formation were mapped following the stratigraphic framework provided by Donnell (1969). None of the cross-stratification observed in the lower part of the Wasatch indicated drainage away from the Grand Hogback. Volcaniclastic debris, which comprises most of the basal Atwell Gulch Member of the Wasatch, indicates a source area to the east-southeast in the region of the present Sawatch Range (Bruce Bryant, oral commun., 1997). This indicates that during the early Paleocene, the White River Uplift (at least the part east of Glenwood Springs) was not a drainage barrier, nor was the present White River Uplift a significant sediment source.

Deposits of high-level gravelly alluvium, on Parker Ridge (QTg) at the head of Harris Gulch in the northwestern part of the map area at elevations above 2,800 m, probably are valley-fill of the ancestral Colorado River derived from the east. The clasts are mostly angular to subrounded Paleozoic limestone along with minor amounts of chert and sandstone and rare quartzite. Especially important are the presence of distinctive subrounded cobbles of Tertiary basalt and Proterozoic metamorphic rocks.

Small deposits of gravelly alluvium (Qg) between 20 and 170 m above and north of Rifle Creek and Rifle Gap Reservoir in the southeastern part of the map area probably are remnants of terraces that were deposited during the late and middle Pleistocene. The presence of sandstone, limestone, chert, and quartzite clasts and lack of Proterozoic metamorphic and granitic clasts in the alluvium indicate that the source area contained rocks similar to those presently exposed in the northern part of the map prior to exhumation of Proterozoic rocks in the upper part of the valley of Main Rifle Creek. The 1.5-m size of the larger clasts requires a relatively nearby source.

Map units that consist chiefly of landslide debris (Qlsy, younger landslide deposits, Qls, landslide deposits, Qlso, older landslide deposits, and Qcm, mass movement deposits) are recognized to distinguish among landslide deposits that have distinct landforms (Qlsy, Qls), those that have less distinct landforms and are partially dissected (Qlso), and those that contain evidence of several mechanisms of mass movement (Qcm). Mechanisms that produced mass movement deposits probably include debris-slide, debris-slump, slump-earth-flow, and earth-flow (Varnes, 1978), but also include debris-flow and creep. At some localities, very poorly stratified boulders in a sandy and silty matrix suggests a debris-flow mechanism of emplacement, and at others, small-scale pull-apart structures suggest a creep mechanism. Some mass movement deposits have no recognizable landforms related to the driving mechanisms; these deposits probably are middle Pleistocene in age, old enough for erosion to have obscured the original depositional morphology of the landforms.

Structure

The upper, strike-parallel part of the canyon formed by Middle Rifle Creek is structurally the monoclinal axis of the White River uplift within the quadrangle and is likely fault controlled. Although exposures in the floor of the canyon are few and generally poor, a northeast-dipping, southeast-trending normal fault is inferred to be present for much of its length. To the southeast, the fault is exposed in the southwest wall of the canyon in the NW ¼, section 12, T. 4 S., R. 93 W. Near the eastern edge of the quadrangle (in section 18, T. 4 S., R. 92 W.), opposing northwest-trending normal faults form a central graben (cross section *B–B'*). In the southwestern part of the quadrangle, the Grand Hogback bends northward and the uplift is flanked on the west by the central part of the Piceance Basin. Both basin and western part of the uplift were partitioned following early Paleocene time (see eastward thickening of Upper Cretaceous and Paleocene rocks northwest of Rifle, in Johnson and Finn, 1986).

The location of a diapir near the confluence of Butler Creek with Middle Rifle Creek suggests structural control in part for these drainages where they cross the diapiric Eagle Valley Evaporite. South of this confluence, in the E ½, section 24, T. 4 S., R. 93 W., gentle dips in Pennsylvanian through Triassic clastic rocks toward and away from the south-southeast course of Middle Rifle Creek suggest associated halite and anhydrite/gypsum flowage in the underlying Eagle Valley

Evaporite. The structural attitudes of these beds that strike parallel to Middle Rifle Creek are secondary to the southeast-striking, south-dipping regional structural grain of the bedrock. To the north, the Eagle Valley Formation exposes a wealth of generally strike-parallel folds, less than about 20 m in amplitude and wavelength. Additional discussion of evaporite tectonism in and near the map area is in Scott, Bryant, and Perry (2002).

Normal faulting along the upper part of Middle Rifle Creek displaces basement rocks and may date in part to the development of the White River uplift. Normal faults and small-scale anticlines and synclines exposed on either side of the valley of lower Middle Rifle Creek may be due to evaporite flowage and (or) withdrawal as suggested in cross section *B–B'*. Evaporite flowage into the valley of lower Brush Creek indicates that diapirism continued into the Holocene and possibly continues to the present time. Diapirism may be entirely Neogene (Miocene and Pliocene) or may have originated somewhat earlier during the initial growth and unroofing of the White River uplift, the axis of which plunges northwestward through the quadrangle parallel and beneath the upper part of Middle Rifle Creek.

The southwest-facing thrust inferred in cross section *B–B'* to ramp upward southward into bedding in the Eagle Valley evaporite is hypothetical. It mimics on a smaller scale the overall structure of the Grand Hogback as a fault-propagation fold cored by a structural wedge, revealed by seismic data south of Glenwood Springs (Perry and others, 1988, 2002). A larger scale southwest-facing blind thrust probably underlies the Grand Hogback monocline in the area between Glenwood Springs and Rifle but is not defined by drilling or available seismic data. It would be too deep to show on cross sections *A–A'* and *B–B'*.

Geologic Hazards

Geologic hazards in the map area include erosion, volume change, debris flows, and flooding (table 3). Erosion produced by mass wasting processes includes processes that move rock and surficial material downslope under the influence of gravity, such as landsliding, debris flow, and rock fall. These processes and their associated deposits are generally more prevalent on steeper slopes. Gullying and piping commonly occur in silty sand on gentle slopes. Expansive surficial deposits and bedrock are those unconsolidated materials and rocks that expand when wet and contract when dry. Most stream floods are restricted to low-lying areas, but sheet floods can occur on gently sloping surfaces that are well above stream level (Shroba and others, 1979). Table 3 summarizes the geologic hazards that are likely to occur on, or in, geologic units in the map area.

The term "landslide" as used in this report includes several mechanisms of rapid to slow mass transport of surficial and bedrock material downslope. These mechanisms in the map area (Varnes, 1978) commonly produce debris-slide, rock-slide, debris-slump, rock-slump, slump-earth-flow, earth-flow, debris-flow, and creep deposits. These deposits are indicated on the map by symbols Qlsy, Qlso, and Qls (landslide deposits), Qd (debris-flow deposits), Qc (colluvium, undivided), and Qcm (mass-movement deposits). These deposits were identified and mapped by their surface morphology observed on aerial photographs and in the field. These morphologic features include hummocky topography, deflection of stream channels at the toes of deposits, headwall scarps, lobate form of the deposits, differences in vegetation on these deposits compared to that on adjacent stable areas, material downslope from their sources, and overturned strata along the dip slope of the Grand Hogback. Map units Qc and Qcm locally include old landslide and debris-flow deposits that are not mappable as separate units because their surface morphology has been muted or obliterated by erosion.

Landslide and debris-flow deposits in the map area are commonly derived from shale-, mudstone-, or claystone-rich units, particularly from the upper part of the Mancos Shale (Km), Eagle Valley Formation (ℙev), Belden Formation (ℙb), and the stratigraphic sequence consisting of the Dakota Sandstone (Kd) and Morrison Formation (Jm). The Mancos-Dakota-Morrison sequence is particularly vulnerable to mass wasting because of the low shear strength and smectitic clays in the Morrison Formation, which fail readily on low-angle dip slopes. Landslide deposits that involve this stratigraphic

Table 3. Geologic hazards and related map units in the Horse Mountain quadrangle.

Erosion					Volume Change		Debris-Flow Deposition		Flooding	
Mass wasting			Gullying	Piping	Hydro-compaction	Expansive materials				
Qlsy	Qc	Qd	Qac	Qac	Qlo	Km	Qfy	Qd	Qac	Qfy
Qlso	Qta	Kd	Qlo	Qlo		Qfy	Qac	Qls	Qp	
Qls	Jm	Km				Qac	Qp	Qcm		
Qcm	ℙb	TRc				Qls	Qc			
Kicc						Qc				
ℙev						Qd				

sequence on low-angle dip slopes were recognized in the adjacent Rifle Falls (Scott, Shroba, and Egger, 2001) and New Castle (Scott and Shroba, 1997) 7.5′ quadrangles, the Colorado National Monument 7.5′ quadrangle (Scott, Harding, and others, 2001) about 100 km to the southwest, the Grand Junction 7.5′ quadrangle (Scott, Carrara, and others, 2002) and the Wolcott quadrangle about 80 km to the east (Lidke, 1998). This Mancos-Dakota-Morrison stratigraphic sequence is less commonly involved in landslides where the dip slope is steeper than about 20° (Scott and Shroba, 1997), perhaps because meteoric water falling on gentler dip slopes can more readily infiltrate and wet the expansive smectitic clays in the Morrison Formation, thereby reducing the shear strength of the expansive clays. Because of the common landslide hazards associated with low-angle dip slopes composed of the Mancos-Dakota-Morrison sequence of strata, construction of roads or structures on these slopes is likely to reactivate landsliding or other mass wasting processes.

To a lesser degree, landslide deposits also consist of debris derived from the Chinle Formation (TRc) near Middle Rifle Creek as well as from the Cozzette Sandstone and Corcoran Sandstone Members of the Iles Formation, undivided (Kicc), below exposures on the north flank of the Grand Hogback. Commonly, both debris-flow and landslide deposits are mapped as colluvium (Qc) where these deposits lack distinct surface morphology.

The upper part of the Mancos Shale (Km) and the Morrison Formation (Jm) locally contain expansive, smectite-rich beds that are locally overlain by expansive soils and surficial deposits. These expansive materials can expand significantly when wet and contract when dry; these properties tend to disrupt building foundations and other structures. Where strata containing different amounts of smectitic clay dip steeply, such as in the southern part of the map area, the detrimental effects are commonly more pronounced than if the strata were nearly horizontal because of uneven heaving of foundations and other structures (Noe, 1996; Noe and Dodson, 1995). Colluvial and some alluvial deposits derived from these units may also have expansive characteristics.

Stream flooding is generally restricted to low-lying young surficial units such as undivided alluvium and colluvium (Qac), but also occurs on higher units such as young alluvial-fan and debris-flow deposits (Qfy). Because of the potential for flooding, construction of permanent structures on undivided alluvium and colluvium (Qac) along Middle Rifle Creek, West Rifle Creek, and their tributaries should be avoided. Sheet flooding may occur on pediment deposits (Qp) in areas outside of stream channels.

Geologic Resources

Coal was produced from seven mines in the quadrangle. All of these mines are on the Grand Hogback, in the Rifle Gap coal district (Horn and Gere, 1954), and all seven are now abandoned. Four mines are near Rifle Gap in the southeast corner of the quadrangle, in section 7, T. 5 S., R. 92 W. Two mines are just to the west, in section 12, T. 5 S., R. 93 W. One mine was opened in section 3, T. 5 S., R. 93 W. Only the North Canon Mine, NE1/4 SW1/4 section 12, produced more than 100,000 tons of coal (126,482 tons total production, Collins, 1976, p. 136). The mine opened in 1926, was abandoned in 1959, and was the only mine in the quadrangle to produce coal from the Williams Fork Formation of the Mesaverde Group. Numerous clinker beds in the lower Williams Fork and Iles Formations of the Mesaverde Group at the surface are evidence that coal seams have burned locally in the past, likely due to lightning strikes. We observed no evidence that any of the coal seams in the quadrangle are currently burning.

The other six mines each produced less than 100,000 tons of coal from Black Diamond and Fairfield coal groups of the Iles Formation, lower Mesaverde Group (Collins, 1976). The former is beneath the Corcoran Sandstone Member. The latter is above the Rollins Sandstone Member. Dumps near the mine openings are comprised of carbonaceous material, shale as well as impure coal, siltstone, sandstone, and seat earth. Despite the coal mining in the map area, we observed no evidence of acid mine drainage.

Oil and gas resources in the quadrangle have not been adequately tested, although several shallow unsuccessful test wells have been drilled in the southwestern part of the quadrangle, as shown on the accompanying geologic map. The exposure of the entire Phanerozoic stratigraphic section within the quadrangle along the axis of the White River uplift reduces the chances for significant hydrocarbon accumulations to be preserved.

Sand and gravel deposits along Middle Rifle Creek, West Rifle Creek, and their major tributaries have not been not extracted for aggregate resources. These deposits would be suitable for fill material, but not for concrete or asphalt aggregate. The gravel is rich in weak sandstone clasts. The sand locally contains abundant silt and clay.

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