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GEOLOGIC MAP OF THE RIFLE FALLS QUADRANGLE, GARFIELD COUNTY, COLORADO

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Contents

Tables

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. Fractional map symbols (for example, Qlo/Qp) are used where loess mantles older surficial deposits and the underlying deposits have been identified. These fractional units are not described here; instead refer to descriptions of individual units. Thin, discontinuous colluvial deposits, residual material on bedrock, small artificial fills, and small talus deposits were not mapped. Areas underlain by the Mancos Shale (Kmu, Kmn, Kml), Maroon Formation (PIPms, PIPml), Eagle Valley Formation (IPev), and Belden Formation (IPb) 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 based chiefly on two regional rates of stream incision of about 0.14 m/k.y. (k.y., thousand years) and 0.16 m/k.y. and on a regional rate of tectonic uplift of about 0.18 m/k.y. The first incision rate is based on an average of three values for stream incision since the deposition of the 620-ka (kilo-annum, thousands of years old or ago) Lava Creek B volcanic ash: (1) about 90 m above the Colorado River near the east end of Glenwood Canyon (Izett and Wilcox, 1982), (2) about 88 m above the Roaring Fork River near Carbondale, Colorado (Piety, 1981), and (3) about 80-85 m above the White River near Meeker, Colorado (J.W. Whitney, oral commun., 1992; Whitney and Andrews, 1983). The second incision rate, possibly a minimum rate, is based on about 1,600 m of downcutting by the Colorado River since the eruption of the about 10-Ma (mega-annum, millions of years old or ago) basalt on Grand Mesa (Marvin and others, 1966) near Palisade, Colorado, about 70 km southwest of the map area. The rate of tectonic uplift of about 0.18 m/k.y. was determined for the Derby Peak fauna in the Flat Tops area (Colman, 1985), which is about 50 km east-northeast of the map area.

Soil-horizon designations are those of the Soil Survey Staff (1975), Guthrie and Whitty (1982), and Birkeland (1984). 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 III Bk or 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.

A previous Open-File Report of this map was published recently (Green and others, 1993); however, incorrect location of bedrock stratigraphic contacts, incomplete subdivision of mappable units in bedrock, incorrect location and identification of faults and folds in bedrock, and lack of drill-hole information in that report has made this revision necessary.

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 and uncompacted material composed mostly of silt, sand, and rock fragments

af **Artificial fill (latest Holocene)**—Compacted and uncompacted fill material composed mostly of silt, sand, and rock fragments beneath structures at the Rifle Falls State Fish Hatchery, in mine dumps, and in earthen dams. Thickness generally less than 10 m

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

Multiply	By	To obtain
centimeters (cm)	0.39	inches
meters (m)	3.3	feet
kilograms	2.2	pounds
kilometers (km)	0.62	miles
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)
		Quaternary	Holocene	0 to 10 ka
			Pleistocene	10 ka to 1.65 Ma*
	CENOZOIC	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 million 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).

ALLUVIAL DEPOSITS

Silt, sand, and gravel in flood plains and stream channel deposits and in stream deposits on hillsides and hilltops along East Rifle Creek, Dry Rifle Creek, West Elk Creek, and unnamed intermittent streams

Qfp **Flood-plain and stream-channel deposits (Holocene and late Pleistocene)**—Chiefly interstratified sandy silt, silty sand, and locally lenses of pebbly sand, and poorly sorted, clast-supported pebble and cobble gravel in the lower part of the unit. The unit locally may include organic-rich deposits, such as organic mud. Clasts are commonly subangular to subrounded sandstone, limestone, quartzite, gneiss, and granitic rocks. Deposits of sandy silt and silty sand are prone to gullying and piping. Low-lying areas of the map unit are prone to stream flooding. Unit Qfp was deposited by minor streams near the southeastern corner of the map area. Maximum exposed thickness is 15 m along West Elk Creek near the northwest corner of the adjacent New Castle quadrangle (Scott and Shroba, 1997)

Qg **Gravelly alluvium (late to early? Pleistocene)**—Small deposits of stream alluvium on hillsides and hilltops about 10, 30, 35, 50, 60, 75, 100, 110, 120, 135, 145, 160, 255, and 290 m above East Rifle Creek, Dry Rifle Creek, West Elk Creek, and unnamed intermittent streams in the southeastern part of the map area. 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 commonly mantled by about 1-2 m of loess (Qlo). Deposits of unit Qg that are about 10-160 m above stream level are probably of late and middle Pleistocene age; whereas, those that are about 250 m above stream level are probably of early Pleistocene age. The 10-50 m-high deposits are probably equivalent to units Qty and Qto and the 60-160 m-high deposits are probably equivalent to unit Qtt in the adjacent New Castle and Silt quadrangles (Scott and Shroba, 1997; Shroba and Scott, 2000). Exposed thickness is 1.5-20 m; maximum thickness is possibly about 30 m

QTg **High-level gravelly alluvium (early Pleistocene or late Pliocene)**—Valley-fill(?) deposits, about 415-530 m above East Rifle Creek, that locally mantle the crests and slopes of ridges in the northern part of the map area. 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. Some of the sandstone clasts are as long as 2 m. Unit QTg is mantled by a thin (probably less than 1.5 m) layer of pebbly silty sand, which is probably loess (Qlo) that has been mixed with the underlying alluvium. Unit QTg may be more extensive than mapped on the northwest-trending ridge near the northeast corner of the map area. Unit QTg may be roughly equivalent in age to unit QTba in the adjacent New Castle quadrangle (Scott and Shroba, 1997). Thickness is possibly about 5-25 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 **Younger fan-alluvium and debris-flow deposits (Holocene and latest Pleistocene)**—Mostly poorly sorted, clast- and matrix-supported, slightly bouldery, pebble and cobble gravel in a 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 (Kmu, Kmn, Kml) 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. 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 (Qfp), 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 (Kmu, Kmn, and Kml) 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 1-8 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

Qfo **Older fan alluvium and debris-flow deposits (late Pleistocene)—**Fan-shaped deposit on the north side of West Elk Creek in the southwestern part of the map area. The unit is poorly exposed, but it probably consists mostly of poorly sorted, clast and matrix-supported, slightly bouldery, pebbly and cobbly gravel, sandy pebble gravel, and pebbly sand. Clasts are chiefly subangular to subrounded sandstone, conglomerate, and siltstone from the Maroon Formation (P₱ms, P₱ml). Probably poorly bedded and probably contains discontinuous beds and lenses. Unit Qfo has about 1-3 m of loess (Qlo). Deposited by a small intermittent stream tributary to West Elk Creek. Locally includes sheetwash deposits (Qsw). Maximum thickness is possibly about 25 m

Qp **Pediment deposits (middle Pleistocene)**—Gravelly alluvium and debris-flow deposits at three levels that overlie gently sloping surfaces cut on Mancos Shale (Kmu, Kmn, Kml) in the southern part of the map area. Unit Qp is shown on map only 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 25, 35, and 55 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. The intermediate and highest pediment deposits along East Rifle Creek near the southwestern corner of the map area appear to be graded to terrace remnants composed of gravelly alluvium (Qg) that are about 35 and 55 m, respectively, above stream level. Exposed thickness is 1-2 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 and late 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 (Kmu, Kmn, Kml) 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, 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 north side of the Grand Hogback near the southern boundary of the map area. Exposed thickness is 1-1.5 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 upper and lower members of the Mancos Shale (Kmu and Kml), mass-movement deposits (Qcm), and landslide deposits (Qls). Common on gentle to moderate slopes and in depressions caused by landsliding. 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

Qls **Landslide deposits (Holocene and late 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 the Belden Formation (IPb), Eagle Valley Formation (IPev), Maroon Formation (Pms, PIPml), State Bridge Formation (TRPs), Chinle Formation (TRc), Morrison Formation (Jm), and Mancos Shale (Kmu, Kmn, Kml). Younger landslide deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. Unit Qls includes debris-slide, rock-slide, debris-slump, slump-earth-flow, earth-flow, and debris-flow deposits as defined by Varnes (1978). The sizes and lithology 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 (Kmu, Kmn, and Kml) and Morrison Formation (Jm) are rich in clay. Mancos-derived clay from the upper member (Kmu) contains expansive clay that locally probably has high shrink-swell potential. Unit Qls locally includes unmapped sheetwash (Qsw) and creep-derived colluvial (Qc) deposits. Exposed thickness is 1-3 m; maximum thickness is possibly 150 m

Qcm **Mass-movement deposit (Holocene to middle? Pleistocene)**—Chiefly unsorted, poorly stratified to unstratified rock debris and sediment characterized by slightly hummocky topography. Unit forms on 10-20^o dip slopes of the Mancos Shale (Kmu, Kmn, and Kml), Dakota Sandstone (Kd), and Morrison Formation (Jm). Unit Qcm is a complex of landslide, debris-flow, and creep deposits that mostly lack distinctive surface morphology. Unit Qcm locally includes debris-slide, debris-slump, slump-earth-flow, earth-flow, and debris-flow deposits (Varnes, 1978), but it also includes a series of repeated blocks of Dakota Sandstone (Kd) that dip in directions opposite that of the dip slope. Apparently, the mass movement mechanisms included a series of highly listric-shaped breakaways that rotated blocks of the Dakota as much as 90^o·to produce the repeated-block geometry (note slide block shown in cross sections A-A', B-B', and C-C'). The lithology of the clasts and the grain-size distributions of the matrices of these deposits reflect those of the bedrock units and surficial deposits that were displaced by mass movement. Exposed thickness locally exceeds 60 m; maximum thickness is possibly 100 m

Qd **Debris-flow deposits (Holocene(?) to late Pleistocene)**—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, 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 are mainly subangular sand- stone. Some of the deposits are mantled by loess (Qlo) and locally by other colluvial de- posits (Qc) in their steep upper parts. Debris-flow deposits locally form on Belden Formation (ℙb), Eagle Valley Formation (ℙev), and the State Bridge Formation (TRPs). 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 1-2 m; maximum thickness is possibly 15 m

SPRING DEPOSITS

Spring-deposited calcium carbonate along East Rifle Creek and its tributaries

Qtu **Tufa deposits (Holocene and late Pleistocene?)**—Porous, weakly to moderately indurated calcium carbonate deposited by evaporation of calcium carbonate-rich water. Unit is associated with springs near the diapiric intrusion of Eagle Valley Evaporite (ℙee) along East Rifle Creek at Rifle Falls and the Rifle Falls Fish Hatchery. It is also associated with active springs at the Belden Formation (ℙb)-Leadville Limestone (Ml) stratigraphic contact 4.5 km upstream from the fish hatchery and with seeps near the base of the Belden Formation along Huffman Gulch. At one locality, unit Qtu may be associated with a large normal fault in the Maroon Formation (Pms, Pℙml) that projects from the western edge of the map area to just west of East Rifle Creek. Below the fish hatchery, the unit may be associated with the intrusion of Eagle Valley Evaporite (ℙee). Some of the vertically oriented tubes in the tufa are actively depositing calcium carbonate on plant stems. One tufa sample, collected along East Rifle Creek in NE$^1/_4$ sec. 22, T. 4 S., R. 92 W., is composed of 95 percent calcium carbonate and 5 percent very fine to coarse sand. Unit Qtu may locally include dense, well-indurated travertine and tufa-cemented sand and gravel. Maximum exposed thickness is about 15 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 in and near the map area commonly consists of 22-46% sand (0.05-2 mm), 43-62% silt (0.0020-05 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 adjacent New Castle quadrangle (Scott and Shroba, 1997). 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 (1) a relatively short distance of eolian transport and (2) that 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. Unit Qlo commonly mantles level to gently sloping surfaces near the southern boundary of the map area. Exposed thickness is 1-2 m; maximum thickness is possibly 8 m

Qlo/Qp **Loess over pediment deposits**

Qlo/Qg **Loess over gravelly alluvium**

Qlo/Qfo **Loess over older fan alluvium and debris-flow deposits**

BEDROCK UNITS

Ki **Iles Formation (Upper Cretaceous)**—Marine shale and nonmarine sandstone and siltstone. The exposed part of the formation from top down consists of an upper tongue of marine shale, and two sandstones, the Cozzette and Corcoran Sandstone Members undivided (Kicc), separated by an unmapped lower tongue of marine shale. Marine shale consists of monotonous medium-dark-gray to light-olive-gray fissile shale lithologically similar to the upper member of the Mancos Shale (Kmu), described below. The base of the Corcoran Sandstone Member overlies the Mancos Shale. The lower part of the Iles Formation is exposed in the southwestern part of the map area. Although the upper part of the Iles Formation, including the Rollins Sandstone Member, is not exposed in the map area, the unit is about 260-300 m thick in the adjoining Silt quadrangle (Shroba and Scott, 2000)

Kicc **Cozzette Sandstone and Corcoran Sandstone Members undivided**—Two sandstone intervals separated by a marine shale interval. The upper sandstone, the Cozzette Sandstone Member, is very 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 ex- posed in the southwestern part of the map area. Clasts in the sandstone consist of about 80% quartz, 15% feldspar, 5% dark rock fragments and mafic minerals, and a trace of muscovite. 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 map area. 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, 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

Mancos Shale (Upper Cretaceous)—Formation consists of three members, an upper member, the Niobrara Member, and a lower member. Members of this formation are commonly involved in landslide, debris flow, and creep mechanisms that form a mass movement deposit (Qcm) or undifferentiated colluvium (Qc). The Mancos Shale thickness is about 1,490-1,565 m

Kmu **Upper member**—Medium-dark-gray to dark-gray, fissile shale that weathers light gray. Dark-gray to dark-yellowish-orange concretions typically 10 cm in diameter are common in the upper part of the unit, and dark-gray concretions about 30 cm in diameter are common in the lower part of the unit. Very pale orange, fine-grained sandstone forms beds 0.2-2.5 m thick near the top of the map unit. The middle part of the unit is predominantly a monotonous sequence of fissile, dark-gray shale, broken only by several 1-15-cm-thick dark-yellowish-orange bentonitic (smectite-rich) beds. Near the lower contact with the Niobara Member (Kmn), calcareous shale is abundant in the member. Exposures in the map unit are generally poor except where active stream erosion or roadcuts create fresh exposures. Older landslide deposits and debris flow deposits that no longer have geomorphologically distinct character coalesce to form a thick mantle of colluvium (Qc) that covers much of the upper member of the Mancos in the southern part of the map area on the northeast slope of the Grand Hogback. The crest of the Hogback is present in the northern part of the Silt quadrangle (Shroba and Scott, 2000). Because the shale commonly contains expansive clays, the upper member locally may have high shrink-swell potential. This geologic hazard is exacerbated where the strata dip more than 30^{o} because expansive-clay-rich beds may expand upward more than adjacent beds less rich in expansive clays, causing differential heaving of foundations and other structures. Noe and Dodson (1995) and Noe (1996) describe this hazard formed by steeply dipping Pierre Shale along the Front Range in the Colorado Piedmont. The Mancos Shale, however, may have fewer beds rich in expansive clays than the Pierre Shale, which is found 60 km east of the map area. Gypsum exists locally between shaley partings, and Na^+- and Cl^--rich connate water is present in the shale of the upper member; these may create local chemical conditions damaging to untreated concrete and uncoated steel. The thickness of the upper member is about 1,290 m

Kmn **Niobrara Member**—Light-gray-to very light gray-weathering, fissile calcareous shale and blocky shaley limestone that commonly contains pearly fossils of pelecypods (*Inoceramus*). The change from medium-gray-weathering shale of the upper member (Kmu) to the light-gray rocks of the Niobrara Member is gradational, and the contact is located at the most conspicuous color change from the darker gray of the upper member (Kmu) to the lighter gray of the Niobrara Member. In contrast, the lower contact of the Niobrara is placed at the base of the lowest limestone bed above the dark shale of the lower member (Kml). Limestone-rich intervals near the base of the member (2-5 m thick) are interbedded with shale-rich intervals (3-6 m thick); beds are commonly less than 1 m thick in the upper part, but are commonly 1 m thick at the bottom of the member. Excellent exposures of the unit are on either side of Dry Rifle Creek. The Niobrara Member is about 60-85 m thick

Kml **Lower member**—An upper part is characterized by dark-gray fissile shale interbedded with intervals that are medium-gray to light-olive-gray, weathering to pale-yellowish-brown to dusky-yellow, medium-to thin-bedded and laminated calcareous siltstone and sandstone characterized by fragments of brownish-black pelecypod fossils. Merewether and Cobban (1986) and Molenaar and Cobban (1991) recognize this upper part as the Upper Cretaceous Juana Lopez Member of the Mancos; poor exposure in the map area precludes mapping this unit as a separate member as was done where it is better exposed in the New Castle quadrangle adjacent to the southeast (Scott and Shroba, 1997). A lower part of the lower member is characterized by a monotonous sequence of pale-yellowish-brown-weathering, dark-gray fissile shale that is Lower Cretaceous (Merewether and Cobban, 1986; Molenaar and Cobban, 1991). Toward the base of the map unit, thin interbeds of brownish-gray to light-brownish-gray sandstone overlie a gradational contact with the Dakota Sandstone (Kd). Distinction between the upper part (Juana Lopez unit) and the lower part of the lower member is best observed along the east side of East Rifle Creek about 1 km northwest of the junction of Dry Rifle and East Rifle Creeks. Thickness of the lower member ranges from about 140 to 190 m

Kd **Dakota Sandstone (Lower Cretaceous)**—Very pale orange to very light gray, medium-grained, well-sorted quartz sandstone. Unit forms a prominent narrow hogback because strong siliceous cement makes the Dakota the most resistant unit in the map area. In many localities, the base of the unit is characterized by granules and pebbles of chert and quartzite less than 2 cm in diameter. 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^o, mass movement mechanisms including landslides, debris flows, creep, and shallow, highly listric breakaways commonly create a mass movement deposit (Qcm). Good exposures of the Dakota crop out on either side of East Rifle Creek. The base of the Dakota Sandstone is in sharp unconformable contact with the underlying Morrison Formation (Jm). Thickness of the map unit is about 45-55 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 intervals of very light gray to medium-gray, medium- to fine-grained sandstone. Locally contains pebble and granule conglomerate, and light-gray to medium-light-gray limestone beds are present in the lower part of the unit. The sandstone contains dark organic partings and bright-yellow deposits of carnotite on fracture surfaces. The base of the Morrison Formation makes a sharp contact with the underlying Entrada Sandstone. The Morrison Formation locally contains expansive clays that locally have high shrink-swell potential (Noe, 1996). Also the upper part of the formation that contains high concentrations of expansive clay is commonly the breakaway zone associated with landslides and debris flows that form mass movement deposits (Qcm). The central part of the map area has been extensively prospected for uranium commonly in the form of carnotite and tyuyamunite, but only small deposits were found in isolated sandstone layers that contained plant fossils. Thickness of the map unit is about 160-180 m

Je **Entrada Sandstone (Middle Jurassic)**—Grayish-orange-pink to very light gray, fine-to very fine grained, well sorted, friable, calcareous cemented quartz sandstone. Large-scale, steep crossbedding is common, reaching heights as much as 15 meters. Rock weathers to smooth, rounded exposures that commonly form small cliffs at the base. A vanadium-uranium-type roll deposit was mined from either side of East Elk Creek. The principal vanadium minerals are a mica roscoelite, a mixed-layer smectite, a chlorite, and minor montroseite. Uranium minerals include either carnotite or tyuyamunite. The base of the unit forms a sharp unconformable contact with the underlying Chinle Formation (TRc). Thickness of the map unit is about 25-35 m

Jg **Glen Canyon Sandstone (Lower Jurassic)**—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. The upper part of the unit contains small- to large-scale crossbeds that range from a few tenths of a meter to nearly 10 meters in height, smaller than the large-scale (locally 15 meters in height) crossbeds of the Entrada Sandstone (Je). Crossbeds 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 Sandstone forms nearly vertical slabby cliffs whereas the overlying Entrada Sandstone forms steep, smooth, rounded cliffs. Previously in the map area, the Glen Canyon Sandstone was called the Navajo Sandstone (Poole and Stewart, 1964). Thickness of map unit is about 20 m but thins toward the east and southeast to pinch out west of the New Castle quadrangle (Scott and Shroba, 1997)

Jeg **Entrada Sandstone (Middle Jurassic) and Glen Canyon Sandstone (Lower Jurassic), undivided**

TRc **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 (Stewart and others, 1972). Contact with underlying State Bridge Formation is difficult to locate because the mottled member and Gartra Member present in the South Canyon Creek valley in the Storm King Mountain quadrangle (Stewart and others, 1972) 30 km to the southeast were not recognized 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 moderate red and grayish red of the State Bridge Formation (TRPs). Thickness of the Chinle Formation is about 80-110 m

TRPs **State Bridge Formation (Lower Triassic and Permian)**— The upper part consists of moderate-red, dusky-red, pale-red, and grayish-red siltstone and silty claystone interbedded with minor beds of pale-red and grayish-pink to grayish-red sandy siltstone and beds of light-olive-gray and greenish-gray to light-greenish-gray, fine-grained, mottled sandstone. The lower part consists of pale-red to grayish-red siltstone and fine-grained silty sandstone containing light-gray and light-olive to greenish-gray mottles. Thickness of the formation is about 80 m

Maroon Formation (Lower Permian to Middle Pennsylvanian)—The formation contains two members that are shown on the map, the Schoolhouse Member (Pms) and lower member (PIPml). Formation ranges from about 800 to 1,220 m thick

Pms **Schoolhouse Member (Lower Permian)**—Very light gray to medium-dark-gray, yellowish-gray, and pale-red, very fine grained to very coarse grained, calcareous cemented sandstone and sparse pebble and cobble conglomerate. Minor pale-red to light-greenish-gray siltstone and minor mudstone occur between some sandstone beds. Crossbedding and channels are common. Clasts in the sandstone include about 50% quartz, 35% feldspar, 15% rock fragments and dark mafic minerals, and traces of muscovite and biotite. Clasts in the conglomerate include quartz, feldspar, felsic and mafic metamorphic rocks, quartzite, granitic rocks, and limestone as much as 12 cm in diameter. The map unit ranges from 60 to 120 m thick

PIPml **Lower member (Lower Permian? to middle Pennsylvanian)**—Pale-red, grayish-red, light-red, and grayish-pink, calcareous, fine- to coarse-grained, micaceous sandstone and pebble and cobble conglomerate interbedded with moderate-red and grayish-red calcareous siltstone and mudstone. Conglomerate is more common in the upper part of the member than in the lower part. Lower in the member, yellowish-gray, pinkish-gray, pale- pink, and very light gray, fine-to coarse- grained calcareous sandstone interbedded with minor pale-red to light-greenish-gray siltstone is common but not a distinct mappable zone as found in the New Castle quadrangle (Scott and Shroba, 1997). Sandstone, siltstone, and mudstone contain mottles where the red oxidized iron colors have been reduced to light greenish gray and very light gray. Crossbedding and channels are common. Clasts in the sandstone include about 40% quartz, 45% feldspars, 14% rock fragments and dark mafic minerals, and 1% muscovite. Clasts in the conglomerate include quartz, feldspar, felsic and mafic metamorphic rocks, and granitic rocks as much as 8 cm in diameter. Near the base of the member, pale-pink to light-gray, pale- red, pale-reddish-brown, and grayish-red, fine-to coarse-grained, calcareous and highly micaceous sandstone, siltstone, and mudstone are common. These micaceous strata are interbedded with discontinuous light-gray to medium-light-gray, nonfossiliferous limestone and silty limestone beds 1-2 m thick. Contact with the underlying Eagle Valley Formation is gradational and is located at the base of the lowest sequence of pale-red to grayish-red sandstone beds. Thickness of the map unit ranges from 740 to 1,100 m along unfaulted sections

IPev **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 mudstone interbedded with at least one major bed of highly fossiliferous limestone (IPevl, described below). Bedding is parallel to subparallel and contains few crossbeds and channels. Bass and Northrop (1963) reported that in the upper 120 m of the formation fossiliferous limestone beds contain Desmoinesian age (Middle Pennsylvanian) fossils. About 250 m of the map unit is exposed in the map area in contrast with the 800-1,000 m found in the Storm King Mountain (Bryant and others, 1998) and New Castle (Scott and Shroba, 1997) quadrangles 20 km to the east; although stratigraphic and structural relations are unclear, this thickness is probably close to the total thickness of the unit in the Rifle Falls quadrangle

IPevl **Limestone bed**—Dark-gray to medium-gray, weathering to light-brownish-gray, fossiliferous limestone bed within upper part of Eagle Valley Formation in the eastern part of the map area; other minor limestone beds are present but are not mapped. In the central part of the map area, the bed is absent, and in the western part, it is only locally present. This major limestone bed is about 40 m thick where it is prominent along ridge crests

IPee **Eagle Valley Evaporite (Middle Pennsylvanian)**—White to medium-gray and brownish-gray, laminated, highly contorted gypsum, anhydrite, minor siltstone and carbonate beds, and possibly halite at depth. In the center of the map area, one pod-shaped body of the evaporite remains; all its contacts with adjacent Eagle Valley Formation appear to be tectonic, probably caused by diapiric injection of the evaporite into overlying Eagle Valley Formation. Similar pod-shaped bodies of evaporite are to the west in the adjoining Horse Mountain quadrangle (Perry and others, in press b) and to the east in the Deep Creek Point quadrangle (R.B. Scott, unpub. reconnaissance mapping, 1996) and to the southeast in the New Castle (Scott and Shroba, 1997) and Storm King Mountain (Bryant and others, 1998) quadrangles. In all these cases, the Eagle Valley Evaporite appears to have intrusive contacts with the Eagle Valley Formation (IPev). In the Eagle Valley area, widespread Eagle Valley Evaporite forms a laterally continuous, lithologically distinct formation that appears to be stratigraphically below the Eagle Valley Formation (Tweto and others, 1978; Lidke, 1998). Thus, we conclude that in the Rifle Falls quadrangle, the Eagle Valley Evaporite was originally deposited below the Eagle Valley Formation. Besides the geologic hazard related to local sinkholes, the presence of gypsum, anhydrite, and possible halite can cause damage to untreated concrete and uncoated steel. In the map area, the evaporite intrusion is 400 m wide and 2,400 m long

IPb **Belden Formation (Middle and Lower Pennsylvanian)**—Dark-gray to brownish-black, slope-forming, carbonaceous shale interbedded with dark-gray to medium-gray, thin-bedded, ledge-forming, limestone, minor light-gray shaley limestone, and light-brownish-gray calcareous siltstone. Limestone beds are highly fossiliferous locally. Except on the slopes of Mansfield Creek, the Belden is very poorly exposed and is generally covered by landslide deposits (Qls) and an unmapped veneer of colluvium (Qc). Map unit thickness is about 120-130 m thick

Ml **Leadville Limestone (Lower Mississippian)**—The upper part is generally medium-gray with a weak, but distinctive, pale-blue hue, poorly bedded to massive limestone. The lower part is a medium-gray to brownish-gray, medium-bedded limestone that includes minor dolomitic limestone and nodular dark-gray chert. The contact with the underlying Coffee Pot Member of the Dyer Dolomite (Ddc) is indistinct and was picked where dolomite became dominant below the base of the Leadville. That contact is generally coincident with an overhanging cliff at the base of the Leadville Limestone that is well exposed along East Rifle Creek. The most accessible exposures of the Leadville are on the west side of Canyon Creek at the north edge of the map area. Map unit is about 85 m thick

Dc **Chaffee Group (Upper Devonian)**—In the map area, the Chaffee Group contains from top down the Dyer Dolomite and the Parting Formation. The Dyer Dolomite contains light-gray and dark-gray, fossiliferous dolomite, dolomitic limestone, and limestone. The Parting Formation consists of yellowish-gray conglomerate, quartzite, and dolomitic shale and sandstone. The top of the Chaffee Group at many localities is formed by the thin (less than 2 m thick) Gilman Sandstone. However, the Gilman Sandstone was not observed in the map area. The Chaffee Group is about 70 m thick and is shown only in cross section A-A'

Dyer Dolomite—Consists of light-gray to dark-gray, fossiliferous dolomite, dolomitic limestone, and limestone. The unit contains two members, the Coffee Pot and Broken Rib Members. The Dyer Dolomite is not shown as a map unit and is about 50 m thick

Ddc **Coffee Pot Member**—Light-gray to dark-gray, fossiliferous, thin-bedded dolomite, dolomitic limestone, and limestone. Possible stromatolitic structures are ex- pressed as thin lamellae (Campbell, 1970). Upper part of unit contains intraformational dolomite breccia. Map unit is exposed north of the fish hatchery and has a thickness of about 30 m (Campbell, 1972)

Ddb **Broken Rib Member**—Medium-gray, fossil-fragment-rich, thick-bedded, cliff-forming, nodular limestone and dolomitic limestone. Map unit is exposed north of the fish hatchery and has a thickness of about 20 m (Campbell, 1972)

Dp **Parting Formation**—Yellowish-gray to very pale orange dolomite and sandy dolomite that is interbedded with pale-green and greenish-black, dolomitic, micaceous, silty shale. Cross-bedded quartzite and conglomerate are locally present. Map unit is exposed north of the fish hatchery and has a thickness of about 20 m (Campbell, 1972)

O€u **Ordovician and Cambrian units, undivided**—Includes from top down, the Manitou Formation (Lower Ordovician), which consists of light-brown dolomite, gray flat-pebble conglomerate, and glauconite-bearing, greenish-gray to brown shale, sandstone, limestone, and dolomite; the Dotsero Formation (Upper Cambrian), which consists of yellowish-gray to greenish-gray dolomitic sandstone, shale, and conglomerate; and the upper part of the Sawatch Quartzite (Upper Cambrian), which consists of a light-brown fine-grained quartzite. Exposures of the map unit are present on the western part of the map near Butler Creek and have a thickness of about 75-80 m; total thickness of all three Ordovician and Cambrian units in the quadrangle is about 215 m (Perry and others, in press b)

Xu **Metamorphic rocks, undivided (Early Proterozoic)**—Shown only in cross section A-A'. These rocks are probably similar to those mapped in detail in the Storm King Mountain quadrangle about 22 km to the east that include granodiorite gneiss, biotite-quartz-feldspar gneiss, amphibolite, biotite quartzite, biotite-microcline-magnetite-plagioclase-sillimanite schist, and migmatitic gneissic granite and pegmatite (Bryant and others, 1998)

STRATIGRAPHY

An impressive record of gravelly alluvium (Qg) between about 10 and 290 m above modern drainages is probably remnants of side-stream terraces and valley-bottom sediments deposited during the Pleistocene. The presence of sandstone, limestone, chert, and quartzite and ab- sence of Proterozoic metamorphic and granitic clasts in the alluvium indicates that the source areas were rocks similar to those presently exposed north of the map area (Tweto and others, 1978). Also, the subangular to subrounded clasts require a relatively nearby source.

Landslide (Qls) and mass-movement (Qcm) deposits are mapped as separate units in order to distinguish deposits that have distinct landslide morphology (Qls) from those that have slightly hummocky surface morphology produced by different types of mass movement (Qcm). Transport mechanisms of mass movement deposits locally include debris-slide, debris-slump, slump-earth-flow, and earth-flow (Varnes, 1978), but they also include debris flow and creep. At some localities, very poorly stratified boulders in a sandy and silty matrix suggest a debris-flow mechanism of transport and emplacement, and at other localities, pull-apart structures suggest a creep or slide mechanism. Some of the mass-movement deposits (Qcm) lack surface morphology related to a landslide mechanism. These deposits may be old and erosion may have obscured or removed their original landslide morphology; however, they may have been formed by creep and never had landslide morphology. Within the mass-movement deposits (Qcm), large structural blocks of bedrock units were mapped on the western side of the Elk Park fold-and-fault complex. These structural blocks have been identified on the map and cross sections as bedrock units even though they are technically part of the mass-movement deposits.

Unlike the Maroon Formation east of the map area that has several mappable members (Scott and Shroba, 1997), the unit in this map area has only two mapped members, the Schoolhouse Member (Pms) and the lower member (PIPml). The white sandstone member in the adjacent New Castle quadrangle is not mappable in spite of the increase in light-colored sandstone beds near the base of the Maroon Formation in this map area. Even the Schoolhouse Member is less distinctive here. Also, the steep slopes formed by the State Bridge Formation (ŦPs), Chinle Formation (Ŧc), Glen Canyon Sandstone (Jg), and Entrada Sandstone (Je) have shed colluvial debris over much of the Schoolhouse Member.

Exposures of the Eagle Valley Evaporite (IPee) neither mark the unit's original stratigraphic position nor indicate the original thickness of the unit. However, we assume that the evaporite deposits originally interfingered with the Eagle Valley Formation (IPev), similar to the relationships depicted by De Voto and others (1986). Intrusive relationships characterized by pod-shaped exposures dominate the map unit along the southwest flank of the White River uplift (Scott and others, 1999; Scott and others, 1998).

STRUCTURE

Structures in the map area appear to be primarily the result of Laramide (about 70-50 Ma, Tweto, 1975) contractional tectonics, superimposed Neogene uplift, normal faulting, salt tectonism, and large-scale Quaternary mass wasting. Cross sections show many of the resulting structures. Near Glenwood Springs, Colo., 40 km to the east, a seismic line has been interpreted to show several kilometers of offset on a blind, west- to southwest-directed, low-angle, Laramide overthrust of Proterozoic rocks over Eagle Valley Evaporite (IPee) (Perry and others, 1988; Perry and others, in press a). We agree with Perry and others (1988) and consider that the hogback is part of a major fault-propagation fold created by that blind thrust. Also we accept a similar explanation for the hogback south of the Rifle Falls quadrangle. A part of the Grand Hogback monocline is shown in the southern side of cross section A-A', but the blind thrust probably is present below the level of the cross section.

Attitudes of strata between the Grand Hogback, which dips as much as 70° toward the southwest, and the nearly flat-lying strata on the White River uplift in the northern part of the map area, do not form a smooth concentric fold as would be expected from other Laramide-age structures and other fault-propagation folds. Instead they form a small sub-horizontal bench of gentle folded strata just south of the southernmost of east-west-striking faults and form small, discontinuous, unmapped anticlines and synclines just south of the pod-shaped body of Eagle Valley Evaporite (IPee) (cross section A-A'). Similar structural irregularities found elsewhere along the southwest flank of the White River uplift have been explained by removal of thick evaporite from under the Eagle Valley Formation (Unruh and others, 1993; Kirkham and others, 1995; Scott and others, 1998, Bryant and others, 1998; Scott and others, 1999; Scott and others, in press a). Evaporite, which has clearly been extruding and dissolving from a diapiric pod-shaped intrusive body in the map area, can also explain the structural irregularities in the Rifle Falls quadrangle. Restoration of the Neogene(?) Rifle Falls normal fault and an unnamed normal fault on the west side of the map and calculation of the departure of the present fold shape from an assumed smooth concentric fold allows an estimate of 12 km^3 of evaporite removed by dissolution. We conclude that both the normal faults and the structural irregularities are logically related to flow and (or) dissolution of evaporite from under the folded flank of the uplift.

Two enigmatic structures exist in the map area. Where East Rifle Creek exits the flat-lying strata of the uplift near Rifle Falls, a blister-like structure deforms the upthrown side of the Rifle Falls normal fault. Strata of the Chaffee Group dip as much as 49° to the north along a strike distance of about 1 km and a dip distance of about 0.2 km. The blister is centered just north of the diapiric body of evaporite; therefore, we conclude that the evaporite intruded across the Rifle Falls fault, as originally postulated by W.J. Perry, Jr. (U.S. Geological Survey, oral commun., 1999), probably intruding between the Proterozoic rocks and overlying Paleozoic strata as shown in cross section A-A' (Scott and others, 1999). `

The second enigmatic structure is not so readily explained. East-west across the southern fifth of the map area, is a complex of sharp folds and spatially related faults, the Elk Park fold and fault complex. An east-west-striking, down-to-the-south fault dips northward where its trace forms a “V” pointing northward in the canyon cut by East Rifle Creek; clearly this is the geometry of a steep thrust. At this locality, the upthrown side places Morrison Formation over Dakota Sandstone on a fault plane that dips about 40^{o} to the north. A small high-angle reverse fault within the Morrison Formation also dips northward west of the creek. But about 1.5 km to the east of the creek along the apparent trace of the fault, a 63^{o} southward fault dip was measured where the northern footwall of the Morrison Formation underlies the hanging wall of the lower member of the Mancos Shale; clearly local normal fault relationships exist here. The large, open, east-west-trending synclinal axis outlined by the Dakota Sandstone (Kd) and the complex of discontinuous, smaller and tighter folds in the Niobrara Member (Kmn) and lower member (Kml) of the Mancos Shale over a distance of three kilometers east of East Rifle Creek (cross section B-B’) appear to be characteristic of contractional structures. The folds are offset and cut by small north-striking tear faults. Because numerous and widespread structures appear to have a contractional origin, we conclude that this complex of faults and folds are contractional and that the one normal fault is anomalous. Furthermore, we conclude that the chaotic and discontinuous structures are not part of an organized through-going structure like the Grand Hogback, and therefore they are unlikely to be Laramide structures. Instead these structures are interpreted as large gravity-driven slide blocks (cross sections A-A’, B-B’, and C-C’) that follow the bedding planes of the clay-rich lower part of the Morrison Formation. At the toe of these gravity-driven slide blocks, various styles of contractional structures are displayed in an area called the Elk Park fold and fault complex. The eastern side of the Elk Park fold and fault complex (cross section B-B’) is interpreted to display a blind-thrust-like base of the slide block. On the west side of East Rifle Creek, complex contractional structures appear to be involved with probable middle Pleistocene mass movement deposits (Qcm) that repeat parts of the bedrock sequence and are shown in cross sections A-A’ and C-C’.

We suspect that the Rifle Falls normal fault is a Tertiary normal fault related to Neogene extension recognized by Tweto (1975) where it cuts strata older than the Pennsylvanian strata. However, the normal fault cutting the Maroon Formation on the west side of the map area between the Rifle Falls fault and the Elk Park fold and fault complex may be the result of collapse during evaporite withdrawal because the fault is associated with small discontinuous folds and a structural bench similar to those found in areas of salt withdrawal elsewhere (Bryant and others, 1998). In the northern part of the map area, the Eagle Valley Formation (IPev) has significant departures from horizontal, unlike the nearly horizontal underlying Belden Formation (IPb) and Leadville Limestone (Ml). Also in the northern and northeastern part of the map area, sinkholes in the Eagle Valley Formation are observed. In these northern areas, we conclude that much of the Eagle Valley Evaporite (IPee) that originally was probably below and partly interbedded with the Eagle Valley Formation (IPev) (De Voto and others, 1986) has already flowed out or dissolved out from the clastic formation. In the north-central part of the map area, a zone of steep dips is present in the Leadville Limestone (Ml). This narrow zone of folded strata can be explained as a small Laramide blind thrust, which is shown near the northern end of cross section A-A’.

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 or surficial material downslope under the influence of gravity, such as landsliding, debris flow, or 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 prone 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 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 distinctive 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 no longer 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- or mudstone-rich units, particularly from the upper member of the Mancos Shale

Table 3. Geologic hazards and related map units in the Rifle Falls quadrangle.

EROSION					VOLUME CHANGE		DEBRIS-FLOW DEPOSITION		FLOODING	
Mass wasting			Gullying	Piping	Hydro-compaction	Expansive materials				
Qls	Qc	Qd	Qac	Qac	Qlo	Kmu	Qfy	Qd	Qfp	Qfy
Qcm			Qlo	Qlo		Qfy	Qac	Qls	Qac	Qp
Kicc	Kmu					Qac	Qp	Qcm		
Kml	Kd	Jm				Qls	Qc			
IPev	IPb					Qc				
						Qd				

(Kmu), Eagle Valley Formation (IPev), Belden Formation (IPb), and the stratigraphic sequence consisting of the lower member of the Mancos Shale (Kml), 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. In unusually good exposures west of East Rifle Creek and north of the Elk Park fold-and-fault complex, the geometry of mass movement deposits (Qcm) suggests that an imbricate pattern of listric shear planes emplaced multiple low ridges of Dakota Sandstone that dip northward rather than southward in the same direction as the dip slope of the underlying bedrock (cross section C-C'). Landslide deposits that involve the above stratigraphic interval on low-angle dip slopes were recognized in the adjacent Horse Mountain (Perry and others, in press b) and New Castle (Scott and Shroba, 1997) 7.5' quadrangles, the 7.5' Colorado National Monument quadrangle about 100 km to the southwest (Scott and others, 2001), the 7.5' Grand Junction quadrangle (Scott and others, in press b) and the Wolcott quadrangle about 80 km to the east (Lidke, 1998). Commonly at the toes of the landslides (here represented by the Elk Park fold and fault complex), landslide deposits ramp up onto bedrock at the base of the slides, causing folding associated with minor thrust-like faults that form the base of the landslides. These features are similar to those of landslide deposits along the eastern edge of the Front Range (Braddock and Eicher, 1962; Braddock, 1978). This Mancos-Dakota-Morrison stratigraphic sequence is less commonly involved in landslides where the dip slope is steeper than about 20^{o} (Scott and Shroba, 1997), perhaps because meteoric water falling on gentler dip slopes can more readily infiltrate and wet the expansive smectites in the Morrison Formation, thereby reducing the shear strength of the expansive smectites. 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 lower member of the Maroon Formation (PIPml) near East Rifle Creek and derived from the Cozzette Sandstone and Corcoran Sandstone Members of the Iles Formation, undivided (Kicc), below exposures on the north-facing flank of the Grand Hogback in the adjacent Silt quadrangle (Shroba and Scott, 2000). Commonly both debris-flow and landslide deposits are mapped as colluvium (Qc) where these deposits lack distinct surface morphology.

The upper member of the Mancos Shale (Kmu) 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 smectite 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) and flood-plain deposits (Qfp), but also occurs on higher units such as young alluvial-fan and debris-flow deposits (Qfy). Because of the potential of flooding, construction of permanent structures on undivided alluvium and colluvium (Qac) along East Rifle Creek and West Elk Creek should be avoided.

GEOLOGIC RESOURCES

Although the mines in the map area are abandoned, the area contained one of the largest vanadium-uranium deposits in Colorado (Chenoweth, 1980). Fisher (1960) has studied the East Rifle Creek deposits. The Rifle Mine is on the east side of East Rifle Creek, the Garfield Mine on the west. Ores principally were recovered in the Glen Canyon

Sandstone and secondarily in the underlying Chinle Formation and overlying Entrada Sandstone. Only small deposits were found in the Morrison Formation. The vanadium ore minerals are the vanadium mica roscoelite, a mixed-layer smectite, a chlorite, and minor montroseite. Uranium ore minerals include tyuyamunite and carnotite. The vanadium-uranium ratio is about 20:1. Although a wide range of concentrations of vanadium, uranium, selenium, lead, and chromium are present throughout the three mineralized layers, a general pattern exists. The thickest (average 3 m) is the vanadium-uranium-rich ore layer. Adjacent to the vanadium-uranium layer is a thin (3 mm) layer that contains the highest concentrations of a solid solution of galena and clausthalite (PbS-PbSe). Adjacent to the lead-selenium layer is the more poorly defined, chromium-rich layer that is less than 1 m thick and contains greenish micas that may be similar to mariposite. The asymmetric pattern of mineralization and the chemistry suggests an oxidation-reduction "uranium-roll" origin. Although about 750 x 10^6 kg of vanadium-uranium ore have been removed from the mines, further economic exploitation is unlikely in today's market.

Except for a minor amount of sand and gravel in stream-channels in the valley of East Rifle Creek, there are few other geologic resources in the map area. The overhanging cliffs of the Leadville Limestone north of the Rifle Falls fault attracts rock climbers who have defined over 40 climbing routes, and the Rifle Falls campground is a popular tourist site.

ENVIRONMENTAL ISSUES

High concentrations of heavy metals such as Pb, Se, V, U, and Cr may create environmental problems in ground waters near the mines mentioned above. Large piles of fine sand and silt mine tailings are subject to erosion and transport into East Rifle Creek. Minor As- and Zn-bearing sulfides are also present in the mineralized areas in the map area. Careful analysis of trace elements in well water would be advisable.

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