U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

REVISED PRELIMINARY GEOLOGIC MAP OF THE RIFLE QUADRANGLE, GARFIELD COUNTY, COLORADO

by

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DESCRIPTION OF MAP UNITS

[Surficial deposits shown on the map are estimated to be at least 1 m thick. Fractional map symbols (for example, Qlo/Qty) are used where loess mantles older surficial deposits and the underlying deposits have been identified. Thin, discontinuous colluvial deposits, residual material on bedrock, small artificial fills, and small talus deposits were not mapped. Areas underlain by the Wasatch Formation (Tw) and the Williams Fork Formation (Kwf) commonly have small unmapped colluvial deposits especially in areas of forest vegetation or dense oak brush. Divisions of Pleistocene time correspond to those of Richmond and Fullerton (1986). Age assignments for surficial deposits are based chiefly on the degree of modification of original surface morphology, height above stream level, and degree of soil development. Age assignments for units Qtt and Qdo are based chiefly on the basis of 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 (ka, thousand year old) Lava Creek B volcanic ash: (1) about 90 m along the Colorado River near the east end of Glenwood Canyon (Izett and Wilcox, 1982), (2) about 88 m along the Roaring Fork River near Carbondale, Colorado (Piety, 1981), and (3) about 80-85 m along the White River near Meeker, Colorado (J.W. Whitney, oral commun., 1992; Whitney and others, 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 (Ma, million year old) basalt on Grand Mesa (Marvin and others, 1966) near Palisade, Colorado, about 60 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 65 km east-northeast of the map area. Tentative correlations of map units Qfp, Qty, Qto, and Qtt with other alluvial units is based chiefly on the height of the alluvial unit above stream level and the geomorphic relations of the alluvial unit to moraines of known or inferred age. 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 IV 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 commonly range from light brownish gray (2.5Y 6/2) to light brown (7.5YR 6/4). 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 streamflow 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. A previous Open-File Report of this map was published recently (Shroba and others, 1995); however, incorrect location of bedrock stratigraphic contacts, incomplete subdivision of mappable units in bedrock, incorrect location and identification of folds in bedrock, and lack of drill hole information on 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)]

Table 1. Conversion 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
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

ERA	Period	Epoch	Age (years)
CENOZOIC	*Quaternary*	*Holocene*	*0 to 10 thousand*
		Pleistocene	*10 thousand to 1.65 million*[*]
	Tertiary	*Pliocene*	*1.65 to 5 million*
		Miocene	*5 to 24 million*
		Oligocene	*24 to 38 million*
		Eocene	*38 to 55 million*
		Paleocene	*55 to 66 million*
MESOZOIC	*Cretaceous*		*66 to 138 million*

After Hansen (1991); [*]exception: 1.65 million from Richmond and Fullerton (1986).

ARTIFICIAL-FILL DEPOSITS—Compacted and uncompacted material composed mostly of silt, sand, and rock fragments placed above the Rifle Colorado Uranium Mill Tailings Repository, at mill tailings sites, and beneath highways and railroad beds

af **Artificial fill (latest Holocene)**—Compacted and uncompacted fill material composed mostly of silt, sand, and rock fragments. The unit is mapped above the Rifle Colorado Uranium Mill Tailings Repository west of Estes Gulch in the north part of the map area, at uranium and vanadium mill tailings piles that have been removed from two localities along the Colorado River (NE_ sec. 16 and SE_ sec. 18, T. 6 S., R. 93 W), beneath segments of Interstate 70 and Colorado highway 13, and beneath the nearby tracks of the Denver and Rio Grande Western Railroad. Although the uranium and vanadium tailings and some of the underlying sediment have been removed from the two sites near the Colorado River, potentially hazardous gamma radiation and radon gas (Duval, 1991) may still be present from residual decay products of uranium. The underlying flood-plain and stream-channel deposits (Qfp) and ground water in these deposits below the uranium mill tailings sites may have been contaminated. The mill tailings were susceptible to wind erosion and have contaminated the ground surface within several hundred meters of the now-removed tailings piles (Stover, 1993). These mill tailings are now buried above the Shire Member of the Wasatch Formation west of Estes Gulch at the Rifle Colorado Uranium Mill Tailings Repository. The distribution of the fill at the repository was mapped with the aid of a Global Positioning Systems (GPS) instrument to a precision better than +/- 2 m. The unit locally may include small areas of flood plain and stream-channel deposits (Qfp) and young alluvial-fan and debris-flow deposits (Qfy). Thickness generally less than 10 m, but possibly as much as 20 m in the repository. Thicknesses of fill are estimated because the base of the fill is not exposed

ALLUVIAL DEPOSITS-Silt, sand, and gravel in flood plains, stream channels, fans, and beneath terraces along the Colorado River, Rifle Creek, Government Creek, and the unnamed stream in Hubbard Gulch

Qfp **Flood-plain and stream-channel deposits (Holocene and late Pleistocene?)**—Along the Colorado River, the upper 1-5 m of the unit is commonly slightly silty to silty, very fine to medium sand that locally contains minor amount of pebbles and cobbles and thin lenses of silt and clayey silt. The lower 1.2-7 m of the unit is chiefly clast-supported, cobbly, pebble gravel in a sand matrix. Deposits along Rifle Creek and the lower part of Government Creek commonly contain more sand and silt than those deposits along the Colorado River. The unit is poorly to well bedded. Clasts are poorly to moderately well sorted, and are commonly subangular to rounded; their lithologies reflect those of the bedrock exposed upstream. Clasts along the Colorado River are an assortment of sedimentary, igneous, and metamorphic rocks; whereas those along Rifle Creek and the lower part of Government Creek are mostly sandstone. Low-lying areas of the map unit are prone to periodic flooding. The unit locally includes small alluvial-fan and debris-flow deposits (Qfy), low terrace deposits that are commonly less than 5 m above modern stream level, and sheetwash deposits (Qsw) that are too small to map separately. The upper part of the unit may be a complex of alluvial cut-and-fill deposits of Holocene and late Pleistocene(?) age. The lower part of the unit is probably equivalent, at least in part, to the younger terrace alluvium (Qty), which is of late Pleistocene age. The map unit is tentatively correlated with deposits of terrace T8 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo. Sand and gravel have been mined in unit Qfp along the Colorado River. Thickness is about 3-10 m along the Colorado River and about 5-7 m along Rifle Creek (Colorado Highway Department, unpublished data). Maximum thickness is probably about 12 m along the Colorado River and possibly 10 m along Rifle Creek and the lower part of Government Creek

Qty **Younger terrace alluvium (late Pleistocene)**—Stream alluvium that underlies terrace remnants that are about 10-15 m above the unnamed stream in Hubbard Gulch and about 18 m above Rifle Creek and Government Creek. The unit consists mostly of poorly sorted, clast-supported, locally slightly bouldery, cobbly pebble gravel with a sand matrix, and moderately well sorted, clast-supported, cobbly pebble gravel with a slightly silty sand matrix. The clasts are mostly subangular to subrounded sandstone. The unit is well exposed in roadcuts in Hubbard Gulch and along Rifle Creek. The larger deposits are overlain by one loess sheet (Qlo) about 1-1.5 m thick. Widespread younger fan deposits (Qfy) along the Colorado River probably overlie deposits of younger terrace alluvium. Unit Qty is probably equivalent in part to outwash of the Pinedale glaciation, which is about 12-35 ka (Richmond, 1986, chart 1A). Unit Qty is tentatively correlated with deposits of terraces T7 and T6 of Piety (1981) along the Roaring Fork River farther upstream between Glenwood Springs and Carbondale, Colo. (Piety, 1981), and with deposits of terraces A and B farther upstream between Woody Creek and Aspen, Colo. (Bryant, 1979). Exposed thickness is 2-4 m along the stream in Hubbard Gulch, 1-3 m along Rifle Creek, and 2.7 m along Government Creek. Maximum thickness along these drainages is probably about 7.5 m

Qto **Older terrace alluvium (late middle Pleistocene)**—Stream alluvium that underlies terrace remnants about 35-50 m above the Colorado River, Rifle Creek, and Government Creek. Along the Colorado River, the upper part of the unit was deposited by tributary streams and the lower part of the unit was deposited by the Colorado River. The upper 7.5-15 m of the unit commonly consists of slightly silty to silty sand that is locally slightly pebbly and locally contains thin, discontinuous beds and lenses of poorly to moderately well sorted, clast-supported, non-bouldery to bouldery, cobbly pebble gravel and pebble gravel with a sand matrix. The lower 3-12 m of the unit is mostly poorly to moderately well sorted, clast-supported, cobbly pebble gravel with a sand matrix. Thin beds and lenses of non-silty, medium to very coarse sand and non-silty to silty, fine to very fine sand are locally present. Some of the beds have climbing ripples and involute bedding. The base of the unit is locally cemented by fine-grained calcium carbonate. The clasts in the upper part of the unit are mostly subangular to subrounded sandstone. The clasts in the lower part of the unit are chiefly subrounded to well rounded sandstone, granite, granodiorite(?), gneiss, limestone, quartzite, and minor to trace amounts of basalt, dolomite, chert, siltstone, vein quartz, and schist. Along Rifle Creek and Government Creek, the unit commonly consists of poorly sorted to moderately well sorted, clast-supported, non-bouldery to bouldery, cobbly pebble gravel with a sand matrix, and locally thin beds and lenses of pebble gravel, pebbly sand, silty sand, and silt. The clasts in these deposits are mostly subangular to subrounded sandstone. The unit is mantled by about 1.5-6 m of loess (Qlo) that commonly consists of two sheets, and is locally mantled by intermediate debris-flow deposits (Qdi) near the mouth of Beaver Creek (SW _ sec. 23, T. 6 S., R. 94, W.) and by sheetwash deposits (Qsw). The loess-mantled deposit of older terrace alluvium on Graham Mesa northeast of Rifle marks a former course, or former courses, of Rifle Creek. The morphology of the well developed soil that is locally observed in the top unit (Scott and Shroba, 1997; Shroba and others, 1994) and the presence of the two overlying loess sheets suggest that the unit Qto is of Bull Lake age (Hall and Shroba, 1993; Pierce and others, 1982) and may be about 140-150 ka (Pierce and others, 1976; Pierce, 1979) or about 130-300 ka (late middle Pleistocene; Richmond, 1986, chart 1A). The unit is tentatively correlated with deposits of terraces T5 and T4 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits of terrace C of Bryant (1979) farther upstream between Woody Creek and Aspen. Sand and gravel has been mined in unit Qto along the Colorado River. Exposed thickness along the Colorado River is 14-20 m, 3-6 m along Rifle Creek, and 9-12 m along Government Creek. Maximum thickness along the Colorado River probably is about 25 m and possibly 15 m along Rifle Creek and Government Creek

Qtt **Oldest terrace alluvium (middle Pleistocene)**—Stream alluvium that underlies small terrace remnants that are about 75, 90, and 180 m above the Colorado River; about 75, 90, and 110 m above Rifle Creek; and about 55, 75, and 110 m above Government Creek. Terrace alluvium about 180 m above the Colorado River is exposed at the north end of Grass Mesa in the southeastern part of the map area, but it is not shown on the map because it is buried by older debris-flow deposits (Qdo). Along the Colorado River, the unit is mostly a poorly to moderately well sorted, clast-supported, cobbly pebble gravel with a sand matrix. The unit locally consists of thin lenses and beds of pebble gravel, pebbly sand and silty sand. Clasts are mostly rounded to well rounded and consist of sandstone, granodiorite(?), quartzite, gneiss, limestone and minor to trace amounts of basalt, granite, metasiltstone(?), chert, conglomerate, siltstone, and dolomite that were deposited by the Colorado River. Biotite-bearing granitic clasts near the top of the unit are extensively weathered and are easily disintegrated. Locally on the north side of the Colorado River, the clasts in the upper part of the unit are mostly subangular to subrounded sandstone that were deposited by south-flowing tributary streams. Deposits along Rifle Creek and Government Creek are mostly poorly sorted, clast-supported, slightly bouldery to bouldery, cobble pebble gravel with a non-silty to silty sand matrix and thin beds and lenses of pebbly gravel, pebbly sand and sand. The clasts in the deposits along Rifle Creek are mostly subangular to subrounded sandstone along with a minor amount of limestone and a trace amount of quartzite. The clasts in the deposits along Government Creek are mostly subangular to subrounded sandstone, siltstone, and marlstone. A stage III K soil horizon, 30-75 cm thick, is locally present in the top of the unit. The base of the unit is locally cemented by a fine-grained calcium carbonate. The unit is locally mantled by 1-5 m of loess (Qlo) that commonly consists of two or more sheets. Small deposits of oldest terrace alluvium near the eastern boundary of the map area, north of the Colorado River, mark former courses of Rifle Creek. The 90-m-high terrace alluvium of unit Qtt may be correlative with other terrace deposits within about 55 km of the map area that contain or are overlain by the 620-ka Lava Creek B volcanic ash. The unit is tentatively correlated with deposits of terraces T3 and T2 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits of terrace D of Bryant (1979) farther upstream between Woody Creek and Aspen. Exposed thicknesses are commonly 1.5-6.5 m along the Colorado River, 1-9.5 m along Rifle Creek, and 2.5-14 m along Government Creek. Maximum thicknesses are possibly 18 m along the Colorado River and possibly 15 m along Rifle Creek and Government Creek

ALLUVIAL AND COLLUVIAL DEPOSITS—Clay, silt, sand, and gravel in flood plains and in fans on flood plains and terraces; on gently sloping pediment surfaces cut on bedrock; and in sheets of pebbly, silty sand and sandy silt that locally mantle valley bottoms and adjacent valley sides and hill slopes

Qfy **Younger fan-alluvium and debris-flow deposits (Holocene and latest Pleistocene)**—Mostly poorly sorted, poorly stratified, clast- and matrix-supported, slightly bouldery, cobbly pebble gravel with a silty sand matrix, and locally silty sand that contains thin discontinuous beds and lenses of cobbly pebble gravel, pebble gravel, and sand. The unit locally contains boulders as long as 1 m; some of the larger boulders were probably deposited by debris flows. Clasts are commonly angular to subangular sandstone north of the Colorado River and angular to subrounded sandstone and basalt south of the Colorado River. Thick beds of silty sand are prone to piping and gullying primarily along desiccation fractures. The unit is undissected to slightly dissected and was deposited chiefly by small intermittent streams graded to the flood plains of modern streams (Qfp) and locally to the tops of terraces that are underlain by younger terrace alluvium (Qty). The unit locally includes small unmapped deposits of intermittent steams and colluvium (Qac), sheetwash deposits (Qsw), and colluvium (Qc). The unit probably contains hyperconcentrated-flow deposits. Surface is locally subjected to flooding and debris-flow deposition. Exposed thickness is 3-12 m; maximum thickness is probably about 25 m

Qac **Undivided alluvium and colluvium (Holocene and late Pleistocene)**—Chiefly undifferentiated flood plain and stream-channel deposits (Qfp), young fan-alluvium and debris-flow deposits (Qfy), debris-flow deposits (Qd), sheetwash (Qsw), and probably hyperconcentrated-flow deposits. Some of these deposits probably grade laterally and vertically into each other. The alluvium commonly consists of interstratified silty sand, sandy clayey silt, and thin beds and lenses of cobbly pebble gravel, pebble gravel, and pebbly sand. Sheetwash deposits are typically pebbly, silty sand, and sandy silt. Low-lying areas of the map unit are prone to periodic flooding and debris-flow deposition. Some of the alluvial deposits are prone to extensive gullying and piping. Alluvial deposits form flood plains, low terraces, and small fans along small intermittent streams and the upper part of Government Creek. Sheetwash deposits locally mantle the valley bottoms and the adjacent valley sides and hill slopes. Exposed thickness of the alluvium is 1-6.5 m; maximum thickness is possibly 15 m. Exposed thickness of the colluvium is 1-1.5 m; maximum thickness is possibly 6 m

Qfo **Older fan-alluvium and debris-flow deposits (middle Pleistocene)**—One deposit near the northeastern corner of the map area that was deposited by an intermittent stream that was graded to a surface about 50-55 m above Rifle Creek. Mostly poorly sorted, poorly stratified, clast-supported, slightly bouldery, cobbly pebble gravel with a silty sand matrix, and discontinuous beds and lenses of pebble gravel and pebbly, silty sand. Clasts are chiefly angular to subrounded sandstone. The unit probably contains minor, unmapped hyperconcentrated-flow deposits. The unit is deeply dissected and is mantled by loess (Qlo). Exposed thickness is 5 m; maximum thickness is possibly 30 m

Qp **Pediment deposits (middle Pleistocene)**—Gravelly alluvium and debris-flow deposits at four or more levels that commonly overlie gently sloping surfaces cut on the Shire Member of the Wasatch Formation (Tws). Locally there is as much as 6 m of relief on the underlying bedrock where it is incised by stream channels (Shroba, 1996). Mostly poorly sorted, clast-supported, non-bouldery to bouldery, cobbly pebble gravel with a non-silty to silty sand matrix, and thin beds and lenses of poorly sorted clast- and matrix-supported pebble gravel to pebbly, silty sand. Clasts are chiefly angular to subrounded sandstone and locally minor amounts of siltstone, limestone, and marlstone. The unit probably locally includes minor, unmapped sheetwash deposits (Qsw), colluvium (Qc), and hyperconcentrated-flow deposits. Bouldery, debris-flow deposits are locally common in the upper part of the unit. Some of the sandstone boulders in the upper part of the unit are as long as 1.5 m. A stage III K soil horizon is locally present in the upper 50-75 cm of the unit, and some of the sandstone cobbles in the upper 2 m have weathered and disintegrated to sand-size particles. The unit is locally mantled by about 2-3 m of loess (Qlo), which locally consists of two or more sheets. The lower limits of the unit are about 50, 60, and 120 m above the Colorado River, about 60 and 85 m above Rifle Creek, and about 55 and 90 m above Government Creek. The lowest pediment deposits along the Colorado River appear to be graded to terrace remnants underlain by older terrace alluvium (Qto) that are about 35-50 m above the Colorado River. Exposed thickness is commonly 1.5-11.5 m; maximum observed thickness is 14.5 m; maximum thickness is possibly 20 m

COLLUVIAL DEPOSITS—Silt, sand, and gravel on valley sides and hill slopes that were mobilized, transported, and deposited by mass wasting processes and sheet erosion

Qc **Colluvium, undivided (Holocene and late Pleistocene)**—Mostly clast-supported, pebbly, cobbly, and bouldery gravel with a silty sand matrix, and matrix-supported, gravelly silty sand, sandy silt, and clayey silt. The unit is 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. The unit locally includes sheetwash (Qsw), creep, younger debris-flow (Qdy), probably hyperconcentrated-flow deposits, landslide deposits (Qls), deposits of alluvium and colluvium (Qac) in and along minor drainageways, and possibly talus (Qta) 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. Thin loess (Qlo) mantles may be locally present on older gently sloping colluvial deposits. Exposed thickness is 1-15 m; maximum thickness is possibly 30 m

Qdy **Younger debris-flow deposits (Holocene to late Pleistocene)**—Small lobate and fan-shaped masses of debris and bouldery levees with well preserved surface morphology that were deposited by sediment-charged flows in Yellow Slide Gulch and near the mouth of Beaver Creek in the southwestern part of the map area. Much of the unit is poorly exposed, but it appears to consist mostly of very poorly sorted and very poorly stratified boulders to granules supported in a matrix of silty sand and locally includes poorly sorted, clast-supported, bouldery, cobbly pebble gravel with a silty sand matrix in levees and lenticular beds. The clasts in the deposit in Yellow Slide Gulch are mostly subangular to subrounded sandstone, siltstone, and marlstone, and those in the deposit near the mouth of Beaver Creek are mostly subangular to subrounded basalt and minor amounts of sandstone, siltstone, and marlstone. Some clasts are as long as 1.2 m. The top of the unit is less than 15 m above stream level, irregular, and locally mantled by loess (Qlo). The unit probably locally includes minor stream-flow and hyperconcentrated-flow deposits. Low-lying areas along the channel in the upper reach of Yellow Slide Creek and the upper reaches of some of the other intermittent streams with steep gradients near the northern, southern, and western boundaries of the map area are prone to debris-flow deposition. Exposed thickness is about 0.5-3 m; maximum thickness is possibly 15 m

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Mostly pebbly, silty sand and sandy silt that are derived chiefly from weathered bedrock and loess (Qlo) by sheet erosion. Common on gentle to moderate slopes in areas underlain mostly by the Shire Member of the Wasatch Formation (Tws) and loess. Low-lying areas of the map unit are prone to periodic sheet flooding. The unit locally includes small deposits of loess (Qlo) and undivided alluvium and colluvium (Qac) in and along minor drainageways and exposures of Wasatch that are too small to map separately; may locally include minor creep-derived colluvium (Qc) deposits. Exposed thickness is 2-5 m; maximum thickness is probably about 10 m

Qls **Landslide deposits (Holocene to middle(?) Pleistocene)**—Deposits of unsorted and unstratified debris that are commonly characterized by a lobate form and hummocky topography. Many of the landslides and their associated deposits are complex (Varnes, 1978) and commonly form on steep, unstable dip slopes of the Williams Fork Formation (Kwf, Kwfl, Kwfu) on the south side of the Grand Hogback near the northern boundary of the map area; and on steep, unstable slopes of the Wasatch Formation (Twd, Tws, Twm, Twav, Twal) in various parts of the map area. Landslides that involve the Williams Fork Formation are unique in that they all were derived from a source area characterized by sandstone layers of the Williams Fork that are overturned and highly fractured (Scott and Egger, 1997); these landslides are late to middle(?) Pleistocene, stand 25-80 m above modern drainage, and armor pediment deposits that overlie the Wasatch Formation. Younger landslide deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. The unit includes debris-slide, rock-slide, debris-slump, rock slump(?), earth slump, slump-earth-flow, earth-flow, and debris-flow deposits as defined by Varnes (1978), and probably hyperconcentrated-flow deposits. The sizes and lithologies of the clasts and the grain-size distributions of the matrices of these deposits reflect those of the displaced bedrock units and surficial deposits that were displaced by sliding, slumping and flowing. The unit locally includes unmapped sheetwash (Qsw) and creep-derived colluvium (Qc) deposits that are too small to be mapped separately. Exposed thickness is 2-35 m; maximum thickness is possibly 120 m

Qta **Talus deposits (Holocene and late Pleistocene)**—Mostly crudely sorted and stratified, angular, bouldery to pebbly rubble on steep slopes produced chiefly by rock fall from exposures of Williams Fork Formation sandstone units (Kwf, Kwfl, Kwfu) at Rifle Gap near the northeastern corner of the map area. The matrix is mostly sand and silt; some of the matrix may be of eolian origin. The upper part of the unit locally lacks matrix. Maximum thickness is possibly 30 m

Qdi **Intermediate debris-flow deposits (middle Pleistocene)**—Mostly debris-flow deposits and a minor amount of stream alluvium and probably hyperconcentrated-flow deposits that underlie three gently sloping, fan-shaped, geomorphic surfaces near the southwestern corner of the map area. The lower limits of these surfaces are about 55, 100, and 120 m above the Colorado River. The debris-flow deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of slightly clayey, silty sand to clayey, sandy silt, and locally includes lenticular beds of poorly sorted, clast-supported, bouldery, cobbly pebble gravel with a silty sand matrix. Clasts are commonly randomly oriented and are mostly subangular to subrounded, and include minor amounts of sandstone, siltstone, marlstone, and claystone, and locally trace amounts of rounded to well rounded igneous, sedimentary and metamorphic pebbles and cobbles derived from Colorado River terrace deposits. Basalt clasts are as long as 3 m. Stream alluvium commonly consists of poorly sorted, poorly stratified, clast-supported, slightly bouldery, cobbly pebble gravel with a slightly silty sand matrix, and lenses of cobbly pebble gravel and pebble gravel. Some of these clast-supported deposits could be hyperconcentrated-flow deposits. The soil formed in the top of the unit in the eastern part of Taughenbaugh Mesa consists of a stage III K horizon 110 cm thick that overlies a stage II Bk horizon 15 cm thick and a stage I Bk horizon greater than 20 cm thick. The unit overlies the Wasatch Formation (Twd, Tws), but near its lower limits it overlies unmapped terrace alluvium (units Qto and Qtt) that is about 40, 75, and 90 m above the Colorado River. The unit is mantled by greater than 2 m of loess (Qlo), although large basalt boulders locally protrude through the loess mantle. Broad debris-flow levees locally flank both sides of Beaver Creek. Much of the material in the unit was probably mobilized by mass-wasting processes on the steep northern flank of Battlement Mesa, about 10 km south of the map area, and transported by sediment-charged flows down the valley of Beaver Creek. With time, deposition generally shifted from east to west. Deposits in the eastern part of Taughenbaugh Mesa are higher and older than those in the western part of the mesa, and deposits in the western part of the mesa are higher and older than those near the mouth of Beaver Creek. Debris-flow deposits near the base of the unit on Taughenbaugh Mesa are locally interbedded with the uppermost part of the underlying, unmapped terrace alluvium. Unit Qdi is not prone to future debris-flow deposition. Exposed thicknesses are 5-30 m; maximum thickness is possibly 45 m

Qdo **Older debris-flow deposits (early(?) Pleistocene)**—Mostly debris-flow deposits and a minor amount of stream alluvium and probably hyperconcentrated-flow deposits that underlie Grass Mesa, a gently sloping, fan-shaped, geomorphic surface near the southeastern corner of the map area. The lower limit of the surface is about 245-260 m above the Colorado River. The debris-flow deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of slightly clayey, silty sand to sandy, clayey silt, and locally includes lenticular beds of poorly sorted, clast-supported, bouldery, cobbly pebble gravel with a silty sand matrix. The deposits are commonly about 1-2.5 m thick and are locally overlain by layers of slightly silty sand 5-40 cm thick. Clasts are commonly randomly oriented and are angular to rounded basalt, sandstone, siltstone, and marlstone. Basalt clasts are as long as 1.5 m. Stream alluvium is locally present near the top of the unit and commonly consists of poorly sorted, poorly stratified, clast-supported, slightly bouldery to bouldery, cobbly pebble gravel with a sand matrix, and lenses of cobbly pebble gravel and pebble gravel. Some of these clast-supported deposits could be hyperconcentrated-flow deposits. The alluvium is mostly stream-channel deposits that are about 2-4 m thick. The soil at the top of the unit consists of a stage IV K horizon 90 cm thick that overlies a stage III K horizon 10 cm thick and a stage II Bk horizon 50 cm thick. No buried soils were noted in the unit. The unit overlies the Wasatch Formation, but near its lower limit, it overlies unmapped oldest terrace alluvium (Qtt) that is about 180 m above the Colorado River. Unit Qdo is mantled by greater than 1 m of loess (Qlo) and may be similar in age to the high-level basaltic alluvium (QTba) in the nearby New Castle quadrangle (Scott and Shroba, 1997). Exposed thicknesses are 35-70 m in the map area and about 20 m in the adjacent North Mamm Peak quadrangle about 1.2 km south of the map area. Maximum thickness is possibly 75 m

EOLIAN DEPOSITS—Wind-deposited sand, silt, and clay that mantle 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 % 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 (2-0.05 mm), 43-62% silt (0.05-0.002 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 (0.05-0.02 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, in part due to its low dry density (about 1,440 kg/m^3), grain size, sorting, and weakly developed 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 (Shroba, 1994). Deposition may have continued into Holocene time. Possible sources for the loess include flood-plain deposits of the Colorado River and its major tributaries, sparsely vegetated outcrops of Tertiary siltstone and mudstone in the Piceance Basin west of the map area (Tweto, 1979), and large areas of exposed sandstone in the Canyonlands region in southeastern Utah (Whitney and Andrews, 1983). However, the relatively high content of very fine sand and coarse silt and the relatively high coarse silt/total silt ratios (about 0.7) of the unweathered loess suggest (1) a relatively short distance of eolian transport and (2) 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. The unit commonly mantles level to gently sloping surficial deposits as old as or older than the younger terrace alluvium (Qty). Younger terrace alluvium (Qty) is mantled by one loess sheet. Older terrace alluvium (Qto) is locally mantled by two loess sheets. Pediment deposits (Qp) and the oldest terrace alluvium (Qtt) are locally mantled by two or more loess sheets, and the high-level basaltic alluvium (QTba) in the New Castle quadrangle 11 km to the east (Scott and Shroba, 1997) is mantled by five or more loess sheets. The soil that is formed in the upper loess sheet on the older terrace alluvium commonly consists of the following sequence of horizons: an organic-enriched A horizon about 20 cm thick; a cambic B horizon about 10-20 cm thick; a weak to moderate prismatic, argillic B horizon about 20-40 cm thick; and a stage I Bk horizon greater than 75 cm thick. The buried soil that is formed in the lower loess sheet on the older terrace alluvium contains more clay and calcium carbonate than the soil in the upper loess sheet and commonly consists of the following horizons: a cambic B horizon about 20 cm thick; a moderate to strong prismatic, argillic B horizon about 55-75 cm thick that contains weak stage I-II calcium carbonate; a weak stage III K horizon about 40 cm thick; and a stage I-II Bk horizon from about 30 to greater than 60 cm thick. Where the upper loess sheet is composed of very sandy silt, the soil formed in it has a weakly developed, non-prismatic argillic B horizon that is about 35 cm thick. If the upper and lower loess sheets on the older terrace alluvium correlate with loess units A and B, respectively, that are on and adjacent to the eastern Snake River Plain in eastern Idaho, then (1) the uppermost loess sheet in the map area accumulated between about 10-70 ka and is of late Pleistocene age and (2) the underlying loess sheet accumulated during an interval that ended shortly after 140-150 ka and is partly or entirely of latest middle Pleistocene age (Pierce and others, 1982). Exposed thickness is 0.5-6 m; commonly 1-5 m thick. Maximum thickness is possibly 7.5 m

BEDROCK UNITS

Tga **Green River Formation, Anvil Points Member (Eocene)**—Lacustrine marlstone and calcareous sandstone. The marlstone is light gray to medium light gray, greenish gray, and light olive gray, is micaceous, ranges from massive to moderately fissile, and commonly contains ostracods about 1-2 mm long. The sandstone is grayish orange, grayish orange pink, and yellowish gray and is cemented with abundant calcium carbonate commonly in the form of crystals about 1-cm-diameter that form a matrix to the sand grains. Dark brownish-gray organic material occurs on parting surfaces in some layers. The sandstone is evenly bedded, has beds about 3-10 cm thick, and has oscillation ripple marks. The clasts in the sandstone are very fine to medium grained and consist of about 75 % quartz, 20 % feldspar, 3 % dark mafic minerals, and 2 % muscovite flakes. In the Anvil Points Member, as defined here, there is an absence of fluvial sandstone that contains conglomerate, channel-fill structures, and cross bedding. Stratigraphically below the lowest marlstone and lacustrine sandstones of the Anvil Points Member fluvial sandstone and multicolored mudstone are present; the fluvial intervals of sandstone and intervening mudstone are considered in this report to be the upper part of the Wasatch Formation because they resemble Wasatch lithology. Only the lower 75 m of the Anvil Points Member are exposed at three localities along the western border in the map area

Tw **Wasatch Formation (early Eocene to Paleocene)**—Formation symbol (Tw) shown in cross section only. Formation includes (from youngest to oldest) an informal, newly proposed member, the Doodlebug Gulch member (Twd), and three members, the Shire (Tws), the Molina (Twm), and the Atwell Gulch (Twa) Members. Based on drill hole data and map relations, about 2,275 m of the formation are exposed

Twd **Doodlebug Gulch member**—Nonmarine, predominantly multicolored fine-grained clastic intervals of claystone, mudstone, and siltstone interbedded with abundant intervals of coarse-grained clastic beds of fluvial, calcareous sandstone; about 25 percent of the strata in the Doodlebug Gulch member are sandstone. In contrast, similar fluvial sandstones form less than 3 % of the underlying Shire Member (Tws). This Doodlebug Gulch member is an informal, newly proposed member in this report that is well exposed in and near Doodlebug Gulch near the northwest corner of the map area (S _ sec. 29 and NW _ sec. 31, T. 5 S., R. 94 W.). This member incorporates about 14 fluvial sandstone intervals greater than 1 m thick and 13 intervening mudstone intervals. Sandstone and mudstone intervals in the Doodlebug Gulch member had previously been included in the lower part of the otherwise lacustrine Anvil Point Member of the Green River Formation in the adjacent Anvil Points quadrangle (O'Sullivan, 1986). The top of the Doodlebug Gulch member is defined here at the top of the uppermost fluvial sandstone, which occurs below the lowest marlstone and lacustrine sandstone intervals of the Anvil Points Member of the Green River Formation. The base of the Doodlebug Gulch member is defined here at the base of the lowest prominent, 20-m-thick, fluvial sandstone interval. Sandstone intervals range from 1.5 to 20 m thick, average 6 m thick, have common crossbedding and channel-fill structures, include abundant basal conglomeratic layers, are calcareously cemented, are typically very pale orange to grayish orange pink, and grayish pink, contain flattened mudstone rip-up clasts, and consist of 70 % quartz, 25 % feldspar, 5 % dark altered mafic minerals and minor muscovite flakes. Minor lenses of mudstone and siltstone are included in the sandstone intervals. Claystone, mudstone, and siltstone intervals are poorly exposed, range from 8 to 38 m thick, average 22 m thick, are massive, are typically light gray to grayish orange but include pale red, pale reddish brown, pale purple, pale red purple, light brownish gray, light olive gray, greenish gray, and yellowish gray. Landslides on the member create a geologic hazard. The Doodlebug Gulch member is about 370 m thick

Tws **Shire Member**—Nonmarine, predominantly multicolored fine-grained clastic intervals of thick claystone, mudstone, and siltstone interbedded with sparse intervals of minor coarse-grained clastic beds of thin fluvial sandstone, as defined by Donnell (1969). Colors in the intervals of fine 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, yellowish gray, and moderate yellow. Discontinuous, thin (1-15 cm) beds of siltstone of similar colors form less than 1% of the fine clastic intervals. Colors of the sandstone beds include yellowish gray, grayish yellow, light gray, and light olive gray. In general, sandstone, which forms less than 3% of the member, is commonly crossbedded, locally displays channels 0.3-4 m deep and 5-15 m wide, and contains coarse sand and lenses of pebble conglomerate at the base of many channels. The clasts are generally medium grained, are moderately sorted, and consist of about 50% quartz, 30% feldspar, and 20% rock fragments and weathered mafic grains. In sparse localities minor amounts of carbonaceous films are present on sandstone bedding planes, and the sandstone has a weak calcareous cement. Relatively young and some active landslides at several scales are common on the Shire Member and pose a geologic hazard to roads, pipelines, and structures south of the Colorado River below Taughenbaugh and Grass Mesas and elsewhere in the map area. Larger and older slides on the Shire Member are present on the southern slope of Yellow Slide Gulch and on the north and south sides of the ridge south of Goodrich Gulch, both are close to the western boundary of the map area; in both of these areas, roads cross the slide areas increasing the possibility of reactivation of landslide movement. Based on drill hole data and map relations, about 1,550 m of the Shire Member occur in the map area

Twm **Molina Member**—Nonmarine, predominantly multicolored fine-grained clastic intervals consisting of thick claystone, mudstone, and siltstone interbedded with less abundant coarse-grained clastic intervals of thin fluvial sandstone, as defined by Donnell (1969) at the south side of Rifle Gap in the northeast part of the map area. The fine-grained clastic beds are similar to those described above for the Shire Member (Tws). The Molina Member is distinguished from the Shire Member by the presence of about 20 percent sandstone beds that are more resistant than those of the Shire because of a stronger calcareous cement; these sandstone beds form nearly vertical ribs of sandstone in the northeast part of the map area. Sandstone of the Molina is medium-grained, is very pale orange, grayish orange, yellowish gray, and grayish orange, and commonly contains 1-4 cm long claystone rip-up clasts. Clasts are moderately sorted and consist of about 65% quartz, 25% feldspar, and 10% dark rock fragments and mafic minerals; a trace of muscovite flakes is present. Although the sandstone is crossbedded, cut by channels, and slightly conglomeratic at the base of channels, the sandstone beds of the Molina Member are more continuous than those in the Shire Member. The map unit ranges from 105-160 m thick

Twa **Atwell Gulch Member**—Nonmarine unit that includes (1) a volcaniclastic-rich upper part that consists predominantly of multicolored fine-grained clastic intervals that include thick claystone, mudstone and siltstone interbedded with less abundant thinner intervals that include coarse-grained volcaniclastic beds of fluvial sandstone and abundant conglomerate and (2) a lower largely nonvolcanic part that consists predominantly of multicolored fine-grained clastic intervals consisting of thick siltstone, mudstone and claystone interbedded with less abundant intervals consisting of coarse-grained, clastic beds of relatively thin fluvial sandstone and sparse conglomerate. The member was defined by Donnell (1969) at the south side of Rifle Gap in the northeast part of the map area. The upper volcaniclastic-rich part of the member contains fine-grained clastic intervals that are commonly greenish gray, light gray, pale purple, pale pink, moderate red, and pale reddish brown. About 15-30 % of the upper part consists of coarse-grained clastic beds of sandstone and conglomerate that range from 1-15 m thick. The sandstones are predominantly medium- to coarse-grained and sparsely fine-grained and are greenish gray, light-olive gray, dark greenish gray, and light gray. The clasts in the unit range from poorly sorted to well sorted; the clasts are almost exclusively andesitic, range in size from fine sand to cobbles, and contain distinct phenocrysts of augite and plagioclase; clasts of isolated biotite crystals are common. The upper part of the member displays common crossbedding, channels, and conglomerate-rich lower parts of channels; locally, soft-sediment deformation has contorted the bedding of the sandstones. The more conglomeratic parts of the unit are slightly more resistant and are moderately cemented, and the finer sandstone parts containing sparse conglomerate are generally very poorly cemented by calcium carbonate. The largely nonvolcanic lower part of the member consists largely of fine-grain clastic rocks that range from very light gray, light gray, light brownish gray, pale olive, and light olive gray to brownish gray. The coarse-grained clastic intervals form less than 10% of the upper part, range from 1 to 5 m thick, and are brownish gray, pale yellowish brown, grayish green, and very pale orange. In the upper layers of the lower part of the member, a few andesitic clasts are present. In the coarse-grained clastic intervals, clasts are poorly to moderately sorted, weakly cemented by calcium carbonate, and typically consist of about 50% quartz, 30% feldspar, 10% muscovite and biotite flakes, and 10% rock fragments and altered mafic minerals. The abundance of andesitic volcanic clasts in the coarse-grained intervals decreases downward in the lower part, and volcanic clasts are absent near the base; the vast majority of the clasts are chert and quartzite pebbles and cobbles. Only rare rhyolitic pebbles and cobbles are present near the base of the lower part of the member above the Williams Fork Formation. Neither the Paleocene Ohio Creek Formation of Tweto and others (1978) and Gaskill and Goodwin (1963) nor the Ohio Creek Member of the Williams Fork Formation, recognized by dating of palynomorphs by Johnson and May (1980), is present. Also, the distinctive conglomerate that contains clasts similar to the Pando Porphyry of latest Cretaceous age (70 m.y.) of Pando, Colo., found by Izette and others (1985) in the Paleocene Fort Union Formation near Meeker, Colo., is absent in both the upper and lower parts of the Atwell Gulch Member. Member ranges from about 170 and 270 m thick

Kmv **Mesaverde Group rocks undivided (Upper Cretaceous)**—Group symbol (Kmv) shown in cross section only. Group includes the Williams Fork Formation (Kwf) and the underlying Rollins Sandstone Member (Kir) of the Iles Formation (Ki) described below. About 1,400 m of the group are exposed in the northeast part of the map area and in the adjoining Rifle Falls quadrangle (unpublished mapping by R.B. Scott and A.E. Egger) and are reported by drill-hole data in the southwestern part of the map area

Kwf **Williams Fork Formation**—Mudstone and siltstone predominate over intervals of sandstone, shale, thin coal, and burnt coal (clinker). Unit is largely nonmarine. Mudstone and siltstone are light olive gray, greenish gray, light brownish gray, and light gray and are poorly exposed between sandstone layers. Sandstone intervals form about 30% of the formation and are 1-50 m thick and massive but contain channels and crossbeds; conglomeratic sandstones are sparse. The sandstone ranges from yellowish gray and light brownish gray to very light gray, is cemented with calcium carbonate and silica, and is moderately sorted. Clasts in the sandstone consist of about 50% quartz, 35% feldspar, 15% rock fragments and dark mafic minerals; a trace of biotite and muscovite is generally present. Toward the base of the unit the sandstone intervals become more continuous and one has been mapped separately as an unnammed sandstone unit (Kwfu), described below. The base of the formation is defined as the shale unit that overlies the Rollins Sandstone Member of the Iles Formation (Kir). Exposures of the Williams Fork Formation are about 1,100 m thick

Kwfu **Unnamed sandstone unit**—Yellowish-gray, medium-grained, well sorted sandstone interval commonly containing thin, laminated bedding, parallel-bedding, and some crossbedding. Map unit ranges from about 15-20 m thick

Ki **Iles Formation**—Shown in cross section only. Marine shale and nonmarine sandstone and siltstone. The Iles Formation is about 300 m thick in exposures in the northeast part of the map area and the adjoining Rifle Falls quadrangle (unpublished map, R.B. Scott and A.E. Egger); only the Rollins Sandstone Member of the Iles Formation (Kir) is exposed in the map area, but the Cozzette Sandstone (Kiz) and Corcoran Sandstone (Kic) Members and intervening shale intervals are shown in cross section

Kir **Rollins Sandstone Member**—Yellowish-gray to very pale-orange, fine-grained, well sorted sandstone. Beds are commonly massive to thinly bedded containing partings of siltstone and mudstone. Clasts in map unit consist of 70% quartz, 20% feldspar, <10% rock fragments and dark mafic minerals, and a trace of muscovite. Rollins Sandstone Member is in part equivalent to the Trout Creek Sandstone Member of Madden (1989), but because Madden miscorrelated the Trout Creek at Harvey Gap, 7 km to the east-southeast in the adjacent Silt quadrangle, the Rollins Sandstone nomenclature is retained. The Rollins Sandstone Member is about 20-40 m thick

Kiz **Cozzette Sandstone Member**—Shown in cross section only. Member is about 15 m thick in the New Castle quadrangle, about 11 km to the east of the map area (Scott and Shroba, 1997)

Kic **Corcoran Sandstone Member**—Shown in cross section only. Member is about 30 m thick in the New Castle quadrangle, about 11 km to the east of the map area (Scott and Shroba, 1997)

Km **Mancos Shale (Upper Cretaceous)**—Shown in cross section only

STRATIGRAPHY

Members of the Wasatch Formation were mapped following the stratigraphic framework provided by Donnell (1969) in which he described the Shire, Molina, and Atwell Gulch Members of the Wasatch Formation at their type sections and recognized equivalents of these members at exposures south of Rifle Gap in the northeast part of the map area along the Grand Hogback. Units mapped during unpublished mapping (R. B. Scott) in the Silt quadrangle east of the Rifle quadrangle and mapping in the New Castle quadrangle 12 km to the southeast (Scott and Shroba, 1997) are physically correlated to these exposures in the Rifle Gap area. Both the Molina and the Atwell Gulch Members thicken significantly toward the southeast from Rifle Gap where Donnell (1969) measured them as 105 m and 170 m thick, respectively. However, along section A-A', the thicknesses of the Molina and Atwell Gulch Members are about 160 and

270 m thick, respectively. In the New Castle quadrangle, 11 km to the east of the map area, the Molina is 210-280 m and the Atwell Gulch is 240-400 m thick.

A new member is informally proposed at the top of the Wasatch Formation, the Doodlebug Gulch member. The Doodlebug Gulch member is defined here as nonmarine, predominantly multicolored fine-grained clastic intervals of claystone, mudstone, and siltstone interbedded with abundant intervals of coarse-grained clastic beds of fluvial, calcareous sandstone. This new upper member of the Wasatch Formation is proposed because fluvial sandstone and mudstone intervals in the lower part of the otherwise lacustrine Anvil Point Member of the Green River Formation in the adjacent Anvil Points quadrangle (O'Sullivan, 1986) and in the Rifle quadrangle are very similar to the fluvial sandstones of the underlying Wasatch Formation and dissimilar to the overlying lacustrine Green River Formation. The Doodlebug Gulch member contrasts with the underlying Shire Member (Tws) by containing 26 % sandstone intervals instead of less than 3 % sandstone intervals in the Shire Member. The Doodlebug Gulch member incorporates about 14 fluvial sandstone intervals greater than 1 m thick and 13 intervening mudstone intervals. From bottom to top the sequence exposed on the ridge south of Doodlebug Gulch consists of about 20 m of sandstone (ss), 26 m of mudstone (ms), 1.5 m ss, 17 m ms, 1.5 m ss, 32 m ms, 3 m ss, 23 m ms, 5 m ss, 8 m ms, 6 m ss, 38 m ms, 7 m ss, 27 m ms, 4 m ss, 12 m ms, 6 m ss, 11 m ms, 3 m ss, 23 m ms, 8 m ss, 17 m ms, 12 m ss, 38 m ms, 9 m ss, and 15 m ms. The top of the Doodlebug Gulch member is defined here at the top of the uppermost fluvial sandstone, which occurs below the lowest marlstone and lacustrine sandstone intervals of the Anvil Points Member of the Green River Formation. The base of the Doodlebug Gulch member is defined here at the base of the lowest prominent, 20-m-thick, fluvial sandstone interval. Sandstone intervals range from 1.5 to 20 m thick, average 6 m thick, have common crossbedding and channel-fill structures, include abundant basal conglomeratic layers, are calcareously cemented, are typically very pale orange to grayish orange pink, and grayish pink, contain flattened mudstone rip-up clasts, and consist of 70 % quartz, 25 % feldspar, and 5 % dark altered mafic minerals and minor muscovite flakes. Minor lenses of mudstone and siltstone are included in the sandstone intervals. Claystone, mudstone, and siltstone intervals are poorly exposed, range from 8 to 38 m thick, average 22 m thick, are massive, and are typically light gray to grayish orange but include pale red, pale reddish brown, pale purple, pale red purple, light brownish gray, light olive gray, greenish gray, and yellowish gray. The Doodlebug Gulch member is about 370 m thick.

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STRUCTURE

The Rifle quadrangle extends from the Grand Hogback monocline into the southeastern part of the Piceance basin. In the northeastern part of the map area, the Wasatch Formation is nearly vertical, and over a distance of about 1 km, the dip decreases sharply from about 70-85^{o} to about 15-30^{o} toward the southwest. No evidence of a fault in this zone of sharp change in dip is observed but exposures in the Shire Member of the Wasatch Formation are poor, and few marker horizons that might demonstrate offset are distinct. In the central part of the map area, the Shire Member is essentially flat lying. In the south and southwest part of the map area, the dominant dip is slightly to the north, forming an open syncline that plunges gently to the northwest. Evidence for this fold also exists in the subsurface from drill-hole data. According to Tweto (1975), folding of the early Eocene to Paleocene Wasatch Formation along the Grand Hogback reqired an early Eocene age for the last phase of Laramide compression. We find the attitude of the Wasatch Formation to be nearly horizontal, essentially parallel to the overlying Anvil Points Member of the Eocene Green River Formation; therefore, we have no information that either confirms or disputes that early Eocene was the time of the last Laramide event. Near Rifle Gap in the northeast part of the map area, the Mesaverde Group locally dips about 10^{o} less steeply than the overlying Wasatch Formation, indicating that not only had the formation of the Hogback monocline not begun by the time the Wasatch was deposited at this locality, but the underlying Mesaverde Group was locally tilted slightly toward the present White River uplift. Also the basal part of the Atwell Gulch Member of the Wasatch Formation consists of fine-grained mudstones and siltstones containing sparse sandstone and rare conglomerates, indicating that the source of sediment was not from erosion of the adjacent Upper Cretaceous Mesaverde Group. The most likely source of andesitic conglomerate clasts abundant in the upper part of the Atwell Gulch Member was Late Cretaceous-Early Tertiary andesitic igneous rocks, remnants of which are present southeast of the Piceance Basin (Tweto, 1979). Thinning of the Atwell Gulch and Molina Members to the northwest also suggests a southeastern source of sediments, ruling out a northeastern source related to earlier deformation of the Upper Cretaceous Mesa Verde Group.

There is no evidence for a northwestern extension of the Divide Creek Anticline in the Wasatch of the Rifle quadrangle and the Silt quadrangle to the east (unpublished mapping by R.B. Scott). Detection of detachment zones that are parallel to bedding, similar to those demonstrated at the Divide Creek Anticline by Gunneson and others (1995), would be difficult in the subsurface in the absence of a pop-up structure.

GEOLOGIC HAZARDS

Geologic hazards in the map area include mass wasting, gullying, piping, and flooding. Mass wasting involves any rock or surficial material that moves downhill under the influence of gravity, such as landslides, debris flows, and rock falls. Mass-wasting processes and deposits are generally more prevalent on steeper slopes. Gullying and piping generally occur in surficial deposits on more gentle slopes. Piping is erosion of unconsolidated or weakly consolidated material by migrating water that transports material downward or laterally along fractures or other conduits and can locally result in large voids and collapse features. Most flooding is restricted to low-lying areas near perennial and intermittent streams. Table 3 summarizes the geologic hazards that are likely to occur on or in the geologic units in the map area.

Where rock units and surficial units in the Rifle quadrangle occur on steep slopes, mass wasting is common. Most of these rock units that are prone to mass wasting have low shear strength, either because they are clay rich and (or) because they have planes of weakness parallel to bedding planes or jointing. As a result, landslides and creep on these rock units are common. 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 (Varnes, 1978) commonly produce debris-slide, rock-slide, debris-slump, rock slump(?), earth slump, slump-earth-flow, earth-flow, and debris-flow deposits. These deposits are indicated on the map by their map symbols: Qls (landslide deposits), Qdy, Qdi, and Qdo (debris-flow deposits), and Qc (colluvium, undivided). These deposits are mapped both by aerial photographic observation of geomorphic features and by field observation of their 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 adjacent stable areas, anomalous strike and dip attitudes of displaced bedrock, and material found downslope from their source. The map unit Qc locally includes old coalesced landslide and debris-flow deposits that are no longer mappable as separate units because their geomorphologic expression has been obliterated by erosion.

Landslide and debris-flow deposits in the map area are commonly derived from shale- or mudstone-rich parts of the Wasatch Formation, particularly south of the Colorado River. Taughenbaugh Mesa and Grass Mesa are capped by thick sequences of debris-flow deposits and their steep flanks are mantled by abundant landslide and colluvial deposits. The coarse debris in the debris-flow deposits protect the mesa tops, but not the mesa flanks, from erosion (Stover, 1993).

Natural and human-induced factors that impact slope stability, such as increased pore pressure, reduction of lateral support, or removal of vegetation, can result in the reactivation of existing landslide deposits or other potentially unstable geologic materials that are presently inactive. Recent events on and near Storm King Mountain, about 30 km east of the map area, indicate that steep slopes stripped of vegetation by forest fires followed by intense rainfall are especially conducive to the generation of large debris flows. These debris flows and hyperconcentrated flows were activated by runoff that mobilized unconsolidated stream-channel and hillside rock and soil debris that flowed down drainageways (Cannon and others, 1995).

The southwestern dip slope of the Grand Hogback in the northeast part of the map area contains several large Pleistocene slide masses (Scott and Egger, 1997). Dips of the strata that are unaffected by landslides are greater than 60^{o} to the southwest in this segment of the hogback; in contrast, in the New Castle quadrangle (Scott and Shroba, 1997), 12 kilometers to the southeast, dips of the rocks in the Grand Hogback are less than 60^{o} and no landslides occur on the dipslope. Upslope from each of the slide masses, the strata of the Williams Fork Formation are strongly overturned and` dip shallowly to the northeast; the sandstone intervals are highly fractured. At localities where gullies have as much as 100 m of relief in the hogback, southwest-dipping sandstone layers are upright at the bottom of these gullies and gradually become steeper higher on the gully walls and become overturned to the northeast to form a smooth limb of a fold. The lower part of the landslide deposits rests on gently sloping pediment surfaces that are cut on the easily eroded Wasatch Formation; the more resistant sandstone blocks in the slide masses armor the surfaces and protect the underlying Wasatch from erosion. The landslide deposits and these pediment surfaces cap topographic bulges or buttresses to the otherwise uniform dipslope of the hogback. This deformed segment of the hogback contrasts significantly with other segments of the hogback in the eastern part map area that lack landslide deposits. These intervening undeformed segments display right-side-up, unshattered sandstone panels of Williams Fork strata that dip steeply to the southwest at attitudes between 50-60^{o}. Based on these observations, Scott and Egger (1997) conclude that prior to sliding a combination of gravitational and transverse loading, induced by water-saturated mudstone intervals stratigraphically below the sandstone intervals, resulted in the failure of the steeply dipping sandstone intervals by buckling them toward the southwest, shattering the sandstone and thereby providing conditions conducive to catastrophic slope failures in the form of massive landslides. It is likely that wetter climatic conditions, possibly during glacial episodes, triggered the sliding by saturating the mudstone intervals.

We conclude that geologic conditions in the map area along the southwest side of the Grand Hogback, where strata dip in excess of 60°, are conducive to massive sliding. Therefore, future construction sites and areas upslope from these sites should be carefully evaluated for the potential of new landslides, particularly in localities of the hogback where landslides have not formed but dips exceed 60°.

Gullying commonly occurs in well sorted, poorly consolidated silty and sandy alluvial, colluvial, and eolian deposits where runoff is concentrated, such as in the ruts formed in dirt roads. Gullying is more pronounced in undivided alluvium and colluvium (Qac) and loess (Qlo). Piping was observed in undivided alluvium and colluvium and loess.

Loess (Qlo) is prone to hydrocompaction; however, silty undivided alluvium and colluvium (Qac) may also be locally prone to hydrocompaction if it is placed under a heavy load and saturated.

Flooding is generally restricted to low-lying young surficial units, but also occurs on higher units such as younger alluvial-fan and debris-flow (Qfy) and sheetwash (Qws) deposits. Construction of most permanent structures on flood-plain and stream-channel deposits (Qfp) should be avoided along the Colorado River and its major tributaries such as Government Creek and Rifle Creek in and north of the town of Rifle. Intense thunderstorms and probably heavy spring rains on thick snowpacks in the highlands of the White River uplift east of the map area and in the Roan Cliffs to the west have resulted in large floods along these and other streambeds.

Flash floods, sheet floods, and riverine floods occur in the map area. Short duration flash floods and sheet floods are commonly generated by cloudburst rainfall events. Flash floods are likely to occur on undivided alluvium and colluvium (Qac), younger fan-alluvium and debris-flow (Qfy), and younger debris-flow (Qdy) deposits along minor intermittent streams with small drainage basins; whereas, sheet floods are likely to occur on sheetwash (Qws) deposits and on gently sloping bedrock surfaces. Long duration riverine floods are commonly generated by regional-scale, high-volume rainfall events (Edelen, 1981) and (or) by rapid melting of thick, regional snowpack; these floods generally occur on flood-plain and stream-channel (Qfp) deposits along major perennial streams with very large drainage basins, such as the Colorado River.

Claystones in the Wasatch Formation and shales in the Iles Formation and the surficial deposits derived from them, such as landslide (Qls) and debris-flow deposits (Qdy, Qdi, Qdo), may contain a minor amount of expansive clay, although studies of the degree of expansion during wetting and contraction during drying of these units in the map area have not been performed. It is unlikely that rock units, surficial deposits, or the pedogenic soil formed in them in the map area are highly expansive and pose a serious hazard to structures that are properly designed and constructed; however, the water-induced volume changes of these clay-rich units need to be evaluated.

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

EROSION					VOLUME CHANGE		FLOODING	
mass wasting			gullying	piping	hydro-compaction	expansive materials		
Qls	Qc	Qd	Qac	Qac	Qlo	not determined, probably not significant	Qfp	Qfy
Qac	Qfy	Tws	Qlo	Qlo			Qd	Qac
Twal	Twm	Twav					Qsw	
Kwf	Kwfu	Kir						

ENVIRONMENTAL ISSUES

Removal of uranium and vanadium mill tailings piles from two temporary storage sites in the Colorado River flood plain (NE_ sec. 16 and SE_ sec. 18, T. 6 S., R. 93 W) has resolved the principal environmental issue in the Rifle quadrangle. These sites are shown on the map as artificial fill (af). Although the uranium and vanadium tailings and some of the underlying sediment have been removed from these two sites, potentially hazardous gamma radiation and radon gas (Duval, 1991) may still be present from residual decay products of uranium. Ground water in the underlying flood-plain and stream-channel deposits (Qfp) below the uranium mill tailings sites may have become contaminated. Also the mill tailings were susceptible to wind erosion and have contaminated the ground surface within several hundred meters of the now-removed tailings piles (Stover, 1993).

About 5 million tons of these mill tailings are now buried in the Shire Member of the Wasatch Formation beneath artificial fill (af) west of Estes Gulch at the Rifle Colorado Uranium Mill Tailings Repository in the northern part of the map area. The distribution of the fill at the repository was mapped with the aid of a Global Positioning Systems (GPS) instrument to a precision less than +/- 2 m. The repository was built in the remnant of a loess-covered pediment deposits (Qlo/Qp) and the underlying Shire Member of the Wasatch Formation. The loess, gravelly pediment deposits, and some of the Shire Member were removed before the tailings were emplaced. The construction of artificial drainage that diverts intermittent stream flow, either eastward to Estes Gulch or westward to an unnamed gulch, protects the repository from stream erosion. The top of the repository is covered by large boulders and cobbles designed to reduce the probability of surface erosion removing fill from above the repository. The relatively impermeable Shire Member of the Wasatch Formation below the repository inhibits the flow of surface or ground water from the repository into the regional ground water system.

Numerous gas wells and natural gas pipe lines west of Rifle are in the northeastern part of the Rulison gas field (Powell, 1982). Although there was no obvious evidence of environmental problems related to the production of this natural gas from the sandstones of the Mesaverde Group and from the Wasatch Formation, erosion of the Wasatch Formation has been enhanced where gas lines, drilling pads, and dirt roads to these facilities are constructed.

Coal transported from mines in the Grand Hogback north of the map area has been spilled or dumped at several sites between Estes Gulch and Rifle Creek, but it is not likely to create a significant environmental issue.

Near the southwestern end of Rifle Gap, there are two concrete buttresses high on the opposite walls of the water gap. These buttresses anchored the piece of environmental art called the “Valley Curtain” created by the artist Christo Javacheff. Javacheff constructed a nylon curtain that was suspended from a cable strung between the buttresses and anchored to the ground. On 10 August 1972, a spectacular billowing curtain filled the water gap for a day before being destroyed by a windstorm (Cole and Weston, 1982). Only the buttresses remain.

GEOLOGIC RESOURCES

Geologic resources in the Rifle quadrangle include natural gas and sand and gravel. No coal is produced in the map area although the topographic base mistakenly identified a coal loading site as an abandoned coal mine between Rifle Creek and Government Creek in the Shire Member of the Wasatch Formation near the northeastern corner of the map area (SW _ sec. 19, T. 5 S., R. 93 W.). The Rulison gas field mentioned above is the principal source of natural gas. Natural gas products are being actively extracted from the sandstones of the Iles Formation, mostly from the Rollins Sandstone Member (Kir), Cozzette Sandstone Member (Kiz), and the Corcoran Sandstone Member (Kic), as well as from sandstones in the Williams Fork Formation and even from sandstones as shallow as 600 m in the Wasatch Formation (Powell, 1982). About 40 wells were drilled in the map area; the locations of these wells are shown on the map. Of these, 36 produce gas and 4 are dry.

Abundant sand and gravel deposits in the Rifle quadrangle are present in the flood-plain and stream-channel deposits (Qfp) along the Colorado River. Less abundant and (or) lower quality deposits are present in other flood-plain and stream-channel deposits as well as in older terrace alluvium (Qto) and oldest terrace alluvium (Qtt) along the Colorado River and its major tributaries and in younger terrace alluvium (Qty) along Rifle Creek, Government Creek, and the unnamed stream in Hubbard Gulch. Coarse clastic material (pebbles and cobbles) in channel deposits is commonly overlain by sandy and silty overbank or side-stream deposits. Sandy and silty deposits are more common along tributaries than along the Colorado River where gravel commonly dominates. Most of the pebbles and cobbles in deposits along the Colorado consist of granite, gneiss, quartzite, sandstone, and porphyry; whereas those in deposits along tributary streams are mostly sandstone. Several deposits have been partially mined along the Colorado River in units Qfp and Qto, but abundant reserves exist in these units under land primarily used for agriculture.

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