U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE SILT QUADRANGLE, GARFIELD COUNTY, COLORADO

By

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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. For this reason, subdivisions of time for stratigraphic units use the terms “late” and “early” where applied to surficial units, but use the terms “upper” and “lower” where applied to bedrock units.

Metric units are used in this report except where the nominal total depth of drill holes in feet is given as recorded in 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. 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.

ERA	Period	Epoch	Age
CENOZOIC	Quaternary	Holocene	0 to 10 ka
		Pleistocene	10 to 1.65 Ma*
	Tertiary	Pliocene	1.65 to 5 Ma
		Miocene	5 to 24 Ma
		Oligocene	24 to 38 Ma
		Eocene	38 to 55 Ma
		Paleocene	55 to 66 Ma
MESOZOIC	Cretaceous		66 to 138 Ma

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

Surficial deposits shown on the map are estimated to be at least 1 m thick. Fractional map symbols (for example, Qlo/Qto) are used where loess or sheetwash mantles older surficial deposits and the underlying deposits have been identified. These fractional units are not described here; instead, refer to the 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 Wasatch Formation (Tw), Mesaverde Group (Kmv), and Mancos Shale (Kmu) commonly have unmapped colluvial deposits, especially in areas covered by forests or dense oak brush. Also not mapped are four elongate areas above mined coal beds on the south side of the Grand Hogback, at Harvey Gap, and near the northwestern corner of the map area, where the ground surface is highly oxidized, fractured, and prone to subsidence (Stover and Soule, 1985). The northern boundary of unit Qlo/Qto north and west of the town of Silt is approximate.

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 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) 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, Colo. (Piety, 1981), and (3) about 80-85 m along the White River near Meeker, Colo. (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, mega-annum) basalt on Grand Mesa (Marvin and others, 1966) near Palisade, Colo., about 65 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 55 km east-northeast of the map area. Tentative regional correlations of 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 Witty (1982), and Birkeland (1999). Most of the surficial deposits are calcareous and contain various 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 fraction less than 2 mm in diameter. 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. They 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 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 a few to several meters wide. A previous version of this map was published as a U.S. Geological Survey Open-File Report (Shroba and others, 1994); 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 on that report has made this revision necessary]

ARTIFICIAL-FILL DEPOSITS

Compacted material composed mostly of silt, sand, and rock fragments beneath and adjacent to highways, commercial structures, a drilling platform, and in mine dumps

af **Artificial fill (latest Holocene)**—Compacted and uncompacted fill material composed mostly of silt, sand, and rock fragments. Mapped beneath segments of Interstate 70 and U.S. Highway 6, the nearby tracks of the Denver and Rio Grande Western Railroad, in the dam at the south end of Grass Valley reservoir, in minor dams for stock ponds, beneath a drilling platform, and in coal mine dumps on the Grand Hogback. The artificial fill at a landfill site about 1 km southwest of the western end of the Garfield County Airport probably contains significant quantities of non-geologic materials (garbage), some of which may be hazardous. Thickness generally less than 10 m

ALLUVIAL DEPOSITS

Silt, sand, and gravel in flood plains, stream channels, and terraces along the Colorado River and Mamm Creek, and in fan and pediment deposits

Qfp **Flood-plain and stream-channel deposits (Holocene and late Pleistocene)**—Deposits range from clast-supported, slightly bouldery, pebble and cobble gravel in a sand to sandy silt matrix. Along the Colorado River the upper 1-6 m of the flood-plain deposits is commonly slightly silty, very fine to medium sand that locally contains a minor amount of pebbles and cobbles. The lower 3-5 m of the unit is chiefly clast-supported, slightly bouldery pebble and cobble gravel in a sand matrix. Clasts are poorly to moderately well sorted, and unit is poorly to well bedded. Clasts are commonly subangular to rounded;

their lithologies reflect those of the bedrock in the upstream areas. Low-lying areas of the map unit are prone to periodic flooding. Deposits along Mamm Creek contain more sand and silt than those along the Colorado River. Clasts are mostly subangular to rounded sandstone and basalt. Deposits of sandy silt are prone to extensive piping and gullying. 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). The upper part of the unit may be a complex of 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 unit is tentatively correlated with deposits in terrace T8 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo. Sand and gravel has been mined at several places in unit Qfp along the Colorado River. Thickness along the Colorado River is about 5-10 m (Colorado Highway Department, unpub. data, 1992) and is greater than 6 m along Mamm Creek

Qty **Younger terrace alluvium (late Pleistocene)**—Stream alluvium that underlies terrace remnants that are about 9-12 m above the Colorado River and about 15 m above Mamm Creek. Along the Colorado River the lower part of the unit consists mostly of a poorly sorted, clast-supported, slightly bouldery, pebble and cobble gravel that has a sand matrix. Where deposited by minor tributary streams on the north side of the Colorado River, the upper 10 m of the unit commonly consists of sand to sandy silt that contains lenses and as much as 50-cm-thick beds of cobbly pebble gravel to pebbly sand. Clasts in the lower part of the unit are commonly subrounded to rounded and are derived from a variety of sedimentary, igneous, and metamorphic rocks in the upstream areas. Where deposited by minor tributary streams, the clasts in the upper part of the unit are mostly sandstone. Along Mamm Creek, the unit is mostly a poorly sorted, clast-supported, slightly bouldery, cobble and pebble gravel that has a sand matrix. Clasts are chiefly subrounded to rounded sandstone and basalt and a minor amount of siltstone and marlstone. The unit is overlain in part by about 2-3 m of loess (Qlo) and locally by younger fan-alluvium and debris-flow deposits (Qfy) and undivided alluvium and colluvium (Qac). 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 in terraces T7 and T6 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo., and with deposits in terraces A and B of Bryant (1979) farther upstream between Woody Creek and Aspen, Colo. Exposed thickness is 11 m along the Colorado River and 5 m along Mamm Creek; maximum thickness along the Colorado River is possibly 20 m

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Alluvium that underlies small terrace remnants about 20-25 m above West Elk Creek in the adjacent New Castle quadrangle and is exposed in one small remnant in the northeastern part of the Silt quadrangle where the unit is covered by loess (Qlo/Qtm). The unit is poorly exposed, but it appears to consist of poorly sorted, clast-supported, slightly bouldery, pebble and cobble gravel that has a sand matrix. Clasts are mostly subangular to rounded sandstone, quartzite, granite (or gneiss), limestone, conglomerate, and siltstone. The unit is locally weakly cemented by fine-grained calcium carbonate. The unit is inferred to be intermediate in age between the younger and older terrace alluviums (Qty and Qto), and it may be of middle or early Wisconsin age (about 35-65 or 65-80 ka; Richmond and Fullerton, 1986, fig. 2). Thickness is probably about 5m

Qto **Older terrace alluvium (late middle Pleistocene)**—Stream alluvium that underlies terrace remnants about 35-50 m above the Colorado River, Mamm Creek, and Dry Hollow Creek. Along the Colorado River the unit consists of Colorado River alluvium overlain by tributary alluvium. The lower 3-10 m of the unit is mostly a poorly to moderately well sorted, clast-supported pebble and cobble gravel that has a sand matrix. The upper 10-12 m consists of non-pebbly to slightly pebbly, slightly silty to silty sand and 5- to 25-cm-thick lenses of pebble and cobble gravel and sandy pebble gravel. Locally, the lower 1 m of the unit is weakly cemented by fine-grained calcium carbonate. Clasts in the lower part are chiefly subrounded to rounded sandstone, gneiss, quartzite, basalt, granodiorite(?), limestone, and dolomite deposited by the Colorado River. The clasts in the upper part of the unit are mostly sandstone on the north side of the Colorado River and basalt and sandstone on the south side. Along Mamm Creek the unit is mostly a poorly sorted, clast-supported pebble and cobble gravel having a sand matrix that locally contains beds and lenses of slightly bouldery pebble and cobble gravel, pebble gravel, and pebbly sand. Clasts in the unit along Mamm Creek are chiefly angular to subrounded basalt, sandstone, siltstone, and marlstone. Along Dry Hollow Creek the unit is mostly a poorly sorted, clast-supported, slightly bouldery to bouldery pebble and cobble gravel that has a sand matrix. The clasts in the unit along Dry Hollow Creek are mostly subangular to subrounded sandstone and basalt. The unit along the Colorado River and Dry Hollow Creek is mantled by 1.5-6 m of loess (Qlo) and locally by sheetwash deposits (Qsw) and undivided colluvium (Qc). The north-trending loess-mantled deposit of unit Qto in the eastern parts of secs. 17, 20, and 29, T. 6 S., R. 92 W., marks a former course of Mamm Creek. Locally, there is a buried soil formed in the upper part of the unit and possibly in the overlying loess. This soil has an argillic B horizon that is 60 cm thick and was formed in silty alluvium or loess. It overlies a stage III K horizon, 120 cm thick, in the upper part of the underlying gravel. The morphologic development of the soil suggests that the unit is of Bull Lake age (Hall and Shroba, 1993; Nelson and Shroba, 1998) and may be about 140-150 ka (Pierce and others, 1976; Pierce, 1979) or about 130-300 ka (late middle Pleistocene; Richmond, 1986, chart 1A). Locally, there is buried soil formed in the lower of two loess sheets that locally mantle the unit. The unit is tentatively correlated with deposits in terraces T5 and T4 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits in terrace C of Bryant (1979) farther upstream between Woody Creek and Aspen. Sand and gravel has been mined in unit Qto near the Garfield County Airport. Exposed thickness along the Colorado River is 6-21 m, and the maximum thickness is probably about 25 m. Exposed thickness is 1.5-10 m along Mamm Creek and 3-3.5 m along Dry Hollow Creek. Maximum thickness along these creeks is possibly 15 m

Qba **Basaltic alluvium (late middle Pleistocene)**—Stream alluvium that underlies small terrace remnants 35-50 m above Mamm Creek and its tributaries. The unit consists mostly of poorly sorted, clast-supported, boulder, cobble, and pebble gravel in a sand matrix. Locally, the unit is moderately to weakly cemented by fine-grained calcium carbonate. Clasts consist of subangular to subrounded basalt and minor sandstone. The maximum clast diameter ranges from 0.5 to 1.5 m. Unit appears to be in part laterally equivalent to older terrace alluvium (Qto) and is distinctive by consisting chiefly of basaltic boulders and cobbles. Unit probably represents local flood deposits from a basalt-rich source area. Maximum thickness along Mamm Creek and its tributaries is about 10 m

Qg **Gravelly alluvium (late and middle Pleistocene)—**Small deposits on ridges and hilltops about 20, 30, 75, and 90 m above unnamed intermittent streams north of the Colorado River in secs. 13 and 34, T. 5 S., R. 92 W. Much of the unit is poorly exposed, but it appears to consist chiefly of poorly sorted, clast-supported, slightly bouldery to bouldery, cobbly pebble gravel that has a silty sand matrix. Unit Qg locally contains thin beds and lenses of cobbly pebble gravel and non-pebbly to pebbly, silty sand. Clasts are mostly subangular to subrounded sandstone along with a minor amount of limestone and trace amounts of chert and quartzite. Some of the boulders in unit Qg are as much as 2 m in intermediate diameter. Locally, there is greater than 2 m of relief on the underlying Shire Member of the Wasatch Formation (Tws). Unit Qg probably consists mostly of stream alluvium. Exposed thickness is 1-19 m; maximum thickness is possibly about 25 m

Qtt **Oldest terrace alluvium (middle Pleistocene)**—Stream alluvium that underlies small terrace remnants that are about 75, 90, 115, and 150 m above the Colorado River, and about 90 and 115 m above Rifle Creek in the adjacent Rifle quadrangle. Along the Colorado River the unit is mostly a poorly to moderately well sorted, clast-supported, non-bouldery to slightly bouldery pebble and cobble gravel having a sand matrix. It locally consists of 10- to 35-cm-thick lenses and beds of pebble gravel and silty sand. The unit locally grades upward into moderately well sorted, clast-supported pebble gravel having a sand matrix or poorly sorted, matrix-supported cobbly and pebbly sand that is overlain by non-pebbly to slightly pebbly, slightly silty sand. Clasts are mostly subrounded to rounded and are derived from a variety of sedimentary, igneous, and metamorphic rocks in the upstream areas. Locally along the south side of the Colorado River, the upper part of the unit was deposited by tributary streams and is composed of subangular to subrounded sandstone and basalt clasts and a sand matrix. A stage III soil K horizon, 60-90 cm thick, is locally present in the top of the unit, and the lower 1-2 m of the unit is locally weakly cemented by fine-grained calcium carbonate. Deposits in the northwestern part of the map area are mostly a poorly sorted, clast-supported, slightly bouldery to bouldery pebble and cobble gravel having a sand matrix. The clasts in these deposits are mostly subangular to subrounded sandstone along with a minor amount of limestone and a trace amount of quartzite. The basalt clasts are subrounded to rounded and are as long as 2 m. The unit is locally mantled by 1-5 m of loess (Qlo) and in other places by colluvium. The loess mantle locally consists of two or more sheets. Unit Qtt probably spans an age range including that of the 90-m terrace deposits, which occur at three localities within 50 km of the map area. These terrace deposits contain or are overlain by the 620-ka Lava Creek B volcanic ash. The unit is tentatively correlated with deposits in terraces T3 and T2 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits in terrace D of Bryant (1979) farther upstream between Woody Creek and Aspen. Exposed thickness is 3-14 m along the Colorado River and 1.5-5 m east of Rifle Creek; maximum thickness along the Colorado River is possibly 20 m

ALLUVIAL AND COLLUVIAL DEPOSITS

Clay, silt, sand, and gravel in fans on flood plains, beneath terraces; 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 having a silty sand matrix, and locally pebbly and cobbly silty sand that contains lenses of sand, pebble gravel, and cobbly pebble gravel 10-40 cm thick. Deposits derived from the upper member of the Mancos Shale (Kmu), mapped in one area near the eastern shore of Grass Valley Reservoir, have a clayey matrix that is sticky when wet and has shrinkage cracks when dry. These deposits may contain expansive clays, may have high potential for shrinking and swelling, and may be prone to hydrocompaction. The unit locally contains boulders as long as 2.5 m; some of the larger boulders were probably deposited by debris flows. In general, the unit is nonbedded to poorly bedded; beds are commonly less than 1 m thick. Near the mouth of Mamm Creek the unit is mostly sand, silt, and clayey silt (Colorado Highway Department, unpub. data, 1992). Clasts are commonly angular to subangular sandstone north of the Colorado River and are angular to subrounded sandstone and basalt south of the Colorado River. The unit forms fans that are undissected and that were 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). Locally, the unit includes sheetwash deposits (Qsw) and colluvium (Qc) and probably hyperconcentrated-flow deposits. Surface is locally subjected to flooding and debris-flow deposition. Unit may be locally prone to hydrocompaction. Although older fan deposits were not identified in the map area, the unit is named younger fan and debris-flow deposits because it is correlative with younger fan deposits (Qfy) mapped in the adjacent New Castle quadrangle where older fan deposits are also mapped (unit Qfo of Scott and Shroba, 1997). Exposed thickness is 3-15 m; maximum thickness probably about 25 m

Qac **Alluvium and colluvium, undivided (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 deposits (Qsw), and probably hyperconcentrated-flow deposits. Some of these deposits probably grade laterally and vertically into each other. The alluvium typically consists of interbedded silt, silty sand, pebbly sand, and pebble gravel and ranges from thin-bedded 0.5- to 15-cm-thick sandy clayey silt to thick-bedded (>1-m thick), poorly sorted, clast- and matrix-supported pebble and cobble gravel having a sand matrix. Sheetwash deposits are typically clayey silt to pebbly sand. Unit Qac is prone to extensive gulling and piping. Low-lying areas of the map unit are prone to periodic flooding and debris-flow deposition. Deposits derived from the Mancos Shale commonly contain more silt and clay than those derived from other bedrock units. Deposits derived from the upper member of the Mancos Shale (Kmu) contain expansive clays and may have high potential for shrinking and swelling. Some of the flood-plain deposits contain thin, buried soil A horizons that formed during periods of non-deposition and surface stability. Alluvial deposits form flood plains, low terraces, and small fans along intermittent streams that are tributary to the Colorado River. Sheetwash deposits locally mantle the valley bottoms and the adjacent valley sides and hill slopes. Exposed alluvium thickness is 1-3 m; colluvium thickness is 1-1.5 m. Maximum thickness is probably about 15 m

Qp **Pediment deposits (middle Pleistocene)—**Gravelly alluvium and debris-flow deposits at two or more levels that overlie gently sloping surfaces cut on Mancos Shale (Kmu) and Wasatch Formation (Tw). 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, slightly bouldery pebble and cobble gravel that has a sandy silt matrix and poorly sorted, cobbly, sandy pebble gravel to pebbly silty sand. Clasts are chiefly angular to subrounded sandstone. Deposits north of the Colorado River also commonly contain a minor amount of limestone and locally minor amounts of siltstone and quartzite. The quartzite clasts are subrounded to rounded and were probably derived from older fluvial surficial deposits. Deposits south of the Colorado River near Mamm Creek also contain moderate to trace amounts of basalt, siltstone, and marlstone. Unit Qp locally includes minor unmapped sheetwash deposits (Qsw), colluvium (Qc), and probably hyperconcentrated-flow deposits. Nonsorted, bouldery, debris-flow(?) deposits are locally common in the upper part of the unit. Some of the sandstone boulders near the Grand Hogback are as long as 4 m. A stage III soil K horizon is locally present in the upper 50-75 cm of the unit, and some of the sandstone cobbles in the upper 2 m are weathered and disintegrated to sand-size particles. The unit is well exposed in steep-sided gullies and roadcuts but is mapped only without a mantle of loess (Qlo) in one area near the western boundary of the map area. The unit is dissected and is mantled by about 2-4 m of loess (Qlo), which locally consists of two or more sheets. A reddish-yellow (5YR 6/6) argillic B horizon, 60 cm thick, is locally present in the top of the basal loess sheet. The lower limits of the pediment deposits are about 50 and 110 m above the Colorado River and about 50 m above Mamm Creek. Low-lying areas of the map unit that are adjacent to stream channels, especially those near the Grand Hogback, may be prone to periodic flooding and debris-flow deposition. The lower pediment deposits along the Colorado River near the town of Silt and along Mamm Creek appear to be graded to terrace remnants composed of older terrace alluvium (Qto) that are about 50 m above stream level. Some of the loess (Qlo) on gently sloping surfaces and loess overlain by sheetwash deposits (Qsw/Qlo) along and near the Colorado River and on the east side of Mamm Creek may overlie pediment deposits. Along the Grand Hogback there are unmapped pediment deposits concealed by landslide deposits (Qls). These pediment deposits are at elevations of about 116-122, 30-43, and 12-24 m above nearby intermittent streams, and they are probably of late to middle Pleistocene age. Sand and sandstone-rich gravel has been mined at one pit (SW ¼ SE ¼, sec. 33, T. 5S., R. 92 W.) about 5 km northwest of Silt. Exposed thickness is commonly 2-7 m; maximum observed thickness is 11 m; maximum thickness is possibly 15 m

COLLUVIAL DEPOSITS

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

Qc **Colluvium, undivided (Holocene to middle? Pleistocene)**—Mostly clast-supported, pebble, cobble, and boulder gravel that has a silty sand matrix, and gravelly silty sand, sandy silt, and clayey silt. 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. Deposits derived from the upper member of the Mancos Shale (Kmu) commonly contain more silt and clay than those derived from other bedrock units. Deposits derived from the upper member of the Mancos Shale (Kmu) and shale and mudstone from the Mesaverde Group (Kmv) may contain expansive clays and locally may have high potential for shrinking and swelling. The unit is typically unsorted to poorly sorted and unstratified to poorly stratified. The unit locally includes sheetwash (Qsw), creep-derived debris-flow (Qd), landslide (Qls), talus (rock-fall), 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. The map unit 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. Exposed thickness is 1-1.5 m; maximum thickness is probably about 5 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. The unit is common on gentle to moderate slopes in areas underlain mostly by the Mancos Shale (Kmu), Wasatch Formation (Tw), and loess (Qlo). Low-lying areas of the map unit are prone to periodic sheet flooding. The unit may be locally subject to hydrocompaction. The unit locally includes small deposits of loess (Qlo) and undivided alluvium and colluvium (Qac) in and along minor drainageways and may locally include creep in colluvium (Qc). Exposed thickness is 2-5 m; maximum thickness is probably about 10 m

Qsw/Qlo Sheetwash deposits over loess

Qls Landslide deposits (Holocene to middle? Pleistocene)—Chiefly unsorted and unstratified rock debris characterized by hummocky topography. Many of the landslides are complex (Varnes, 1978) and commonly form on unstable slopes that are underlain by the upper member of the Mancos Shale (Kmu), Williams Fork Formation (Kwf), and Wasatch Formation (Tws, Twss, Twm, Twav) along both sides of the Grand Hogback and in the southwestern part of the map area. The younger 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, slump-earth-flow, earth-flow, and debris-flow deposits as defined by Varnes (1978). In addition to those defined by Varnes (1978), Scott and Egger (1997) attributed a new type of landslide on the dip slope of the Grand Hogback to failure of steeply dipping sandstone layers by buckling, overturning, and catastrophic collapse, described below under "Geologic Hazards." The sizes and lithologies of the clasts and the grain-size distributions of the matrices of these deposits reflect those of the displaced bedrock units and surficial deposits. Landslide deposits are prone to continued movement or reactivation due to natural, as well as human-induced, processes. Deposits derived from the Williams Fork Formation and the Iles Formation may contain blocks of rock as long as 10 m. Landslide deposits derived from the Mancos Shale and the Wasatch Formation are rich in clay. Mancos-derived clay from the upper member (Kmu) contains expansive clay and locally may have high potential for shrinking and swelling. The unit locally includes unmapped sheetwash (Qsw) and creep-derived colluvium (Qc) deposits. Exposed thickness is 1-20 m; maximum thickness is possibly 60 m

Qd Debris-flow deposits (Holocene? to middle? Pleistocene)—Lobate and fan-shaped masses of debris, some with bouldery levees, that were deposited by sediment-charged flows and commonly overlie gently sloping surfaces on and near the exposures of the upper member of the Mancos Shale in the northern part of the map area. 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; locally, deposits include lenticular beds of poorly sorted, clast-supported, bouldery, cobbly pebble gravel in a silty sand matrix. Clasts are commonly randomly oriented and angular to subangular. Clasts are mainly subangular sandstone as long as 2 m. Some of the deposits are mantled by loess (Qlo) and locally by other colluvial deposits in their steep upper parts. Debris-flow deposits commonly occur on, and downslope of, the upper member of the Mancos Shale (Kmu) and mudstone-rich parts of the Wasatch Formation (Tws, Twa, Twav). Deposits derived from the upper member of the Mancos (Kmu) contain expansive clays and locally may have high potential for shrinking and swelling. Low-lying areas of the map unit that are adjacent to stream channels are prone to periodic flooding and debris-flow deposition. Unit Qd is locally subject to hydrocompaction. Unit Qd probably includes minor stream-flow and hyperconcentrated-flow deposits. The lower extent of the debris-flow deposits locally ranges from less than 3 to 15 m above unnamed intermittent streams. Exposed thickness is about 1-2 m; maximum thickness is possibly 15 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 that barely extends into the southwestern part of the map area near the southwestern corner. The lower limit of the surface is about 255 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 that has 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 that has 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 in the adjacent Rifle quadrangle (Shroba and Scott, 1997), 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 in the nearby New Castle quadrangle (unit Qtba of Scott and Shroba, 1997). Exposed thickness is 30 m in the map area, about 35-70 m in the adjacent Rifle quadrangle, and about 20 m in the North Mamm Peak quadrangle about 1.4 km south of the map area. Maximum thickness in the Rifle quadrangle is possibly 75 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, calcareous (6-18 percent calcium carbonate), slightly clayey, sandy silt, that is friable when dry and slightly plastic to plastic when wet. The grain-size distribution of the carbonate-free fraction of unweathered loess in and near the map area commonly consists of 22-46 percent sand (2-0.05 mm), 43-62 percent silt (0.05-0.002 mm), and 15-18 percent clay (<0.002 mm). About 55-75 percent of the unweathered loess is composed of very fine sand (0.01-0.05 mm) plus coarse silt (0.05-0.02 mm). Median grain size ranges from 0.03 to 0.05 mm (Shroba, 1994). 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. 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 of coarse silt to total silt (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. Unit Qlo commonly mantles level to gently sloping surficial deposits as old as, or older than, the younger terrace alluvium (Qty) and is absent from younger surficial deposits. 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 in the adjacent New Castle quadrangle (unit QTba of 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 soil that is formed in the lower loess sheet on the older terrace alluvium contains more clay and calcium carbonate than does 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, nonprismatic argillic B horizon that is about 35 cm thick. If the upper and lower loess sheets on the older terrace alluvium correlate with loess units A and B, respectively, that are on and adjacent to the eastern Snake River Plain in eastern Idaho, then (1) the uppermost loess sheet in the map area accumulated between about 10-70 ka and is of late Pleistocene age, and (2) the underlying loess sheet accumulated during an interval that ended shortly after 140-150 ka and is partly or entirely of latest middle Pleistocene age (Pierce and others, 1982). Exposed thickness is 1-6 m; unit is commonly 1-4.5 m thick. Maximum thickness is possibly 8 m

Qlo/Qty **Loess over younger terrace alluvium**

Qlo/Qtm **Loess over intermediate terrace alluvium**

Qlo/Qto **Loess over older terrace alluvium**

Qlo/Qd **Loess over debris-flow deposits**

Qlo/Qtt **Loess over oldest terrace alluvium**

Qlo/Qp **Loess over pediment deposits**

Qlo/Qtm/Qp **Loess over intermediate terrace alluvium over pediment deposits**

BEDROCK UNITS

Tw **Wasatch Formation (Eocene to Paleocene)**—Shown undivided in cross section only. Formation includes three members: the Shire, the Molina, and the Atwell Gulch Members. Based on drill hole data and map relations, nearly 1.8 km of the formation are exposed

Tws **Shire Member (Eocene)**—Nonmarine, predominantly multicolored fine-grained clastic intervals of thick claystone, mudstone, and siltstone interbedded with less abundant intervals of minor coarse-grained clastic beds of thin fluvial sandstone, as defined by Donnell (1969) at Shire Gulch about 5 km southeast of DeBeque, Colo., approximately 50 km west southwest of Silt, Colo. 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, 1- to-20-cm-thick beds of siltstone of similar colors form less than 1 percent 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 percent of the member, is commonly crossbedded, locally displays channels 0.2-3.5 m deep and 10-25 m wide, and sandstone 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 percent quartz, 30 percent feldspar, and 20 percent 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. One 0.6-km-long landslide in the Shire Member occurs in an area of high relief on the south side of the Colorado River on the western border of the map area. Although the Shire Member is generally prone to landsliding in areas of high relief, the relief in the Shire Member in most of the map area is too low to be conducive to landslides. Therefore, the geologic hazard associated with the Shire Member is only moderate in the Silt quadrangle. The Shire Member includes a prominent sandstone unit (Twss), described below. The Shire Member has an estimated exposed thickness of 1.2 km based on drill hole data and map relations

Twss **Sandstone unit**—Calcareously cemented, grayish-yellow to yellowish-gray, medium-grained sandstone interbedded with minor fine-grained clastic intervals similar to those described for the Shire Member (Tws). This informal unit forms a prominent sandstone-capped cuesta that is about 90 m thick and overlies about 400 m of the lower part of the Shire Member in the central-eastern part of the map area and thins to about 40 m thick where it overlies less than about 200 m of the lower part of the Shire Member in the northwestern part of the map area; therefore, that both the sandstone unit (Twss) and the underlying part of the Shire Member (Tws) thin toward the northwest

Twm **Molina Member (Eocene)**—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, defined by Donnell (1969) near the town of Molina, Colo., 53 km to the southwest of the town of Silt. Donnell described exposures as possibly Molina equivalent about 1 km west of the map area, at the south side of Rifle Gap. The fine-grained clastic beds are similar to those described above for the Shire Member. 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 they are thicker and more strongly cemented by calcium carbonate; these sandstone beds form a low ridge that can be traced across the central 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 claystone rip-up clasts 1-3 cm long. Clasts are moderately sorted and consist of about 70 percent quartz, 20 percent feldspar, 10 percent dark rock fragments and mafic minerals, and a trace of muscovite. 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, with the exception of the persistent sandstone unit (Twss). The map unit thins from 400 m thick in the east to 280 m in the western part of the map area

Twa **Atwell Gulch Member (Paleocene)**—Shown in cross section only. The Atwell Gulch Member was defined by Donnell (1969) based on exposures in Atwell Gulch west of the town of Molina, Colo., 53 km southwest of Silt, Colo. Donnell recognized exposures as Atwell Gulch equivalent about 1 km west-northwest of the map area, at the south side of Rifle Gap. In the Silt quadrangle, member includes a volcaniclastic-rich unit (Twav) and a lower unit (Twal). Member ranges from 235 to 250 m thick

Twav **Volcaniclastic-rich unit**—Nonmarine, predominantly multicolored, fine-grained clastic intervals consisting of thick claystone, mudstone, and siltstone interbedded with less abundant intervals consisting of coarse-grained volcaniclastic beds of fluvial sandstone and abundant conglomerate. The fine-grained clastic intervals are commonly greenish gray, light gray, pale purple, pale pink, moderate red, and pale reddish brown. Siltstones are more common than in overlying members of the Wasatch Formation. Coarse-grained clastic intervals of the map unit form low hills that stand above the pediment surfaces, in contrast to the less resistant fine-grained clastic intervals that have been eroded to the level of pediment surfaces. About 10-40 percent of the volcaniclastic-rich unit consists of coarse-grained clastic beds of sandstone and conglomerate that range from 1 to 25 m thick. The sandstones are predominantly medium to coarse grained sparsely fine grained, and greenish gray, light olive gray, dark greenish gray, and light gray. The clasts in the unit range from poorly sorted to well sorted; they 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 map unit displays common crossbedding, channels, and conglomerate-rich lower parts of channels; locally, soft-sediment deformation has contorted the bedding of the sandstones in places with meter-size overturned structures. The more conglomeratic parts of the unit are more resistant and moderately cemented, and the finer sandstone parts containing sparse conglomerate are generally very weakly cemented by calcium carbonate. The more conglomeratic layers form small ridges that can be traced along strike within the unit. Exposures of the volcaniclastic-rich unit range from 145 m on the eastern part of the map area to 250 m on the western part

Twal **Lower unit**—Nonmarine, predominantly 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. Multicolored, fine-grained intervals are largely siltstone and mudstone; colors 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 15 percent of the unit, range from 1 to 4 m thick, and are brownish gray, pale yellowish brown, grayish green, and very pale orange. In the coarse-grained clastic intervals, clasts are poorly to moderately sorted, weakly cemented by calcium carbonate, and typically consist of about 55 percent quartz, 25 percent feldspar, 10 percent muscovite and biotite flakes, and 10 percent rock fragments and altered mafic minerals. The abundance of volcanic clasts in the coarse-grained intervals decreases downward in the unit; sparse pebbles of andesitic composition are present near the top of unit but are absent near the base. Determination of the base of the lower unit of the Wasatch Formation is difficult. At some localities the sandstone contains more muscovite and biotite than the underlying Williams Fork Formation. Sparse conglomeratic layers are generally restricted to the base of the unit and contain clasts of predominantly white to very pale orange chert and rare pebbles and cobbles of quartz-phenocryst-bearing rhyolite. Where rhyolitic volcanic clasts are absent above the base and biotite-bearing clasts are not present, the map unit is difficult to distinguish from the underlying sandstone beds of the Williams Fork Formation (Kwf) of the Mesaverde Group. At these localities, the lower contact of the unit is based upon the lower relief on the more readily eroded Wasatch Formation compared to the higher relief on the resistant, well-cemented Williams Fork Formation. At some of these localities the base of the lower unit is similar to the Ohio Creek Formation of Tweto and others (1978) or to the Ohio Creek Member of the Williams Fork

Formation of Johnson and May (1980). In the absence of dated palynomorphs in the map area and because of the sparsity of conglomerate that contains volcanic clasts at the base of the lower unit, the age of the rocks mapped above the base of the lower unit remains mostly undetermined. A minor angular unconformity is present at Rifle Gap, 1 km to the northwest along the hogback, where Wasatch Formation strata, which contains rare rhyolitic pebbles, dip about 10^{o} more than the underlying Mesaverde Group strata. Carbonaceous films and clasts commonly found in the lower unit may be reworked from the Williams Fork. Although there is no evidence of an angular unconformity in this map area, the presence of minor reworked (?) coal fragments and sparse conglomerates that do not contain rhyolitic clasts suggests that there may be a minor unconformity below the lower unit. However, given the difficulty of determining the age of the strata mentioned above, the nature and age of such an unconformity is also questionable. Because of the ambiguities of the assignment of this unit to either the uppermost part of the Upper Cretaceous Williams Fork Formation or the lowest part of the Paleocene part of the Wasatch Formation, a cursory palynology (pollen and spores from plants) study involving several samples has been initiated to determine the age of the strata. Initial results (F. R. Flemming, written commun., 1997) are not definitive and are summarized in Scott and Shroba (1997). Until we receive more definitive palynological data, the age of the lower unit of the Atwell Gulch Member as mapped here remains in question. Exposures of the lower unit are about 150 m thick on the eastern side of the map area and pinch out within about 4 km to the west

Kmv **Mesaverde Group rocks, undivided (Upper Cretaceous)—**Group includes the Williams Fork Formation (Kwf) and the underlying Iles Formation (Ki). Unit is shown in cross section only. Group is about 1,400 m thick at exposures along section A-A$^{/}$ and thins to about 1,260 m thick as indicated by drill hole data

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 percent of the formation and are 1-60 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 55 percent quartz, 30 percent feldspar, 15 percent rock fragments and dark mafic minerals, and a trace of biotite and muscovite. Toward the base of the unit, the sandstone intervals become more continuous and have been mapped separately as an upper unnamed sandstone unit (Kwfu) and a lower unnamed sandstone unit (Kwfl), both described below. The wedge of finer clastic material below the lower of these two sandstone units is in part a medium-gray fissile shale that contains coquina deposits of pelecypods including oysters. The coquina contains detrital shells and fragments of *Corbula* and *Crassostrea* set in matrices of coarse- to medium-grained sandstone, indicative of a brackish water environment (W.A. Cobban, oral commun, 1997). The base of the formation is defined as the base of this shale unit and overlies the Rollins Sandstone Member of the Iles Formation. Burning of coal beds above and below the upper sandstone unit (Kwfu) and below the lower sandstone unit (Kwfl) baked the shales and sandstones on either side of the coal; these zones were mapped as baked zones (Kmvb), which indicate the general position of past coal beds. Exposures of the Williams Fork Formation are about 1,100 m thick along section A-A′

Kwfu **Upper unnamed sandstone unit—**Yellowish-gray, medium-grained, well-sorted sandstone interval commonly containing thin, laminated bedding, parallel bedding, and some crossbedding. Unit was mapped from eastern margin to Harvey Gap, but seems to be discontinuous to the west. Map unit ranges from about 30 to 60 m thick

Kwfl **Lower unnamed sandstone unit—** Yellowish-gray, medium-grained, well-sorted sandstone interval containing thin laminated bedding and parallel bedding. Map unit ranges from about 25 to 50 m thick

Ki **Iles Formation—**Marine shale and nonmarine sandstone and siltstone. Formation includes, from top down, the Rollins Sandstone Member (Kir), an upper tongue of marine shale, and two sandstones, the undivided Cozzette and Corcoran Sandstone Members (Kicc), separated by a lower tongue of marine shale. Marine shales are monotonous sequences of medium-dark-gray to light-olive-gray, fissile shale lithologically similar to the Mancos Shale (Kmu), described below. The base of the Corcoran Sandstone Member overlies the Mancos Shale. The Iles Formation is about 260-300 m thick

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 percent quartz, 20 percent feldspar, <10 percent 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 the Iles Formation of Madden (1989), but because Madden miscorrelated the Trout Creek at Harvey Gap, the Rollins Sandstone nomenclature is retained. The Rollins Sandstone Member ranges from about 25 to 55 m thick.

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, and very fine grained, contains minor beds of medium-dark-gray shale, and is about 25 m thick in the eastern part of the map area and 20 m thick in the western. Clasts in the sandstone consist of about 80 percent quartz, 15 percent feldspar, 5 percent 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 both the eastern and western parts of the map area. The lower sandstone, the Corcoran Sandstone Member, is light brownish gray to yellowish gray, moderately sorted, fine grained to very fine grained, contains minor interbeds of medium-gray shale, is about 65 m thick in the eastern part of the map area and 55 m thick in the western, and has clasts that consist of about 75 percent quartz, 15 percent feldspar, 10 percent dark rock fragments and mafic minerals, and <1 percent muscovite, which is concentrated along partings. Carbonaceous films are also present on partings. Thickness of the entire map unit is about 130 m in the eastern part of the map area and about 170 m in the western part

Kmvb **Baked zone in the Mesaverde Group**—Light-red, pale-red, and moderate-reddish-orange baked zone on either side of a clinker resulting from both historic and prehistoric burning of coal. This unit is kept in this part of the stratigraphic sequence because the protolith which was baked is Upper Cretaceous. The actual clinker zones of burnt coal are relatively thin, easily eroded, light-gray ashy zones that are difficult to locate accurately in talus-covered slopes. Zone includes exposures of baked shales, siltstones, and sandstones, areas where thin colluvium from the baked zones has covered exposures with red debris, and the clinker zone. Some of the shale melted during the burns; this resulted in an unusual form of igneous rock that commonly has a brownish-gray to light-medium-gray aphanitic groundmass containing vesicles and inclusions of quartz that were pebbles of quartz that did not melt. Coal beds in the Iles Formation on the Grand Hogback are presently burning at two localities in the adjacent New Castle quadrangle. No measurements of thicknesses of baked zones in the Mesaverde Group were made

Kmu Mancos Shale, upper member (Upper Cretaceous)—In the map area exposures of the formation include only the upper member (Kmu). The formation is about 1,540 m thick. Medium-dark-gray to dark-gray fissile shale that weathers light gray. Dark-gray to dark-yellowish-orange concretions typically 6-15 cm in diameter are common in the upper part of the unit. Very pale orange, fine-grained sandstone forms beds 0.1-3 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- to 15-cm-thick, dark-yellowish-orange bentonitic, montmorillonite-rich beds. Landslide deposits (Qls) and debris flow deposits (Qd) coalesce to form a thick mantle of colluvial deposits (Qc) that cover much of the upper member of the Mancos near the northwest corner of the map area. Because the shale commonly contains expansive clays, the upper member locally may have high potential for shrinking and swelling. 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) described the hazard of steeply dipping Pierre Shale along the Front Range in the Colorado Piedmont; however, the Mancos Shale may have fewer beds rich in expansive clays than does the Pierre Shale, found at least 50 km east of the map area. Gypsum occurs locally between shaley partings, and Na^{+}-, $SO_4{}^{-2}$-, 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 1,280 m

STRATIGRAPHY

The terminology of Warner (1964) is used in this report for the lower part of the Mesaverde Group, particularly for the Rollins Sandstone Member (equivalent to the Trout Creek Sandstone Member in northwestern Colorado), the Cozzette Sandstone, and the Corcoran Sandstone Members of the Iles Formation. Although these three sandstone members can be physically mapped from the Rifle quadrangle at Rifle Gap southeastward through the Silt and New Castle quadrangles, map relations are not as obvious in the Storm King Mountain quadrangle, to the east of the New Castle quadrangle. Bryant and others (1998) could not map a continuous interval of the Rollins Sandstone Member (which they called the Trout Creek), either because of limited exposure or local absence of the unit, or both. This sandstone unit was mapped as the Rollins Sandstone Member of the Williams Fork Formation in the Cattle Creek quadrangle southeast of the Storm King Mountain quadrangle (Kirkham and others, 1996). The Cozzette and Corcoran Sandstone Members were mapped as a combined unit, as they were in the New Castle quadrangle by Scott and Shroba (1997) and in Storm King Mountain quadrangle by Bryant and others (1998).

Members of the Wasatch Formation were mapped following the stratigraphic framework provided by Donnell (1969), which describes Wasatch units exposed south of Rifle Gap, which is 1 km west of the Silt quadrangle along the Grand Hogback. At that locality, Donnell recognized equivalents of the Shire, Molina, and Atwell Gulch Members. These units have been mapped from the Rifle quadrangle (Shroba and Scott, 1997) across the Silt quadrangle to the New Castle quadrangle (Scott and Shroba, 1997). Both the Molina and the Atwell Gulch Members thin significantly toward the northwest toward Rifle Gap, where Donnell measured them at 105 m and 170 m thick, respectively. In the Silt quadrangle, the Molina is 280-400 m thick and the Atwell Gulch is 235-250 m thick. In the New Castle quadrangle the Molina is 210-280 m and the Atwell Gulch is 240-400 m thick. Although the Atwell Gulch progressively thins to the northwest, the Molina is thickest in the Silt quadrangle.

Higher stratigraphically in the Wasatch Formation, the sandstone unit of the Shire Member (Twss), which is lithologically similar to the sandstone intervals that characterize the Molina Member, occurs about 500 m above the Molina in the New Castle area. This sandstone unit thins toward the northwest from a 90-m-thick interval within the Shire Member on the southeast side of the map area to less than a 40-m-thick interval on the northwest side. The sandstone unit was too thin to be mapped in the Rifle quadrangle (Shroba and Scott, 1997). The mudstone-rich interval of the Shire Member between the overlying sandstone unit of the Shire Member (Twss) and the underlying Molina Member thins from about 400 m in the New Castle quadrangle to less than about 200 m on the western side of the Silt quadrangle. All the units within the Wasatch Formation from the sandstone unit (Twss) to the base of the formation thin toward the northwest with the exception of the Molina Member.

STRUCTURE

The Silt quadrangle extends from the Grand Hogback monocline to the southeastern part of the Piceance basin. In the central part of the map area, the Wasatch Formation forms the shallow Rifle syncline (Shroba and Scott, 1997) and shows no evidence of deformation related to the Divide Creek anticline, which ends about 19 km southeast of the map area (Gunneson and others, 1995). From the Rifle syncline toward the northwest, the unfaulted Paleocene to Eocene Wasatch Formation and underlying Upper Cretaceous Mesaverde Group gradually increase in dip to form the Grand Hogback monocline, which reaches dips greater than 60^o and locally reaches nearly vertical in the western part of the Grand Hogback. Along the dip slope of the Grand Hogback where southwest dips are greater than 60^o, segments of the Grand Hogback are overturned. In each case, the overturned segments affect only the uppermost part of the Williams Fork Formation and the overturned segments are uphill from landslide deposits (Qls) (Scott and Egger, 1997). We attribute the overturning to local gravitational processes that induced landsliding, not to regional tectonic processes. Because there is not a significant angular unconformity at the base of the Paleocene and Eocene Wasatch Formation and because the upper part of the Wasatch Formation has been deformed by the uplift, this last phase of Laramide deformation must have persisted at least until early

Eocene (Tweto, 1975). Although units in the map area overlie older strata affected by evaporite tectonism in the Rifle Falls quadrangle adjacent to the north (unpublished mapping by R.B. Scott and A.E. Egger, 1997), the intervening Mancos Shale has apparently absorbed the strain related to diapirism and geologic collapse related to evaporite dissolution (Scott and others, 1998), and no evidence of this tectonism exists in the map area.

GEOLOGIC HAZARDS

Geologic hazards in the map area include erosion, expansive and collapsing soils, debris flows, and flooding. Erosion includes mass wasting, gullying, and piping. Mass wasting involves any rock or surficial material that moves downslope under the influence of gravity, such as landslides, debris flows, or rock falls and is generally more prevalent on steeper slopes. Gullying and piping generally occur on more gentle slopes. Expansive soils and expansive bedrock are those unconsolidated materials or rocks that expand when wet and contract when dry. Most floods are restricted to low-lying areas. Table 3 summarizes the geologic hazards that are prone to occur on or in geologic units in the map area.

Table 3. Geologic hazards and related map units in the Silt quadrangle, Garfield County, Colorado.

Erosion					Volume Change		Debris-Flow Deposition	Flooding	
Mass wasting			Gullying	Piping	Hydro-compaction	Expansive materials			
Qls	Qc	Qd	Qac	Qac	Qlo	Kmu	Qfy	Qfp	Qfy
Qac	Qp	Qfy	Qlo	Qlo	Qfy	Qac	Qac	Qp	Qsw
Tws	Twss	Twm			Qsw	Qls	Qp	Qd	
Twav	Twal	Kwf			Qd	Qc	Qc		
Kwfu	Kwfl	Ki				Qd	Qd		
Kir	Kicc	Kmu					Qls		

Where rock units and surficial units in the Silt 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 or because they have planes of weakness parallel to bedding planes or jointing. As a result, landslides and creep 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, slump-earth-flow, earth-flow, and debris-flow deposits in the map area. These deposits are indicated on the map by symbols Qls (landslide deposits), Qd (debris-flow deposits), and Qc (colluvium, undivided). These deposits were identified and mapped both by their geomorphic features observed on aerial photographs and by field observations. These geomorphic features and field observations 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 adjacent stable areas, material found downslope from their sources, and overturned strata along the dip slope of the Grand Hogback. The map unit Qc locally includes old coalesced landslide and debris-flow deposits that are no longer mappable as separate units because their geomorphic expression has been obliterated by erosion.

Landslide and debris-flow deposits are commonly derived from shale- or mudstone-rich units in the stratigraphic sequence, specifically (1) the Wasatch Formation (Tw), (2) the upper part of the Williams Fork Formation (Kwf), (3) the lower part of the underlying Iles Formation (Ki) and the upper member of the Mancos Shale (Kmu), and (4) surficial deposits (Qac, Qls, Qc, Qd, Qfy, and Qp) derived from these bedrock units.

Few landslides formed on the Wasatch Formation in the map area even though this unit is prone to extensive landsliding in the nearby Center Mountain quadrangle (Carroll and others, 1996). Apparently, slopes and relief in most of the map area underlain by the Wastach Formation are low enough to be relatively stable.

The northeastern side of the Grand Hogback has abundant landslides and debris flows. Large areas of colluvium (Qc) on the northeast side of the hogback form a thick apron of old landslide and debris-flow deposits, derived from the lower part of the Iles Formation (Ki) and the upper part of the upper member of the Mancos Shale (Kmu), which almost completely covers the Mancos. Sites for future homes and other human-made structures on this side of the Grand Hogback should be carefully evaluated for the potential of landslides and debris flows. Also, unmapped rock-fall deposits are common downslope from sandstone ledges in the Iles (Ki) and the Williams Fork (Kwf) Formations on the northeast side of the Grand Hogback.

On the southwest-facing dip slope of the Grand Hogback, a new type of large, potentially dangerous landslide has been recognized at ten localities where the dip of the upper part of the Williams Fork Formation exceeds 60^{o} west of Harvey Gap (Scott and Egger, 1997). East of Harvey Gap, where dip of the upper part of the Williams Fork Formation is less than 60^{o}, no landslides exist in the Silt or adjacent New Castle quadrangles. The area covered by each landslide deposit prior to erosion appears to have exceeded 1 km^2. Upslope from each landslide deposit at the breakaway zone of each landslide, the strata of the upper part of the Willams Fork Formation and the lower part of the Atwell Gulch Member of the Wastach Formation have been locally overturned to dip northeast and the sandstone intervals are highly fractured. Between areas affected by landslides, the strata of the hogback dip in the normal southwest direction and the sandstone intervals are relatively unfractured. Locally, the overturned sandstone intervals can be traced over a distance of several tens of meters down dip through a relatively abrupt fold to dips normally found along the hogback; in other localities, overturned sandstone intervals can be traced through a gentle fold over a vertical distance of 100 m to normal attitudes. Well-cemented and thick competent sandstone intervals in the Williams Fork Formation commonly range from 5 to 20 m thick. The landslide deposits along the south flank of the Grand Hogback overlie remnants of pediment surfaces on the Wasatch Formation that range from 12 to 122 m above modern drainages. These elevations of pediment remnants fall into three groups: 116-122 m, 30-43 m, and 12-24 m above modern drainage. If the incision rate is about 0.16 m/ k.y., then the overlying landslide deposits are younger than the underlying pediment deposits, which are about 725-760, 190-270, and 75-150 thousand years old, respectively. We conclude that initially the sandstone intervals in the upper Williams Fork Formation acted as "structural beams" that prevented landslides because each "beam" or interval could support its own weight. However, as the less resistant Wasatch Formation was eroded, the interval over which the sandstone "beams" had little or no lateral support increased. Also, wet climatic periods, such as those during Pleistocene glaciations, may have acted to decrease the strength of mudstone intervals between sandstone intervals, and expansive clay in the mudstone may have applied an additional lateral or transverse force on the uppermost sandstone interval. Ultimately, this transverse force became great enough to cause the sandstone interval or beam to buckle toward the free-standing southwest slope. When the sandstone intervals overturned, the buckling process intensely fractured the rock, causing the sandstone intervals to loose internal coherence. The resulting catastrophic collapse produced large landslide deposits below the hogback. Although none of these slides appears to be active now, sections of the hogback that have not collapsed yet are likely to collapse in the future, particularly during wet periods. Buildings, roads, and utilities within at least 1 km of the hogback, located along segments of the hogback where no slides have occurred, have the potential of being affected by catastrophic landslides in the future. Prediction of the timing of such events would be extremely difficult.

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 in loess (Qlo). Piping was observed in undivided alluvium and colluvium and in loess. Poorly consolidated eolian, alluvial, and colluvial deposits (units Qlo, Qfy, Qsw, and Qd) are subject to hydrocompaction.

The upper member of the Mancos Shale (Kmu) locally contains bentonitic smectite-rich beds and is locally overlain by expansive soils. These bentonitic units and soils 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, as they do in the Silt quadrangle, the detrimental effects are often more pronounced than if the strata were nearly horizontal because of uneven heaving of foundations and other structures (Noe and Dodson, 1995; Noe, 1996). Colluvial and some alluvial deposits derived from these units may also have expansive characteristics.

Flooding is generally restricted to low-lying young surficial units, but also occurs on higher units such as younger fan-alluvium and debris-flow deposits (Qfy). Construction of permanent structures on flood-plain and stream-channel deposits (Qfp) should be avoided to avert the potential of flooding along the

Colorado River, on undivided alluvium and colluvium (Qac) along Mamm Creek and Dry Hollow Creek, and along unnamed intermittent streams north of the town of Silt.

ENVIRONMENTAL ISSUES

The principal environmental issues in the Silt quadrangle are related to past coal mining along the Grand Hogback. Numerous coal mines were active during the latter part of the 19th century and the early part of the 20th century along the Grand Hogback (Gale, 1910; Fishell, 1979). Although the environmental impact of many of these mines (adits shown on the map) has been moderated by on-going reclamation by the State of Colorado, Department of Natural Resources, scattered coal mine tailings are still common in the map area. Organic debris and acid mine waters from these unreclaimed mines is carried in stream flow in washes southwestward and northeastward off the hogback. Numerous baked zones in the Mesaverde Group (Kmvb) adjacent to clinker zones are shown on the map.

GEOLOGIC RESOURCES

Geologic resources in the Silt quadrangle include coal, gas and oil, and sand and gravel. Coal mining in the Silt area began by 1888 and continued intermittently until recently (Gale, 1910; Fishell, 1979). No active mines exist in the map area.

Petroleum in the form of methane produced by coal beds is being extracted from the sandstones of the Iles Formation, mostly from the Rollins Sandstone Member (Kir). The one gas-producing well was drilled to a depth of 2,508 m in the map area. Four dry holes were drilled to depths between 27 and 1,874 m.

Abundant sand and gravel in the Silt quadrangle are present in the lower parts of the flood-plain and stream-channel deposits (Qfp), younger terrace alluvium (Qty), and older terrace alluvium (Qto) along the Colorado River. Less abundant and (or) lower quality deposits are present in other stream deposits along the Colorado River and its major tributaries and in pediment deposits (Qp). Coarse clastic material (mostly pebbles and cobbles) in stream-channel deposits is commonly overlain by sandy and silty overbank and eolian deposits; these sandy and silty deposits are more common along tributaries and in the upper parts of stream deposits along the Colorado River. Most of the pebbles and cobbles deposited along the Colorado consist mostly of sandstone, gneiss, quartzite, basalt, granitic intrusive rocks, limestone, and dolomite clasts; those clasts deposited by tributary streams are mainly sandstone and locally a minor amount of basalt. Two deposits have been mined, but other areas of abundant reserves exist under land primarily used for agriculture.

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