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Geologic Map of the Cattle Creek Quadrangle, Garfield County, Colorado

Description of Map Units, Economic Geology, Sample Data, and References

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STATE OF COLORADO
NIL SINE NUMINE
1876

Bill Ritter Jr., Governor
State of Colorado

COLORADO
DEPARTMENT OF
NATURAL
RESOURCES

Harris D. Sherman, Executive Director
Department of Natural Resources

COLORADO
GEOLOGICAL SURVEY

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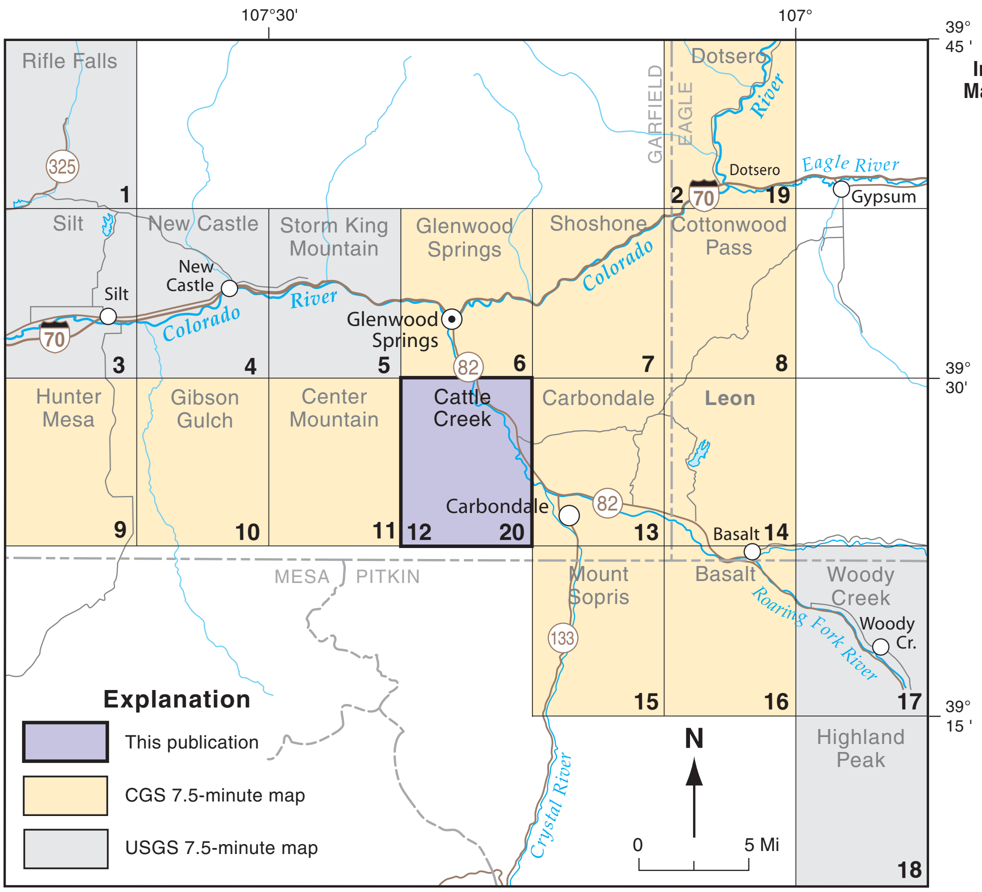
State Geologist and Director
Colorado Geological Survey

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2010

INTRODUCTION

Geologic mapping of the Cattle Creek 7.5-minute quadrangle was undertaken by the Colorado Geological Survey as part of the STATEMAP component of the National Cooperative Geologic Mapping Act of 1992.

The Cattle Creek quadrangle was selected as part of the increasingly developing Roaring Fork River valley between Glenwood Springs and Aspen giving this area a high priority.



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Location map of Cattle Creek quadrangle.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than about 5-ft thick, but may be thinner locally. Residuum and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units occasionally include deposits of another type. Divisions of the Pleistocene correspond to those of Richmond and Fullerton (1986). Age assignments for surficial deposits are based primarily upon the degree of erosional modification of original surface morphology, height above modern streams, and relative degree of soil development. Correlation of terraces and interpretations of their ages is hindered by their discontinuous distribution and by diapirism and subsidence which has deformed many of them, altering their relative heights above stream level. Morphological stages of secondary calcium carbonate used herein are those described by Gile and others (1966).

HUMAN-MADE DEPOSITS—Materials placed by humans

af — **Artificial fill (latest Holocene)—**Fill and waste rock deposited by humans during construction and mining projects. Artificial fill is composed mostly of unsorted silt, sand, and rock fragments, but may include construction materials. Maximum thickness is about 40 ft. It may be subject to settlement when loaded, if not adequately compacted.

ALLUVIAL DEPOSITS—Silt, sand, and gravel deposited in stream channels, flood plains, terraces, and sheet-wash areas along the Roaring Fork and Crystal Rivers and their tributaries.

Qa — **Stream-channel, flood-plain, and low terrace deposits (Holocene and late Pleistocene)—**Includes modern alluvium and other deposits underlying the Roaring Fork River, adjacent flood-plain deposits, and low terrace alluvium that is up to about 12 ft above modern stream level. Mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel interbedded and often overlain by sandy silt and silty sand. Unit is poorly to moderately well sorted and is moderately well to well bedded. Clasts are subangular to well rounded. Their varied lithology reflects the diverse types of bedrock within their provenance. Unit may locally include organic-rich deposits. It may be interbedded with younger debris-flow deposits where the distal ends of fans extend into modern river channels. Maximum thickness is about 40 ft. Flood-plain and terrace deposits included in this unit correlate with deposits in terrace T8 of the Carbondale-Glenwood Springs area of Piety (1981). Low-lying areas are subject to flooding. Unit frequently is a good source of sand and gravel.

Qsw — **Sheet-wash deposits (Holocene and late Pleistocene)—**Includes deposits derived from weathered bedrock and surficial materials which are transported dominantly by sheet wash and accumulate in ephemeral stream valleys, on gentle hillslopes, or in basinal areas. Common on gentle to moderate slopes underlain by shale, basalt, red beds, and landslide deposits. Sheet-wash deposits typically consist of pebbly, silty sand and sandy silt. Locally they are gradational and interfingered with colluvium on steeper hillslopes, and with lacustrine or ponded basinal deposits in closed depressions. Maximum thickness is probably about 25 ft. Area is subject to future sheet-wash deposition. Unit may be susceptible to hydrocompaction, settlement, and piping where fine grained and low in density.

Qty — **Younger terrace alluvium (late Pleistocene)—**Chiefly stream alluvium underlying terraces that range from about 15 to 53 ft above modern stream level. May be capped by a single, thin loess sheet. Stream alluvium is mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand matrix, but unit may include fine-grained overbank deposits. Clasts are mainly subround to round and are comprised of a variety of lithologies reflecting the diverse types of bedrock found in the drainage basin. Clasts generally are unweathered or only slightly weathered. Maximum thickness occasionally exceeds 100 ft, but typically is 20 to 40-ft thick and is much thinner in other areas, such as in the NW 1/4 SW 1/4 of Section 35, T. 6 S., R. 89 W., where only 8 to 10 ft of terrace alluvium overlies bedrock.

North of the quadrangle at the rest area on Highway I-70 in West Glenwood Springs, peat interbedded with tufa that overlies a terrace deposit yielded a ^{14}C date of 12,410 ± 60 years B.P. (Kirkham and others, 1995a; 1996), providing a minimum age for this terrace. This deposit, whose upper surface lies 19 ft above the Colorado River, correlates in part with younger terrace alluvium (Qty) on Cattle Creek quadrangle. Unit includes deposits in terrace T7 in the Carbondale-Glenwood Springs area described by Piety (1981) and may also correlate with terrace A of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Fairer and others (1993) in the Storm King Mountain quadrangle. Unit is probably in part equivalent to outwash of the Pinedale glaciation, which Richmond (1986) estimated to be about 12–35 ka. Younger terrace deposits are locally very slightly tilted away from the Roaring Fork River by upwarping believed to be related to evaporitic diapirism. Unit is a good source of sand and gravel.

Qtm

Intermediate terrace alluvium (late Pleistocene)—Composed of stream alluvium underlying terraces about 55 to 90 ft above modern stream level. Locally the unit is capped by a thin loess sheet. It consists of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix. Fine-grained overbank deposits are locally present. Clasts are chiefly subround to round and consist of various lithologies that reflect the types of bedrock found in their drainage basins. Clasts generally are only slightly weathered at shallow depths. Maximum thickness of the unit is perhaps around 100 ft, but typically it is only 20 to 60-ft thick. Unit includes deposits in terrace T6 of the Carbondale–Glenwood Springs area of Piety (1981), who suggested they were of Pinedale age (12 to 35 ka; Richmond, 1986). It may also correlate with terrace B deposits of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Fairer and others (1993) in the Storm King Mountain quadrangle. Intermediate terraces frequently are slightly tilted away from the river, probably by upwarping related to evaporitic diapirism. Unit is a good source of sand and gravel.

Qto

Older terrace alluvium (middle Pleistocene)—Includes deposits of stream alluvium in terraces along both sides of the Roaring Fork River. Upper surface of unit ranges from about 200 to 280 ft above stream level; however, deposits have been locally upwarped, probably by evaporitic diapirism, and now dip up to 12° away from the river. This process affects the height of terraces above modern river level, making correlations between terraces based solely on height tenuous. Unit is generally a clast-supported cobble or pebble gravel in a sand matrix with occasional small boulders, but may range to a matrix-supported gravelly sand or silt. Locally it may include fine-grained overbank deposits. Clasts are chiefly subround to round, with varied lithologies that reflect the rock types found in the provenance area. Clasts are moderately weathered at shallow depths. Exposed thickness is 10 to 60 ft; maximum thickness is estimated at about 80 ft. Unit is tentatively correlated with terraces T4 and T5 in the Carbondale-Glenwood Springs area of Piety (1981), with terrace C of Bryant (1979) in the Aspen-Woody Creek area, and with older terrace alluvium of Fairer and others (1993). Unit is probably of Bull Lake age, which is thought to be about 140 to 150 ka (Pierce and others, 1976; Pierce, 1979) or about 130 to 300 ka (Richmond, 1986). Piety (1981) reported that snail shells collected from older terrace deposits (Qto) on the valley wall north of Cattle Creek had amino acid ratios suggesting an age of 100 ± 80 ka. Unfortunately, the error margin for this date poorly constrains the age of the deposits. Unit may be a source of sand and gravel.

Qtt

Oldest terrace alluvium (middle Pleistocene)—Consists of stream alluvium in terraces that range from about 220 to 460 ft above adjacent rivers. Unit occurs on a debris-flow-capped terrace at the mouth of Fourmile Creek, on an eroded hill in the valley of the Crystal River in the southeast corner of the quadrangle, and as a narrow remnant capped by older alluvium and colluvium (Qaco) south of the mouth of Cattle Creek. Unit is poorly to moderately well sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. Locally it includes thin lenses and beds of sandy silt and silty sand. Gravel clasts are commonly moderately to strongly weathered, even at considerable depth. Thickness ranges from about 6 to 60 ft. Unit is correlative with T1, T2, and T3 terrace deposits in the Carbondale-Glenwood

Springs area of Piety (1981). A T3 deposit southwest of Carbondale about 1 mi east of quadrangle contains the Lava Creek B ash (Piety, 1981), which is generally considered to be 620 ka (Izett and Wilcox, 1982). Unit is locally upwarped away from the Roaring Fork River, a possible result of evaporitic diapirism. It may be a source of sand and gravel.

QTg **High-level gravel (early Pleistocene and late Tertiary)—**Occurs on hills and ridges 650 to 680 ft above the Crystal River as eroded remnants of formerly extensive fluvial sediments. Unit probably was deposited by ancestral Crystal River. It includes a small, isolated deposit on hilltop north of Edgerton Creek near the eastern edge of the quadrangle and ridge-capping deposits in the southeast corner of the quadrangle which are part of a larger deposit that extends south beyond the boundary of the quadrangle. Unit consists of clast-supported, sandy and silty cobble and pebble gravel. Clasts are subround to well rounded and composed chiefly of granodiorite, quartz monzonite, monzonite, and granite, with lesser amounts of red sandstone, quartzite, basalt, and hornfels. Clasts are very weathered. Thickness is as much as about 50 ft. Unit is a possible source of sand and perhaps gravel.

COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay on valley sides, valley floors, and hillslopes that were mobilized, transported, and deposited primarily by gravity, but frequently assisted by sheet wash, freeze-thaw action, and water-saturated conditions that affect pore pressure.

Qlsr **Recent landslide deposits (latest Holocene)—**Includes active and recently active landslides with fresh morphological features. Deposit is a heterogeneous unit consisting of unsorted, unstratified clay, silt, sand, gravel, and rock debris. Texture and clast lithology are dependent upon source area. Thickness is probably a maximum of about 40 ft. Deposit along western map edge near the northwest corner of quadrangle originated during spring, 1995 as a translational landslide involving colluvium. This mass slid down a dip slope underlain by basalt and evolved into a mudflow or debris flow which ran several hundred feet downslope. A small, elongate landslide southeast of the top of Sunlight ski resort may have initiated as a slump and developed into an earthflow or debris flow. Recent landslides are prone to renewed or continued landsliding and frequently are very wet or water saturated. Distribution of recent landslides is suggestive of the type of environment which may produce landslides in the current climatic regime. Recent landslides may be susceptible to settlement when loaded and to hydrocompaction when derived from evaporites, Maroon Formation, and Wasatch Formation.

Qc **Colluvium (Holocene and late Pleistocene)—**Ranges from clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Colluvium is derived from weathered bedrock and surficial deposits and is transported downslope primarily by gravity, but aided by sheet wash. It grades to sheet wash in the center of Dry Park and west of the water gap along Fourmile Creek cut into the Maroon Formation. Deposits are usually coarser grained in upper reaches of a colluvial slope and finer grained in distal areas. Deposits derived from clay-rich formations such as the Wasatch and Mancos are finer grained and matrix supported. Clasts typically are angular to subangular. Commonly is unsorted or poorly sorted with weak or no stratification. Clast lithology is variable and dependent upon types of rocks occurring with the provenance area. Locally the unit includes talus, landslides, sheet wash, and debris flows that are too small or too indistinct on aerial photography to be mapped separately. Maximum thickness is probably about 50 ft. In part is equivalent to deposits of basaltic colluvium of Carroll and others (1996). Locally is dissected by erosion where small drainages are advancing headward into bluffs at the toe of some colluvial slopes. Areas mapped as colluvium are susceptible to future colluvial deposition and locally subject to sheet wash, rockfall, and small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to hydrocompaction, piping, and settlement, particularly when derived from Maroon Formation, Wasatch Formation, or evaporitic rocks.

Qt **Talus (Holocene and late Pleistocene)—**Angular, cobbly and bouldery rubble on steep slopes that was derived from basalt outcrops and transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Unit frequently lacks matrix material. Locally it is underlain by or incorporated into landslides. Maximum thickness is estimated at about 40 ft. Areas mapped as talus are subject to severe rockfall, rockslide, and rock-topple hazards. Talus deposits usually are a source of high quality riprap and aggregate.

Qbf

Boulder-field deposits (Holocene and late Pleistocene)—Thin deposits of boulders and cobbles of basalt that lack matrix material. Most boulder-field deposits occur within landslides and probably move with them, but they also are found on the basalt-capped mesa east and north of Sunlight Peak, herein called Sunlight Mesa. Unit probably originally formed as talus and rockfall debris that contained little or no matrix. Fines may also have been removed by winnowing effects of wind, or bouldery debris may have been lifted above matrix material by frost heave. Thickness is up to about 25 ft. Some areas mapped as boulder-field deposits may be subject to future landslide activity. Large boulders within this unit affect excavatability and frequently are unstable. Due to the absence of matrix, individual boulders may easily shift when loaded, seriously affecting its suitability for foundations. Unit may be a source of riprap, decorative rock, and aggregate.

Qls

Landslide deposits (Holocene and Pleistocene)—Highly variable deposits similar in texture and lithology to recent landslide deposits (Qlsr). They range in age from active, slowly creeping landslides to long-inactive middle or early Pleistocene landslides. Unit includes rotational landslides, translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Maximum thickness is probably around 200 ft. Large landslide complex in basalt on the west edge of the quadrangle occurs within sediments interbedded with basalt flows. Large landslide east of the base area for Sunlight ski resort includes a large toreva block (mass of intact bedrock incorporated into a large landslide) that underlies a prominent ridge within the mapped landslide. Within the Mancos Shale strike valley along Fourmile Creek, many of the large landslides in tributary valleys evolved into earthflows downslope. Area may be subject to future landslide activity, however, deeply dissected landslide deposits may be stable.

Deposits may be prone to settlement when loaded. Low-density, fine-grained deposits may be susceptible to hydrocompaction. Local areas within this unit may have shallow groundwater.

Qco

Older colluvium (Pleistocene)—Occurs on ridge lines, drainage divides, and hillslopes on valley walls as erosional remnants of formerly more extensive deposits that were transported primarily by gravity and aided by sheet wash. Texture, bedding, and clast lithology are similar to colluvium (Qc). Unit averages 10 to 25-ft thick, with a maximum thickness about 60 ft. Generally is not subject to significant future colluvial deposition, except where adjacent to eroding hillslopes. Unit may be subject to hydrocompaction, piping, and settlement where fine grained and low in density.

Qlso

Older landslide deposits (Pleistocene and late Tertiary?)—Landslide deposits dissected by erosion that lack distinctive landslide geomorphic features. Older landslide deposits are similar in texture, bedding, sorting, and clast lithology to recent landslide deposits (Qlsr). Type of landslide movement generally is not identifiable due to the eroded character of deposits, although deposit west of the Dakota watergap on Fourmile Creek appears to be similar in origin to the large landslide located about 1,000 ft to the south. Maximum thickness locally may exceed 80 ft. Unit probably is not prone to future landsliding unless it is significantly disturbed by construction activities.

ALLUVIAL AND COLLUVIAL DEPOSITS—

Silt, sand, gravel, and clay in debris fans, stream channels, flood plains, and adjacent hillslopes along tributary valleys. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheet-wash processes are commonly dominant on debris fans, hillslopes, and along the hillslope/valley floor boundary.

Qdfy

Younger debris-flow deposits (Holocene)—Sediments deposited by debris flows, hyperconcentrated flows, mudflows, and sheet wash on active debris fans and in stream channels. Unit ranges from poorly sorted, matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble and cobble gravel in a sandy, clayey silt or silty sand matrix. Frequently it is very bouldery, particularly near fan heads. Distal parts of some fans are characterized by mudflow and sheet wash and tend to be finer grained. Younger debris-flow deposits are locally interfingered or interbedded with modern alluvium adjacent to perennial stream channels. Clasts are mostly angular to subround sedimentary rock and basalt fragments up to about 6 ft in diameter. Maximum thickness is about 50 ft. Original depositional surfaces are usually preserved, except where they have been disturbed by human activities. Area is subject to future debris-flow activity following intense rainstorms, except on distal parts of some fans, where mudflow and sheet-wash processes are dominant. Deposits are prone to settlement, piping, and hydrocompaction where fine grained and low in density, subject to sinkhole development by piping where underlain by cavernous evaporitic rocks, and corrosive if derived from evaporitic rocks.

Qac

Alluvium and colluvium, undivided (Holocene)—Unit is chiefly stream-channel, low-terrace, and flood-plain deposits along valley floors, with colluvium and sheet wash common on valley sides. Deposits of alluvium and colluvium probably are interfingered. Locally includes younger debris-flow deposits. Alluvium is typically composed of poorly to well sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel, but colluvium may range to unsorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt. Clast lithologies are dependant upon type of rock within source area. Thickness is commonly 5 to 20 ft, with its maximum thickness estimated at about 40 ft. Low-lying areas are subject to flooding. Valley sides are prone to sheet wash, rockfall, and small debris flows. Deposits derived from Mancos Shale may contain expansive clays and be susceptible to shrink-swell problems. Fine-grained, low-density deposits may be subject to settlement, piping, and hydrocompaction. Unit is a potential source of sand and gravel.

Qdfm

Intermediate debris-flow deposits (Holocene and late Pleistocene)—Similar in texture and depositional environment to younger debris-flow deposits (Qdfy). Geomorphic character of original depositional surfaces are commonly recognizable, but the surfaces are topographically about 10 to 50 ft above active debris-flow channels. Area is generally not susceptible to future debris-flow activity unless a channel becomes blocked or an unusually large debris flow occurs. Hydrocompaction, piping, and settlement may occur where the deposits are fine grained and have low density.

Qaco

Older alluvium and colluvium, undivided (Holocene? and Pleistocene)—Deposits of alluvium and colluvium that underlie terraces and hillslopes ranging from about 10 to 260 ft above adjacent small perennial, intermittent, and ephemeral streams. Texture, bedding, clast lithology, and sorting are similar to alluvium and colluvium (Qac). Unit locally includes debris-flow deposits. Thickness is as much as 40 feet. Unit overlies oldest terrace alluvium (Qtt) on the hill between Cattle Creek and the Roaring Fork River. Area is subject to active colluvial and sheetwash deposition where adjacent to hillslopes. Unit may be a source of sand and gravel.

Qdfo

Older debris-flow deposits (Holocene? and Pleistocene)—Occur as extensive valley-filling deposits along Fourmile Creek above and below the Dakota water gap and as isolated remnants of debris fans deposited by tributaries to the Roaring Fork River. Unit is texturally similar to younger debris-flow deposits (Qdfy) and is interbedded with fluvial deposits along Fourmile Creek. Boulders within older debris-flow deposits (Qdfo) commonly are 1 to 3 ft in diameter, and occasionally exceed 6 ft. Clasts range from unweathered to moderately weathered. Elevation differences between original depositional surfaces and adjacent modern drainages range from about 20 to 160 ft. Unit is in part age equivalent to intermediate debris-flow deposits (Qdfm). Thickness is generally about 20 to 60 ft, but may locally exceed 150 ft. Deposits west of the Glenwood Springs Airport at the mouth of Fourmile Creek, which overlie oldest terrace deposits (Qtt), have been upwarped and tilted away from the river, probably by evaporitic diapirism. Surface on older debris-flow deposit at the mouth of Fourmile Creek dips abruptly away from the river and also climbs in elevation downriver. East edge of the surface is 20 to 100 ft higher than its western edge, which merges with the valley wall. Northern end of the surface is about 100 ft higher than its southern terminus. Direction of apparent folding is opposite the slope of the original depositional surface, suggesting elevation differences on the surface represent a minimum structural relief for the folding. Where fine grained and low in density, unit may be prone to hydrocompaction, piping, and settlement. It is corrosive when derived from evaporitic bedrock and may be a source of sand and gravel.

QTbg

High-level basaltic gravel (early Pleistocene and late Tertiary)—Caps four large, east-sloping mesas near Fourmile and Freeman Creeks. Unit consists of cobbles, pebbles, and boulders in a slightly indurated matrix of carbonate-rich clayey, sandy silt. Clasts are rounded to subangular, are dominantly basalt with minor amounts of intrusive rocks, quartzite, sandstone, and chert, and are very weathered. Stage III carbonate accumulations are locally common. Deposits are as much as 1,000 to 1,700 ft above Fourmile Creek at their western limit, but are only 300 to 600 ft above the creeks at their eastern extent. Unit probably was deposited in valleys as debris flows, hyperconcentrated flows, and earthflows. Thickness is estimated to range from 10 ft to perhaps as much as 140 ft. Knob on ridgeline leading southeast from Sunlight Peak is mapped as high-level basaltic gravel, but may actually be a flow or intrusive plug of basalt. Unit is deformed by a sackungen-like feature at the top of Sunlight ski area. Original depositional surface of unit is fairly well preserved, but has been displaced as much as 70 to 90 ft by numerous parallel, northwest-trending, bedding plane faults. Unit may be difficult to excavate where large boulders are present. It may be a source of riprap or aggregate.

EOLIAN DEPOSITS—Silt, sand, and clay deposited by wind on level to gently sloping surfaces.

Qlo

Loess (late and middle? Pleistocene)—Slightly clayey, sandy silt and silty, very fine to very fine sand deposited by wind and preserved on level to gently sloping surfaces. Typically is unstratified, friable, and plastic or slightly plastic when wet. Sand grains are sometimes frosted. Thickness ranges from about 5 to 20 ft. Deposition occurred during at least two periods of eolian activity. Fairer and others (1993) mapped a single sheet of loess as occurring on deposits equivalent to younger and intermediate terrace alluvium (Qty and Qtm) in the Storm King Mountain quadrangle immediately west of the Glenwood Springs quadrangle, but mappable deposits of loess (minimum thickness of 5 ft) were not identified overlying these units on this quadrangle. At least one and probably multiple sheets of loess overlie older terrace deposits (Qto) along the east edge of the quadrangle and basalt (Tb) in the northeast part of the quadrangle. Mapped distribution of loess is very approximate due to the poor geomorphic expression of loess. Fairer and others (1993) suggest most loess was derived from floodplain sediments of the Colorado River and its tributaries, but recognize that outcrops of Tertiary siltstone and mudstone in the Piceance Basin and extensive areas of exposed sandstone in the Canyonlands area of southeastern Utah may also have served as source areas for loess deposited in this part of Colorado. Low-density loess may be prone to settlement when loaded and perhaps to piping and hydrocompaction when wetted. It is highly erodible.

UNDIFFERENTIATED DEPOSITS

Q

Undifferentiated surficial deposits (Quaternary)—Shown only on cross section.

BEDROCK

Tb

Basalt (Miocene)—Multiple flows of tholeiitic, alkaline and subalkaline basalt and trachybasalt that locally contain abundant phenocrysts of olivine. Locally includes slightly indurated sediments. Flow rocks range from massive to highly vesicular, with occasional amygdules of calcite and iron-rich clay. Groundmass is dominantly plagioclase and pyroxene, with lesser amounts of olivine, glass, pigeonite, augite, and magnetite. Trace minerals include apatite, iddingsite, and hematite. Phenocrysts are generally olivine or rarely plagioclase. Interbedded sediments (Ts) are mapped separately where contacts are readily identifiable. Sediments range from sandy cobble gravel deposited by ancestral Roaring Fork River to matrix-supported gravelly, clayey silt. Maximum exposed thickness is about 209 ft on Sunlight Mesa and about 225 ft in the cliffs northeast of the Roaring Fork River, but is thinner in most other areas.

Includes rocks of Group 2 and Group 3 of Larson and others (1975), which were not differentiated for this study. Basalt flows on Sunlight Mesa, which extend north and east from Sunlight Peak to near the Roaring Fork River, were classified by Larson and others (1975) as Group 2 rocks and believed to range in age from about 9–14 Ma, although no dates were obtained from the basalt on Sunlight Mesa. A whole rock sample we collected from the lowermost exposed flow in a sequence of perhaps seven or eight stacked flows with no interbedded sediments (K. Hon, 1995, oral commun.) on the southern edge of Sunlight Mesa was dated using $^{40}Ar/^{39}Ar$ (L. Snee, 1996, written commun.). The age spectra analysis for this sample is disturbed and indicates significant ^{40}Ar loss. An isochron analysis yields an age of 10.4 ± 0.1 Ma and should be viewed as a minimum age.

Basalt flows between the Roaring Fork River and Spring Valley in the northeast part of the quadrangle were mapped by Larson and others (1975) as Group 3 rocks and thought to have an age of around 8 Ma. Rocks near Catherine and El Jebel about 5 mi and 8 mi east of the quadrangle may be correlative with basalt in the northeast part of this quadrangle. These rocks yielded whole rock K–Ar ages of 8.68 ± 0.4 Ma and 7.86 ± 0.4 Ma (Larson and others, 1975). Kirkham and others (1995a) report a whole rock $^{40}Ar/^{39}Ar$ age of 22.4 ± 0.3 Ma for basalt exposed at the northwest end of Spring Valley that occurs at about the same elevation as the basalt in the northeast part of the quadrangle. A sample we collected from the lowermost basalt flow in the cliff northeast of the Roaring Fork River has a whole rock $^{40}Ar/^{39}Ar$ age of 9.64 ± 0.05 Ma based on its age spectra (L. Snee, 1996, written commun.).

Unit is frequently a source of rockfall debris where exposed in steep cliffs. Matrix-supported interflow sediments are prone to landsliding. Unit is a potential source of high quality riprap and aggregate.

Ts

Interflow sedimentary deposits (Miocene)— Fluvial sediments interbedded with basalt flows. Unit is mapped only where contacts are readily identifiable on northeast side of Roaring Fork River. It consists of clast-supported silty, sandy pebble and cobble gravel and matrix-supported gravelly, sandy silt that is slightly indurated. Clasts are well to moderately well rounded and chiefly composed of quartzite, sandstone, chert, quartz, and basalt with lesser amounts of granodiorite, quartz monzonite, and granite. Clast lithology indicates this unit was deposited by an ancestral Roaring Fork River (Bruce Bryant, 1996, oral commun.). Clasts are very highly weathered; many are disintegrated. Maximum thickness is about 75 ft. Clast-supported interflow sedimentary deposits are a potential source of sand and perhaps gravel.

Tw

Wasatch Formation (Eocene and Paleocene)—Interbedded and lenticular tan, yellowish to reddish brown, and reddish purple claystone, siltstone, sandstone, and conglomerate which unconformably overlie the Upper Cretaceous Mesaverde Group. Johnson and May (1980) suggest the time gap represented by the unconformity extends from late Campanian or early Maestrichtian to late Paleocene. Unit is very poorly exposed in quadrangle, which prevents recognition of individual members. Only good exposure of formation is in Fourmile Creek where purplish, conglomeratic sandstone and pebbly to slightly cobbly conglomerates of basal Wasatch crop out. Clasts are predominantly composed of Tertiary igneous rocks and chert. Formation thickness is probably around 5,000 to 6,000 ft. The Wasatch Formation was deposited in nonmarine lacustrine, flood-plain, and high-energy fluvial environments. It is highly susceptible to landsliding.

MESAVERDE GROUP (Upper Cretaceous)

Kmvu

Upper Williams Fork Formation—Lenticular sandstone, siltstone, shale, and limestone with minor coal beds. Shale, sandstone, siltstone, and coal beds of the Paonia Shale Member comprise lower 500 ft of unit. Coal beds in the Paonia Shale are correlative with the Coal Ridge coal zone. Interval of rocks above the Paonia Shale Member consists of thin, coarse-grained to conglomeratic, channel sandstone, siltstone, shale, and lenticular coal beds. Johnson and May (1980) describe a white, kaolitinic, frequently conglomeratic interval at the top of the Mesaverde Group present in much of the Piceance Basin as the Ohio Creek Member, but it was not recognized in this quadrangle. Total thickness ranges from about 2,000 to 4,000 ft. Most, if not all, of this unit was deposited in a nonmarine environment on an upper deltaic plain (Collins, 1970). Historically the upper Williams Fork Formation has been a minor source of coal (Boreck and Murray, 1979).

Kmvb **Bowie Shale Member of lower Williams Fork Formation**—Shale, sandstone, siltstone, coal, and occasional algal limestone. Includes in ascending order the 90 to 100-ft-thick Cameo-Wheeler-Fairfield coal zone, which consists of shale, sandstone, and coal; a 450-ft-thick interval of shale, sandstone, and siltstone, the 70-ft-thick, gray middle sandstone member; a 160-ft-thick sequence of shale and siltstone; and the 50-ft-thick, gray, upper sandstone member. Both the upper and middle sandstone members form prominent outcrops in the quadrangle. Locally some coal beds have ignited, causing oxidation of adjacent beds. The Bowie Shale Member was deposited in back-beach, fresh to brackish-water peat swamps with cyclical influxes of marine conditions (Collins, 1976). Historically it has produced most of the coal mined in the quadrangle.

Kmvr **Rollins Sandstone Member of lower Williams Fork Formation**—Buff, gray, and white, medium-grained feldspathic sandstone locally containing intertongued shale and siltstone. Reddish colors are locally present, a result of varying iron-oxide content and of oxidation due to burning of coal beds. Unit frequently is calcite-cemented, which upon weathering may produce a thin (less than 0.1 inch) coating of white carbonate on outcrops. Although the Rollins Sandstone Member is commonly a marker horizon that often forms prominent cliffs along much of the southern Grand Hogback, it is poorly exposed in the quadrangle. Thickness averages about 60 ft. It was deposited as a shoreline sandstone in a prograding bar, beach, and delta-front complex (Collins, 1976). The Rollins Sandstone Member has recently been re-assigned to the lower Williams Fork Formation from the uppermost Iles Formation, based on its genetic relationships to overlying coal beds (Tyler and McMurry, 1995).

Kmt **Mancos tongue of Iles Formation**—Light to dark gray, carbonaceous, calcareous shale with thin beds of bentonite, siltstone, and sandstone. Thickness is about 700 ft in the valley of Fourmile Creek, but it thins northward. The Mancos tongue of the Iles Formation was deposited in a marine environment during a major transgression of the Cretaceous sea. It is prone to landsliding on moderate to steep slopes.

Kmvc **Cozzette Sandstone Member of Iles Formation**—Buff to tan, well-sorted, upward-coarsening sandstone with subconchoidal fracture. Unit is about 53-ft thick, and it reportedly includes thin coal beds of the Black Diamond coal zone, but none were observed in the quadrangle. It was deposited in a wave-dominated shoreline or coastal setting during cyclical retreat of the Cretaceous sea.

Km **Mancos Shale (Upper Cretaceous)**—Dominantly light to dark gray, carbonaceous, calcareous shale with thin beds of bentonite, siltstone, and sandstone. Total thickness ranges from about 4,500 to 5,100 ft. A 900-ft-thick calcareous shale zone equivalent to the Niobrara Formation occurs at the base of the unit (Murray, 1966; Tweto and others, 1978). Upper part of unit may include sandstones equivalent to the Corcoran and Sego Sandstones, but these were not recognized in the quadrangle. Unit is very poorly exposed and frequently covered by surficial deposits. The Mancos Shale was deposited in low-energy, off-shore, marine environments. Unit is very prone to landsliding and is susceptible to shrink-swell problems where it contains expansive clays.

Kfm **Frontier Sandstone and Mowry Shale, undivided (Upper Cretaceous)**—Includes the Mowry Shale and overlying Frontier Sandstone. Mowry Shale is a siliceous, gray to black shale about 50 to 70-ft thick which contains fish scales. Frontier Sandstone is a yellowish brown, calcareous, fine-grained sandstone about 300-ft thick. Mowry Shale had previously been considered Lower Cretaceous, but Molenaar and Wilson (1990) report evidence that it is Upper Cretaceous. Unit is generally poorly exposed and frequently covered by surficial deposits. It was probably deposited in marine and coastal environments (Molenaar and Wilson, 1990). Unit may be prone to landsliding.

Kd **Dakota Sandstone (Lower Cretaceous)**—Light gray to tan, medium to very coarse-grained, quartzose sandstone and conglomeratic sandstone interbedded with carbonaceous siltstone, sandstone, and shale. Sandstone commonly is well sorted and silica cemented, with angular to subrounded sand grains. Conglomeratic clasts generally are pebble-sized chert and quartz. Unit includes one to three fairly continuous sandstone beds that occasionally are overlain by lenses of conglomeratic sandstone. Thickness ranges from about 90 to 175 ft. Unit is conformable with overlying Mowry Shale. Upper contact is placed at the top of the uppermost quartzose sandstone beneath the Mowry. Sandstone beds within the formation are generally well exposed and form conspicuous cliffs. The Dakota Sandstone was deposited in a transgressive environment at or near the shoreline of a lower coastal plain and in shallow marine embayments (Fairer and others, 1993).

Jm

Morrison Formation (Upper Jurassic)—Pale green and maroon mudstone and shale with thin beds of silty sandstone in lower part that may be equivalent to Salt Wash Member in nearby areas (Murray, 1966). It includes gray limestone beds up to about 10-ft thick which contain abundant charophytes (Peck, 1957). Thickness is variable, but averages about 400 to 500 ft. The Morrison Formation is very poorly exposed in the quadrangle and is frequently covered by surficial deposits. Contact with overlying Dakota Sandstone is sharp and unconformable, but is difficult to precisely locate except where well exposed. Contact is drawn below the quartose sandstone and carbonaceous beds of the Dakota. It probably was deposited in a lacustrine-dominated, fluvio-lacustrine environment (Fairer and others, 1993).

Je

Entrada Sandstone (Upper Jurassic)—Light gray to light orange, medium to very fine-grained, well sorted, cross-bedded sandstone. Sand fraction is mostly subrounded to well rounded quartz grains. Thickness averages about 50 to 100 ft, but it may vary significantly over a short distance. The Entrada Sandstone is poorly exposed in the quadrangle. It occasionally forms a smooth, slick outcrop, but is usually covered by surficial deposits. Contact with overlying Morrison Formation is sharp and conformable. Cross-bed sets are large scale and are interpreted as resulting from eolian processes in extensive dune fields (Fairer and others, 1993). Basal few inches may include pebbles and very coarse sand comprised of chert and quartz thought to have accumulated as an eolian lag deposit on the Chinle Formation.

ȾPcs

Chinle and State Bridge Formations, undivided (Triassic and Permian)—Includes Lower Triassic? and Permian State Bridge Formation and overlying Upper Triassic Chinle Formation. State Bridge is pale red, grayish red, and reddish brown, micaceous siltstone, clayey siltstone, and shale with minor very fine-grained sandstone. Chinle is comprised of thin, even bedded, and structureless red beds consisting of dark reddish brown, orangish red, and purplish red, calcareous siltstone and mudstone with occasional thin lenses of light purplish red and gray limestone and limestone-pebble conglomerate. Both formations are very poorly exposed in the quadrangle, but an excellent exposure occurs along South Canyon Creek several miles northwest of the quadrangle. At this location the State Bridge Formation includes the South Canyon Creek Dolomite Member (Bass and Northrup, 1950; Stewart and others, 1972b), and the Chinle has a thin basal sandstone, the Gartra Member (Dubiel, 1992). Neither member was recognized on this quadrangle. Combined thickness of the two formations is only 150 to 200 ft, considerably less than in South Canyon. Freeman (1971a) reports that the State Bridge thickens dramatically to the east and southeast. Contact with overlying Entrada Sandstone is sharp and unconformable. Dubiel (1992) suggests the upper Chinle red siltstone beds are lateral-accretion and flood-plain deposits, whereas the basal Gartra Member was deposited as active channel-fill and valley-fill deposits. State Bridge Formation was mainly deposited in a marginal-marine, fluvio-lacustrine environment dominated by lacustrine processes.

PIPm

Maroon Formation (Lower Permian and Pennsylvanian)—Mainly red beds of sandstone, conglomerate, siltstone, mudstone, and shale with minor, thin beds of gray limestone. Includes Schoolhouse Member at top of formation (Johnson and others, 1990; Bass and Northrop, 1963; Stewart and others, 1972b). Conglomerate contains pebble- and cobble-sized clasts. Commonly is arkosic and very micaceous. Schoolhouse Member consists of light gray to greenish black, grayish red, and pale reddish brown, fine-grained, feldspathic sandstone and conglomeratic sandstone. It contains locally abundant interstitial and grain-coatings of solid hydrocarbon (Bass and Northrup, 1963; Johnson and others, 1990). Total thickness is about 3,000 to 5,000 ft, including the 125 to 150-ft-thick Schoolhouse Member. Contact with overlying State Bridge Formation is sharp. Johnson and others (1988) suggest the contact is an angular unconformity. Clastics in the lower part of the Maroon Formation were deposited in basin-margin, alluvial fan and fan-delta environments in the Central Colorado Trough, while the limestones were deposited in shallow marine environments (Johnson and others, 1990). The upper part of the formation was deposited in the Central Colorado Trough in fluvial and eolian environments (Johnson and others, 1988). Formation is prone to rockfall where exposed in steep cliffs.

IPe

Eagle Valley Formation (Middle Pennsylvanian)—Interbedded reddish brown, gray, reddish gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks. Unit represents a stratigraphic interval in which the red beds of the Maroon Formation grade into and intertongue with the dominantly evaporitic rocks of the Eagle Valley Evaporite. It includes rock types of both formations. Thickness is variable, ranging from about 500 to 1,500 ft. The Eagle Valley Formation is conformable and intertonguing with the overlying Maroon Formation and underlying Eagle Valley Evaporite. Contact with Maroon Formation is placed at top of uppermost evaporite bed or light-colored clastic bed. It was deposited in the Central Colorado Trough on the margin of an evaporite basin in fluvial, eolian, and marine environments. Unit may be susceptible to subsidence and sinkholes. Surficial deposits derived from it are prone to compaction, piping, and corrosion problems where evaporitic rocks occur near land surface.

IPee

Eagle Valley Evaporite (Middle Pennsylvanian)—Sequence of evaporitic rocks consisting mainly of massive to laminated gypsum, anhydrite, and halite, interbedded with light colored mudstone and fine-grained sandstone, thin carbonate beds, and black shale. Basal part of formation may include the Gothic Formation (Langenheim, 1954). Beds commonly are intensely folded, faulted, and ductily deformed by diapirism, flowage, load metamorphism, hydration of anhydrite, and Laramide tectonism (Mallory, 1971). Thickness ranges from about 1,200 ft to perhaps 9,000 ft (Mallory, 1971), where it is tectonically thickened along the axis of the Cattle Creek Anticline. The formation is generally poorly exposed except in recent alluvial cuts, in man-made exposures, or in diapirs. Occurrence of prominent gypsum outcrops in diapirs may be evidence of recent or on-going diapiric activity. Contact with overlying Eagle Valley Formation is both conformable and intertonguing and is defined as the base of the lowest red bed within the Eagle Valley Formation.

The Eagle Valley Evaporite was deposited in a marine evaporitic basin known as the Eagle Basin that formed as the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1989) recognized multiple transgressive-regressive sedimentary cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment rather than in a sabkha. Formation may include eolian deposits similar to those reported by Schenk (1987). It contains cavernous voids up to several feet in diameter and tens of feet deep that may have resulted from near-surface dissolution of halite. It is prone to development of sinkholes into which overlying surficial deposits may be piped. Surficial deposits derived from the Eagle Valley Evaporite may be subject to compaction, settlement, and corrosion problems.

Presence of a thick halite sequence near the mouth of Cattle Creek is reported by Mallory (1966) based on the Shannon Oil Company Rose no. 1 well, which encountered 60 ft of alluvial gravel, 2,065 ft of gypsum, anhydrite, and siltstone, and 935 ft of predominantly halite (unpublished lithologic log by American Stratigraphic Company. Drilling stopped in halite; therefore the total halite thickness is not known. The well was spudded near the axis of the Cattle Creek Anticline. The mapped location of the anticline is based upon projections of dips in bedrock exposed on both sides of the Roaring Fork Valley.

The Cattle Creek Anticline has been modified during the Neogene, as evidenced by folded Pleistocene terraces in the Roaring Fork Valley and by structural sagging and tilting of basalt flows. Flowage of evaporitic rocks during the Neogene was probably caused by differential loading that occurred as the Roaring Fork River downcut into the Maroon Formation and underlying rocks. As the valley was carved by erosion, overburden pressures on the evaporitic rocks decreased, allowing thick, ductile beds to flow towards the valley from adjacent areas. Diapiric upwelling, subsidence due to dissolution of halite and gypsum, and expansion resulting from hydration of anhydrite to gypsum have deformed Pleistocene terrace deposits. We believe Spring Valley is a large sag that was created as evaporitic rocks flowed from beneath it. Numerous examples of other sags and faults related to flowage of underlying evaporitic rocks are present in basalt on both sides of the Roaring Fork Valley. Axis of a late Pleistocene and Holocene? anticline is depicted on the geologic map; its location closely parallels the modern channel of the Roaring Fork River, where bedrock overlying the halite is thinnest.

ECONOMIC GEOLOGY

Coal resources have been exploited from two members of the Upper Cretaceous Mesaverde Group in the quadrangle. Most historic production has come from the Bowie Shale Member of the Williams Fork Formation. Four coal seams, in ascending order the A,B, C, and D, have been mined from this sequence and are collectively termed the Cameo-Wheeler-Fairfield coal zone. Coal beds in this zone are moderately continuous and are up to about 10-ft thick, although most are thinner. Limited coal production has also been realized from coal beds occurring in the Paonia Shale Member of the Williams Fork Formation, stratigraphically above the Bowie Shale. Coal beds in this sequence have been correlated with coals of the Coal Ridge coal zone. Coal seams in this zone are much less continuous and thinner than those of the Cameo-Wheeler-Fairfield zone. Only a small percentage of the total coal production from the quadrangle has come from coal beds in the Paonia Shale Member.

A reported 2,227,885 tons of bituminous coal have been produced in the quadrangle (Boreck and Murray, 1979). Of this amount well over half (1,400,000 tons) was mined at the Sunlight/Midland mine along Fourmile Creek. The remainder is from 5 or 6 smaller mines north of Fourmile Creek. Mesaverde coal mined in the Cattle Creek quadrangle is bituminous in grade with high reported heat values (12,000–13,000 BTUs/lb). Chemical analyses of coals from the quadrangle average 4 percent ash, 39 percent volatile matter, 52 percent fixed carbon, 4 percent moisture, and 1 percent sulfur (Boreck and Murray, 1979).

In 1960 Shannon Oil Company drilled the Rose No. 1 well in Section 12, T. 7 S., R. 89 W. near the mouth of Cattle Creek to test Ordovician rocks for oil. The well was drilled to a depth of 3,070 ft and encountered thick sequences of halite, gypsum, and anhydrite. It was plugged and abandoned before reaching its objective, and reportedly did not encounter any oil or gas. The evaporite dome or diapiric anticline into which it was drilled may have potential for underground storage of gas. The 5,820-ft-deep TRW Sunlight Federal No. 2 well was drilled in 1986 in Section 32, T. 7 S., R. 89 W. to test the Mesaverde Group for coalbed methane. It tested the lower Cameo coal zone at a depth of 4,768 to 4,816 ft, but was plugged and abandoned.

WHOLE-ROCK ANALYSES OF THE CATTLE CREEK QUADRANGLE

PERCENT

Sample ID	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	Cr_2O_3	LOI*
CC118	51.4	14.7	7.32	6.72	2.61	1.28	11.2	0.14	1.36	0.32	0.03	0.15
CC122	48.8	14.3	7.26	6.88	2.96	2.32	11.1	0.15	1.73	0.64	0.03	0.25
CC130	49.4	14.4	7.14	6.99	2.69	1.69	11.6	0.14	1.50	0.48	0.03	1.20
CC132	49.5	14.4	7.50	7.30	2.76	1.14	12.1	0.14	1.54	0.42	0.03	1.30
CC140	49.6	14.5	7.59	7.83	2.71	1.39	12.0	0.15	1.34	0.29	0.04	0.00

* Loss on ignition

PPM

Sample ID	Rb	Sr	Y	Zr	Nb	Ba
CC118	21	456	22	130	<10	535
CC122	49	765	34	190	20	1030
CC130	43	542	31	170	18	664
CC132	18	531	25	145	12	580
CC140	33	411	27	144	<10	494

SAMPLE DESCRIPTIONS

CC118: An upper flow in Sunlight volcanic sequence; NW 1/4 SE 1/4 NW 1/4 of Section 31, T. 6 S., R. 89 W.

CC122: Lower flow of upper Spring Valley volcanic sequence; SE 1/4 NE 1/4 SW 1/4 of Section 36, T.6 S., R. 89 W.

CC130: Flow within middle of lower Spring Valley volcanic sequence about 82 ft above base of sequence; NE 1/4 SW 1/4 NW 1/4 SW 1/4 of section 36, T.6 S., R. 89 W.

CC132: Lowest flow in lower Spring Valley volcanic sequence; SE 1/4 SW 1/4 NW 1/4 SW 1/4 of Section 36, T. 6 S., R. 89 W.

CC140: Lowest exposed flow in Sunlight volcanic sequence; SW 1/4 SE 1/4 SE 1/4 NE 1/4 of Section 30, T. 7 S., R. 89 W.

REFERENCES

Bass, N.W., and Northrop, S.A., 1950, South Canyon Creek Dolomite Member, a unit of Phosphoria age in Maroon Formation near Glenwood Springs, Colorado: American Association of Petroleum Geologists Bulletin, v. 34, no. 7, p. 1540–1551.

_____, 1963, Geology of Glenwood Springs quadrangle and vicinity, northwestern Colorado: U.S. Geological Survey Bulletin 1142-J, 74 p.

Boreck, D.L., and Murray, D.K., 1979, Colorado coal reserve depletion data and coal mine summaries: Colorado Geological Survey Open-File Report 79-1, 65 p.

Brill, K.G., Jr., 1944, Late Paleozoic stratigraphy, west-central and northwestern Colorado: Geological Society of America Bulletin, v. 55, no. 5, p. 621–656.

Bryant, Bruce, 1979, Geology of the Aspen 15-minute quadrangle, Pitkin and Gunnison Counties, Colorado: U.S. Geological Survey Professional Paper 1073, 146 p.

Carroll, C.J., Kirkham, R.M., and Stelling, P.L., 1996, Geologic map of the Center Mountain quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-2 (in preparation).

Collins, B.A., 1976, Coal deposits of the Carbondale, Grand Hogback, and southern Danforth Hills coal fields, eastern Piceance Basin, Colorado: Colorado School of Mines Quarterly, v. 71, no. 1, 138 p.

DeVoto, R.H., Bartleson, B.L., Schenk, C.J., and Waechter, N.B., 1986, Late Paleozoic stratigraphy and syndepositional tectonism, northwestern Colorado, *in* Stone, D.S., ed., New interpretations of northwest Colorado geology: Rocky Mountain Association of Geologists, 1986 symposium, p. 37–49.

Dubiel, R.F., 1992, Sedimentology and depositional history of the Upper Triassic Chinle Formation in the Uinta, Piceance, and Eagle Basins, northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 1787-W, 25 p.

Ellis, M.S., and Freeman, V.L., 1984, Geologic map and cross sections of the Carbondale 30′ by 60′ quadrangle, west-central Colorado: U.S. Geological Survey Coal Investigations map C-97A.

F.M. Fox & Associates, 1974, Roaring Fork and Crystal Valleys—An environmental and engineering geology study, Eagle, Garfield, Gunnison, and Pitkin Counties, Colorado: Colorado Geological Survey Environmental Geology 8, 64 p.

Fairer, G.M., Green, M.W., and Shroba, R.R., 1993, Preliminary geologic map of the Storm King Mountain quadrangle, Garfield, County, Colorado: U.S. Geological Survey Open-File Report 93-320.

Franczyk, K.J., Fouch, T.D., Johnson, R.C., Molenaar, C.M., and Cobban, W.A., 1992, Cretaceous and Tertiary paleogeographic reconstructions for the Uinta-Piceance Basin study area, Colorado and Utah: U.S. Geological Survey Bulletin 1787-Q, p. Q1-Q37.

Freeman, V.L., 1971a, Stratigraphy of the State Bridge Formation in the Woody Creek quadrangle, Pitkin and Eagle Counties, Colorado: U.S. Geological Survey Bulletin 1324-F, p. F1–F17.

_____, 1971b, Permian deformation in the Eagle Basin, Colorado: U.S. Geological Survey Professional Paper 750-D, p. D80–D83.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p. 347–360.

Green, M.W., Fairer, G.M., and Shroba, R.R., 1993, Preliminary geologic map of the New Castle quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report 93-310.

Grout, M.A., Abrams, G.A., Tang, R.L., Hainsworth, T.J., and Verbeek, E.R., 1991, Late Laramide thrust-related and evaporite-domed anticlines in the southern Piceance Basin, northeastern Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 75, no. 2, p. 205–218.

Izett, G.A., and Wilcox, R.E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek ash beds (Pearlette family ash bed) of Pliocene and Pleistocene age in the western United States and southern Canada: U.S. Geological Survey Miscellaneous Investigations Map I-1325.

Johnson, J.G., 1971, Timing and coordination of orogenic, epeirogenic, and eustatic events: Geological Society of America Bulletin, v. 82, no. 12, p. 3263–3298.

Johnson, R.C., and May, F., 1980, A study of the Cretaceous-Tertiary unconformity in the Piceance Creek Basin, Colorado: The underlying Ohio Creek Formation (Upper Cretaceous) redefined as a member of the Hunter Canyon or Mesaverde Formation: U.S. Geological Survey Bulletin 1482-B, p. B1–B27.

Johnson, S.Y., 1987, Sedimentology and paleogeographic significance of six fluvial sandstone bodies in the Maroon Formation, Eagle Basin, northwest Colorado: U.S. Geological Survey Bulletin 1787-A, p. A1–A18.

Johnson, S.Y., Schenk, C.J., Anders, D.L., and Tuttle, M.L., 1990, Sedimentology and petroleum occurrence, Schoolhouse Member, Maroon Formation (Lower Permian), northwest Colorado: American Association of Petroleum Geologists Bulletin, V. 74, p. 135–150.

Johnson, S.Y., Schenk, C.J., and Karachewski, J.A., 1988, Pennsylvanian and Permian depositional cycles in the Eagle Basin, northwest Colorado, *in* Holden, G.S., ed., Geological Society of America field trip guidebook: Colorado School of Mines, Professional Contributions 12, p. 156–175.

Kirkham, R.M., Streufert, R.K., and Cappa, J.A., 1995a, Geologic map of the Glenwood Springs quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-file Report 95-3.

_____, 1995b, Geologic map of the Shoshone quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-file Report 95-4.

Kirkham, R.M., Bryant, Bruce, Streufert, R.K., and Shroba, R.R., 1996, Field trip guidebook on the geology and geologic hazards of the Glenwood Springs area, Colorado: Colorado Geological Survey (in preparation)

Langenheim, R.L., Jr., 1954, Correlation of Maroon Formation in Crystal River Valley, Gunnison, Pitkin, and Garfield Counties, Colorado: American Association of Petroleum Geologists Bulletin, v. 38, no. 8, p. 1748–1779.

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

Lincoln-Devore Testing Laboratory, 1976, Garfield County Land Use Studies: unpublished series of maps prepared for Garfield County Land Use Planning Department.

Lovering, T.S., and Mallory, W.W., 1962, The Eagle Valley Evaporite and its relation to the Minturn and Maroon Formation, northwest Colorado: U.S. Geological Survey Professional Paper 450-D, p. D45–D48.

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

Mallory, W.W., 1966, Cattle Creek Anticline, a salt diapir near Glenwood Springs, Colorado: U.S. Geological Survey Professional Paper 550-B, p. B12–B15.

_____, 1971, The Eagle Valley Evaporite, northwest Colorado—a regional synthesis: U.S. Geological Survey Bulletin 1311-E, 37 p.

_____, 1975, Middle and southern Rocky Mountains, northern Colorado Plateau, and eastern Great Basin region, *in* McKee, E.D., and Crosby, E.J., eds. Paleotectonic investigations of the Pennsylvanian system in the United States, Part I: Introduction and regional analyses of the Pennsylvanian system: U.S. Geological Survey Professional Paper 853, p. 265–278.

Molenaar, C.M., and Wilson, B.W., 1990, The Frontier Formation and associated rocks of northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787-M, p. M1–M21.

Murray, F.N., 1966, Stratigraphy and structural geology of the Grand Hogback Monocline, Colorado: University of Colorado, Ph.D. dissertation, Boulder, Colorado.

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

Peck, R.E., 1957, North American Mesozoic Charophyta: U.S. Geological Survey Professional Paper 294-A, p. 1–44.

Perry, W.J. Jr., Grout, M.A., Hainsworth, T.J., and Tang, R.L., 1988, Wedge model for late Laramide basement-involved thrusting, Grand Hogback Monocline and White River Uplift, western Colorado [abstr.]: Geological Society of America Abstracts with Program, v. 20, no. 7, p. 384–385.

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

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

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

Poole, F.G., 1954, Geology of the southern Grand Hogback area, Garfield and Pitkin Counties, Colorado: University of Colorado, M.S. thesis, 128 p.

Poole, F.G., and Stewart, J.H., 1964, Chinle Formation and Glen Canyon Sandstone in northeastern Utah and northwestern Colorado: U.S. Geological Survey Professional Paper 501-D, p. D30–D39.

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

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

Schenk, C.J., 1987, Sedimentology of an eolian sandstone from the Middle Pennsylvanian Eagle Valley Evaporite, Eagle Basin, northwest Colorado: U.S. Geological Survey Bulletin 1787-B, p. 19–28.

_____, 1989, Sedimentology and stratigraphy of the Eagle Valley Evaporite (Middle Pennsylvanian), Eagle Basin, Colorado: University of Colorado at Boulder, Ph.D. dissertation.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

_____, 1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p.

Soule, J.M., and Stover, B.K., 1985, Surficial geology, geomorphology, and general engineering geology of parts of the Colorado River Valley, Roaring Fork River Valley, and adjacent areas, Garfield County Colorado: Colorado Geological Survey Open-File Report 85-1.

Stover, B.K., 1986, Geologic evidence of Quaternary faulting near Carbondale, Colorado, with possible associations to the 1984 Carbondale earthquake swarm, *in* Rogers, W.P., and Kirkham, R.M., eds., Contributions to Colorado Seismicity and tectonics-A 1986 update: Colorado Geological Survey Special Publication 28, p. 295–301.

Tyler, R., and McMurry, R.G., 1995, Genetic stratigraphy, coal occurrence, and regional cross section of the Williams Fork Formation, Mesaverde Group, Piceance Basin, northwestern Colorado: Colorado Geological Survey Open-File Report 95-2, 42 p.

Tweto, Ogden, Moench, R.H., and Reed, J.C., 1978, Geologic map of the Leadville 1° x 2° quadrangle, northwest Colorado: U.S. Geological Survey Miscellaneous Investigations map I-999.

Unruh, J.R., Wong, Bott, J.D., Silva, W.J., and Lettis, W.R., 1993, Seismotectonic evaluation, Rifle Gap Dam, Silt Project, Ruedi Dam, Fryingpan-Arkansas Project, northwestern Colorado: unpublished report prepared by William R. Lettis & Associates and Woodward-Clyde Consultants for U.S. Bureau of Reclamation, 154 p.