Map Series 31

Geologic Map of the Glenwood Springs Quadrangle, Garfield County, Colorado

By
Robert M. Kirkham, Randall K. Streufert, and James A. Cappa

Description of Map Units, Economic Geology, Geochemical Analyses, and References

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than about 5 ft thick. 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 clast weathering and soil development. Correlation of terraces and interpretations of their ages is hindered by their discontinuous distribution. Some terraces are deformed by salt diapirism and/or collapse into dissolution caverns in underlying evaporites, further complicating correlation of terraces.

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)**—Fill and waste rock deposited by man during construction and mining projects. Composed mostly of silt, sand, and rock fragments, but may include construction materials. Remnant debris from the coke ovens west of the Glenwood Springs Municipal Airport is also mapped as artificial fill. Maximum thickness about 50 ft. Poorly compacted fill may be subject to settlement when loaded.

ALLUVIAL DEPOSITS—Silt, sand, and gravel deposited in stream channels, flood plains, glacial outwash terraces, debris fans, and sheetwash areas along the Colorado River, Roaring Fork River, and their tributaries.

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Includes modern alluvium and other deposits along the Roaring Fork and Colorado Rivers, adjacent flood-plain deposits, and low-terrace alluvium that is as much as about 15 ft above modern stream level. Unit is mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel in a sandy or silty matrix. It is locally interbedded with and commonly overlain by sandy silt and silty sand. Unit is poorly to moderately well sorted and is moderately well to well bedded. Clasts are well rounded to subangular. Their varied lithology reflects the diverse types of bedrock within their provenance. Unit may locally include organic-rich deposits or lacustrine clay or silt. It may be interfingered with younger debris-flow deposits where the distal ends of fans extend into modern river channels. Maximum thickness is about 154 ft in Glenwood Canyon (Bowen, 1988). 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 commonly is a good source of sand and gravel.

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Includes deposits locally derived from weathered bedrock and surficial materials which are transported predominantly by sheetwash and deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, or in basinal areas. Common on gentle to moderate slopes underlain by limestone, shale, basalt, red beds, and landslide deposits. Sheetwash 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 slackwater deposits in closed depressions. Maximum thickness is probably about 25 ft. Area is subject to future sheetwash 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 19 to 56 ft above modern stream level. Locally the unit may be capped by a single, thin loess sheet. It consists mostly of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix that was deposited as glacial outwash. Fine-grained overbank deposits are locally present. Clasts are mainly subrounded to rounded and are comprised of a variety of lithologies reflecting the diverse types of bedrock found in their drainage basins. Clasts are generally unweathered or only slightly weathered. Maximum thickness may locally exceed 100 ft, but is much thinner in other areas.

At the rest area on I-70 in West Glenwood Springs, the top of the unit is about 19 ft above the Colorado River and is overlain by a tufa deposit which includes an interbedded thin, 0.1 to 0.3-ft thick layer of organic-rich clayey sandy silt and peat. A conventional radiocarbon age of 12,410 ± 60 years BP was obtained on the peat (Trimble, 1995, written commun.; sample no. USGS-3544), providing a minimum age for this terrace. Unit includes deposits in terrace T7 in the Carbondale-Glenwood Springs area described by Piety (1981). It may also correlate with terrace A of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Bryant and Shroba (1997) 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 to 35 ka. Unit is a good source of sand and gravel.

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Composed of stream alluvium underlying terraces about 58 to 95 ft above modern stream level. Locally the unit is capped by a single, thin loess sheet. It consists mostly of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix that was deposited as glacial outwash. Fine-grained overbank deposits 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 are generally only slightly weathered at shallow depths. Thickness averages about 20 to 50 ft, with a maximum thickness probably around 100 ft.

Unit correlates with deposits in terrace T6 of the Carbondale-Glenwood Springs area of Piety (1981). It may correlate with terrace B deposits of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of Bryant and Shroba (1997) in the Storm King Mountain quadrangle. Unit is probably equivalent to outwash from the Pinedale glaciation, which Richmond (1986) suggests is 12 to 35 ka. Unit is a good source of sand and gravel.

Qto **Older terrace alluvium (middle Pleistocene)**—Includes deposits of stream alluvium in terraces that range from about 110 to 160 ft above adjacent rivers on the north side of the Colorado River near and west of Glenwood Springs, along the Roaring Fork River near the mouth of Threemile Creek, and also along the river at the eastern edge of the quadrangle. Unit was deposited as glacial outwash and 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 gravelly silt. Locally it may include thin, tufa-cemented gravel beds and also fine-grained overbank deposits. Clasts are chiefly subround to round, with varied lithologies that reflect the heterogeneous nature of the provenance area. Clasts are moderately weathered at shallow depths. Locally older terrace alluvium may be overlain by older debris-flow deposits (Qdfo) or a prominent bed of tufa (Qtu). It may interfinger with older debris-flow deposits (Qdfo) in West Glenwood Springs.

Unit is tentatively correlated with terrace 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 Bryant and Shroba (1997). Deposits may be 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 alluvium south of the Glenwood Springs quadrangle on the east side of the Roaring Fork River valley 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 deposit. Exposed thickness about 50 ft; maximum thickness is estimated at about 130 ft. Unit may be a source of aggregate.

Qtt **Oldest terrace alluvium (middle Pleistocene)**—Consists of a single deposit of stream alluvium west of the Glenwood Springs Municipal Airport that ranges from about 220 to 360 ft above the adjacent Roaring Fork River. It is, in part, overlain by older debris flow deposits (Qdfo). Unit is poorly to moderately well sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix that was deposited as glacial outwash. 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. Along with the overlying older debris flow deposits (Qdfo), oldest terrace alluvium appears to have been deformed by salt tectonism. The deformation has altered the relative elevation difference between the older terrace deposits and the Roaring Fork River, which complicates assignment of even a relative age to this deposit. Piety (1981) tentatively mapped the remnant as a terrace T3 deposit and correlated it to deposits which contain the Lava Creek B volcanic ash in sec. 4, T. 8 S., R. 88 W. about 8 mi south-southeast of the quadrangle. The Lava Creek B ash, formerly called the Pearlette type O ash, is generally considered to be 620 ka (Izett and Wilcox, 1982). Maximum thickness is about 100 ft. It may be a potential source of sand and gravel.

QTg **High-level gravel (early Pleistocene or Pliocene)**—Includes a single, very poorly exposed deposit of river gravel which caps a ridge on the south side of the Colorado River about 1,500 ft above river level near the north quarter corner of sec. 7, T. 6 S., R. 88 W. Deposit was recognized based on the presence of subrounded to rounded cobbles and pebbles of quartzite, granite, and pegmatite in float observed on the ground surface. The unit is not exposed. It probably was deposited by the ancestral Colorado River. Thickness of the unit is unknown. It may be a potential source of sand and gravel.

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

Qlsr **Recent landslide deposits (latest Holocene)**—Includes active and recently active landslides with fresh morphological features. Unit consists of unsorted, unstratified rock debris, gravel, sand, silt, and clay. Recent landslide deposits near the southwest corner of the quadrangle occurred within the Mancos Shale or in landslide deposits (Qls) derived from the Mancos Shale. The recent landslide deposits along the former Red Hill ski hill developed in roadcuts into older debris-flow deposits (Qdfo), whereas those along Mitchell Creek formed when the stream eroded into the toe of landslide deposits (Qls) on the east side of the creek. Thickness is probably a maximum of about 75 ft. Unit is prone to renewed or continued landsliding and is suggestive of the type of conditions which may produce landslides in the current climatic regime. It may be susceptible to settlement when loaded and to hydrocompaction and subsidence when derived from evaporites or Maroon Formation.

Qc **Colluvium (Holocene and latest Pleistocene)**—Ranges from unsorted, 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 is aided by sheetwash. Locally it grades to sheetwash deposits on flatter slopes and to debris-flow deposits in some drainages. Deposits are usually coarser grained in upper reaches of a colluvial slope and finer grained in distal areas where sheetwash processes predominate. Clasts typically are angular to subangular. Unit commonly is unsorted or poorly sorted with weak or no stratification. Clast lithology is variable and dependent upon types of rocks on the slopes beneath and above the deposit. Locally the unit includes talus, landslides, sheetwash, and debris flows that are too small or too indistinct on aerial photography to be mapped separately. Unit grades to and interfingers with alluvium and colluvium (Qac), younger debris-flow deposits (Qdfy), and sheetwash deposits (Qsw) along some tributary drainages and hillslopes. Colluvial deposits locally are dissected by erosion where small drainages are advancing headward into bluffs at the toe of some colluvial slopes. Maximum thickness is probably about 40 to 60 ft.

Areas mapped as colluvium are susceptible to future colluvial deposition and locally subject to sheetwash, rockfall, 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 or evaporitic rocks. It may be corrosive when derived from evaporitic rocks.

Excavation into colluvium may be difficult where it contains large boulders of basalt.

Qt **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble on steep slopes that is derived from bedrock outcrops and is transported downslope principally by gravity as rockfalls, rockslides, rock avalanches, and rock topples. Locally it may be aided by water and freeze-thaw processes. Talus generally is derived from well indurated Precambrian and lower Paleozoic rocks or basalt. Locally it lacks matrix material. Deposits mapped as talus may include alluvium and colluvium (Qac), particularly on narrow valley floors where talus is mapped on both sides of the valley floor. Areas delineated with a triangle pattern in No Name Creek indicate two very large deposits of talus that may have resulted from rapid rotational rockslides or large rock topples perhaps related to oversteepening of slopes due to glaciation or stream erosion. Maximum thickness is estimated at about 80 ft. Areas mapped as talus are subject to severe rockfall, rockslide, rock avalanche, and rock topple hazards. Unit may be a source of high quality riprap and aggregate, and usually it is difficult to excavate.

Qls **Landslide deposits (Holocene and Pleistocene)**—Highly variable deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Clast lithology dependant upon its provenance. They range in age from recently or currently active landslides to long-inactive middle or early Pleistocene landslides. Unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Maximum thickness is probably around 250 ft; usually it is much thinner. 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 dissected hillslopes on valley walls as erosional remnants of formerly more extensive deposits that were transported primarily by gravity and aided by sheetwash. Genesis, texture, bedding, and clast lithology are similar to colluvium (Qc). Unit averages 10 to 25 ft thick. Areas mapped as older colluvium generally are not subject to significant future colluvial deposition, except where adjacent to and below eroding hillslopes. Unit may be subject to collapse, piping, and settlement where fine grained and low in density.

Qlso **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion that lack distinctive landslide morphologic features. Older landslide deposits are similar in texture, bedding, sorting, and clast lithology to landslide deposits (Qls). Type of landslide movement generally is not identifiable due to the eroded character of the deposits. Maximum thickness is estimated at about 60 ft. Most older landslide deposits are probably not prone to reactivation unless significantly disturbed by construction activities, but each deposit should be individually evaluated for stability.

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 primarily alluvial, while colluvial and sheetwash processes commonly dominant on debris fans and hillslopes and along the hillslope/valley floor boundary.

Qdfy **Younger debris-flow deposits (Holocene)**—Sediments deposited by debris flows, hyperconcentrated flows, streams, and sheetwash on active fans and in stream channels. Unit ranges from poorly sorted to moderately well-sorted, matrix-supported, gravelly, sandy, clayey silt to clast-supported, pebble and cobble gravel in a sandy, clayey silt or silty sand matrix. It is commonly very bouldery, particularly near fan heads. Distal parts of some fans are characterized by mudflow and sheetwash 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. Original depositional surfaces are usually preserved, except where they have been disturbed by human activities. Maximum thickness possibly is as much as 120 ft.

Area is subject to flooding and to future debris-flow, hyperconcentrated-flood, and alluvial deposition following intense rainstorms, except on distal parts of some fans, where mudflow and sheetwash processes prevail. Younger debris-flow deposits are prone to settlement, piping, and hydrocompaction where fine grained and low in density, subject to sinkhole development by piping or collapse where underlain by cavernous evaporitic rocks, and corrosive if derived from evaporitic rocks. Numerous sinkholes related to piping failure have reportedly developed in younger debris-flow deposits south of and across the river from Funston. Surface depressions created by settlement, hydrocompaction, or piping frequently may have been backfilled with unclassified fill placed by man and covered with soil, creating potentially hazardous foundation conditions for structures located over them. Unit may be a source of aggregate where derived from Precambrian and lower Paleozoic rocks.

Qac **Alluvium and colluvium, undivided (Holocene and latest Pleistocene)**—Unit is chiefly stream-channel, low-terrace, and flood-plain deposits along the valley floors of ephemeral, intermittent, and small perennial streams, with colluvium and sheetwash common on valley sides. Deposits of alluvium and colluvium probably are interfingered. Locally includes younger debris-flow deposits or may grade to debris-flow deposits in some drainages. Alluvium is typically composed of poorly sorted to well-sorted, stratified, interbedded pebbly sand, sandy silt, and sandy gravel. 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 sheetwash, rockfall, and small debris flows. 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 surface is topographically about 20 to 40 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 (Pleistocene)**—Includes deposits of alluvium and colluvium that underlie terraces and hillslopes 10 to 60 ft above adjacent small perennial, ephemeral, and intermittent streams. Texture, bedding, clast lithology, sorting, and genesis are similar to alluvium and colluvium (Qac). Unit locally includes debris-flow and sheetwash deposits. Maximum thickness is about 30 ft. Area is subject to active colluvial and sheetwash deposition where adjacent to and below eroding hillslopes. It may be a source of sand and gravel.

Qdfo **Old debris-flow deposits (Pleistocene)**—Occurs on ridglines and mesas as remnants of formerly extensive debris fans deposited by tributaries to both the Roaring Fork and Colorado Rivers. Unit is genetically, texturally, and lithologically similar to younger debris-flow deposits (Qdfy), but may be highly calcareous. Boulders in this unit may exceed 5 ft in diameter. Old debris-flow deposits locally include thin interbeds of tufa and tufa-cemented gravel near West Glenwood Springs. Original depositional surfaces are locally preserved and may be mantled with loess, but at other locations the deposits are deeply eroded and now geomorphically resemble the valley-wall topography developed on bedrock. Elevation differences between original depositional surfaces and adjacent modern drainages range from about 40 to 320 ft. Thickness generally about 30 to 60 ft, but may locally exceed 160 ft.

Deposits west of the Glenwood Springs Municipal Airport at the mouth of Fourmile Creek have been deformed by salt tectonism. This locality underlies the northern boundary of a halite dome within the Eagle Valley Evaporite described by Mallory (1966, 1971), and it is within the regional collapse area reported by Kirkham and Widmann (1997) and Kirkham and others (1997). The upper surface on the older debris-flow deposit at Fourmile Creek dips abruptly away from the river. More importantly, the distal end of this old fan is now about 100 ft higher in elevation than the original fan head. This deformation is probably largely a result of evaporite flowage and diapiric upwelling, although collapse into a dissolution cavern may be responsible for part of it.

Where fine-grained, unit may be prone to piping, settlement, and perhaps hydrocompaction. It may be corrosive when derived from evaporitic bedrock. It is a potential source of sand and gravel.

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by ice in moraines.

Qti **Till (late and middle Pleistocene)**—Heterogeneous deposits of gravel, sand, silt, and minor clay deposited by ice in lateral, end, and ground moraines in the northwest corner of the quadrangle in Dry Possum Creek and in two tributaries to Mitchell Creek. Unit is dominantly unsorted or poorly sorted, unstratified or poorly stratified, matrix-supported bouldery, pebble and cobble gravel with a matrix of silty sand. Deposits may locally be clast-supported where composed mostly of gravel. Clasts are typically angular to round pieces of Precambrian and lower Paleozoic bedrock that occasionally exceed 10 ft in length.

End and lateral moraines are commonly hummocky, steep-sided, and bouldery, and have closed depressions encompassed by ridges. Moraine crests are moderately well preserved, but outermost lateral moraine on east side of Dry Possum Creek is weathered and its crest is rounded. Lower limit of glaciation is at an altitude of about 9,400 ft. Terminal moraines in both tributaries of Mitchell Creek are narrowly breached by stream erosion, whereas the terminal moraine in Dry Possum Creek has been modified considerably by stream erosion. Although glacial deposits are not mapped along No Name Creek, glaciers may have extended into the quadrangle for about one mile down the creek from the northern boundary of the quadrangle, on basis of the geomorphic character of the canyon and the presence of till immediately north of the quadrangle. Unit is probably in part of Pinedale age (approximately 12–35 ka, Richmond, 1986), but some of the outermost moraines, particularly in Dry Possum Creek, are probably of Bull Lake age or perhaps even older. Maximum thickness is estimated at about 240 ft. Till may be prone to landsliding. Unit may be a potential source of sand and gravel.

LACUSTRINE DEPOSITS—Sediments deposited in lakes.

Ql **Lacustrine deposits (Quaternary)**—Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, and well sorted medium-red-brown, fine to coarse sand. Unit is very poorly exposed except in a depression excavated through the water table to provide for stock watering in the SW1/4NW1/4 of section 29, T. 1 S., R. 88 W. Minimum thickness as determined by a test hole hand augered in the excavated depression is 8.5 ft. Maximum thickness is unknown.

According to Calvin Cox (1994, oral commun.), a lake existed in Spring Valley until near the end of the last century. His ancestors hand excavated a ditch at the northwest end of Spring Valley to drain the lake and then farmed the exposed lake bottom to demonstrate agricultural use of the land for homesteading purposes. Land ownership was transferred from the federal government to his ancestor in 1896, therefore dewatering of the lake occurred prior to that year. The lake in Spring Valley did not result from landsliding, glaciation, or faulting which blocked the outlet. We conclude that the valley floor apparently subsided as a half-graben or synclinal sag when underlying evaporitic rocks either dissolved or flowed out from beneath the valley. Lacustrine deposits may have low bearing capacity and be prone to settlement when loaded.

EOLIAN DEPOSITS—Silt, sand, and clay deposited by wind.

Qlo **Loess (late and middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited 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 12 ft. Deposition occurred during at least two periods of eolian activity. Fairer and others (1993) and Bryant and Shroba (1997) 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 in this quadrangle. At least one and perhaps multiple sheets of loess overlie older debris-flow deposits (Qdfo) which rest on older terrace deposits (Qto) near West Glenwood Springs. In the southeast part of the quadrangle two or more sheets of loess locally overlie basalt and Maroon Formation. 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 flood-plain 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 Canyonands 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 hydrocompaction and piping when wetted. It is highly erodible.

SINTER DEPOSITS—Chemical sediment deposited by a mineral spring.

Qtu **Tufa (Holocene and Pleistocene?)**—Low-density, porous chemical sedimentary rocks consisting of calcium carbonate precipitated from mineral-charged spring, ground, and surface water. Tufa occurs as massive ledges and as a gravel-cementing material north of the Colorado River in and near West Glenwood Springs. Large bed of tufa below the Glenwood Springs golf course forms a prominent, continuous outcrop about 0.6-mi long which caps older terrace alluvium (Qto). Much of this ledge is resistant to erosion and forms near vertical outcrops, but other areas are easily eroded and in one instance a road-cut into tufa has been protected by a thin layer of reinforced concrete grout to reduce spalling problems. Another ledge of tufa overlies older debris flow deposits (Qdfo) in lower Oasis Creek. A bed of tufa beneath the rest area on Highway I-70 in West Glenwood Springs includes an organic-rich layer of clayey, sandy silt and peat which has a radiocarbon age of 12,410 ± 60 years BP (D. Trimble, 1995, written commun.; sample no. USGS-3544). Small, unmapped, discontinuous areas of tufa-cemented gravel were noted within both older debris-flow deposits (Qdfo) and older terrace alluvium (Qto) near the mouth of Oasis Creek and in adjacent areas. Tufa deposits also occur near Hobo hot springs in the SW1/4 SW1/4 sec. 4, T. 6 S., R. 89 W.

Tufa deposition is associated with both cold-water and hot-water springs. A cold-water spring with small active tufa mound occurs in Mitchell Creek above the Glenwood Springs fish hatchery. Thermal waters were encountered during 1993 in excavations for homes at the base of the prominent tufa ledge west of Glenwood Springs (location indicated on map as a thermal spring). Tufa deposition may have initiated during or perhaps even before the Pleistocene and has continued at one or another location intermittently to the present.

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q **Surficial deposits, undifferentiated (Quaternary)**—Shown only on cross sections. May include any of the above surficial deposits.

BEDROCK

Tb **Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. In places the unit includes slightly indurated sediments which range from rounded pebble and cobble gravel to slightly gravelly silt. Petrographically most flows are olivine basalt; many are porphyritic. Flow rocks range from massive to highly vesicular and locally contain amygdules of calcite, iron-rich clay, and zeolites. Groundmass is predominantly plagioclase and pyroxene, with lesser amounts of olivine, glass, pigeonite, augite, and magnetite. Accessory minerals include apatite, iddingsite, and hematite. Phenocrysts are chiefly olivine and less commonly plagioclase. Unit may contain rare xenocrysts or xenoliths of quartz or quartzite. Individual flows commonly are 5 to 25 ft thick. Maximum thickness of the entire sequence of flows is around 240 ft, but it generally is 20 to 40 ft.

A sequence of interbedded pebble and cobble gravel, silty sand, and sandy silt that is strongly oxidized at the base of the exposure apparently overlies basalt in a small gravel pit in the $N^1/2N^1/2NE^1/4$ sec. 30, T. 6 S., R. 89 W. It contains abundant, well rounded clasts of granodiorite, quartz monzonite, and granite, many of which are grussified. Percentage of basaltic clasts increases from zero at the base of exposure to about 30 percent in the upper unit exposed in highwall. B. Bryant (1994, oral commun.) believes part of the clasts were derived from middle Tertiary rocks in the Aspen area, suggesting the existence of an ancestral Roaring Fork River valley at this location.

Isotopic dating suggests the basalt flows in the Glenwood Springs quadrangle fall into two general age ranges; one is about 10 Ma and the second is about 22 Ma. A sample collected from a road cut exposure at the northwest end of Spring Valley has a whole-rock $^{40}Ar/^{39}Ar$ age of 22.4 ± 0.3 Ma (L. Snee, 1995, written commun.). Larson and others (1975) reported a whole-rock K–Ar age of 10.1 ± 0.5 Ma for a flow on Lookout Mountain. Preliminary whole-rock $^{40}Ar/^{39}Ar$ dating of a sample from this same outcrop suggests an age of 9.7 Ma (M.J. Kunk, 1997, written commun.). Whole-rock $^{40}Ar/^{39}Ar$ dating of a flow exposed at the base of the cliffs near Sunlight Peak on Cattle Creek quadrangle yielded a minimum age of 10.4 ± 0.7 Ma (Kirkham and others, 1996b). This flow probably correlates with basalt in the southwest corner of the Glenwood Springs quadrangle.

Steep cliffs of basalt are a source of rockfall debris. Basalt may be very difficult to excavate and require blasting. Matrix-supported interflow sediments are prone to landsliding. Unit is a potential source of high quality riprap and aggregate.

Kmv **Mesaverde Group (Upper Cretaceous)**—Shown only on cross section A—A'.

Km **Mancos Shale, Niobrara Formation, Frontier Formation, and Mowry Shale, undivided (Upper Cretaceous)**—Includes in ascending order from its base the Mowry Shale, Frontier Formation, a calcareous shale zone equivalent to the Niobrara Formation (Murray, 1966; Tweto and others, 1978), and Mancos Shale, which constitutes the majority of the unit. Mowry Shale is a siliceous, gray to black shale about 50 to 70 ft thick that contains fish scales. Frontier Formation is a yellow-brown calcareous shale and sandstone unit about 300 ft thick. B. Bryant (1997, personal commun.) suggests the Frontier Formation should be called the Juana Lopez Formation. The calcareous shale zone equivalent to the Niobrara Formation is about 900-ft thick (Murray, 1966; Bass and Northrop, 1963; Tweto and others, 1978). Mancos Shale is dominantly light- to dark-gray, carbonaceous shale that contains thin bentonite beds and is about 4,200 ft thick.

Unit is very poorly exposed in mapped area and frequently covered by residuum, colluvium, landslides, sheetwash, or basalt. Contacts between formations are generally not mappable in the quadrangle. Deposition occurred primarily on the continental slope in low-energy depositional environments. Unit is prone to slope stability problems and susceptible to shrink-swell problems where it contains expansive clays.

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 well sorted and silica cemented, with angular to subrounded sand grains. Conglomeratic clasts are generally pebble-sized chert and quartz. Unit includes one to three fairly continuous sandstone beds that occasionally are overlain by lenses of conglomeratic sandstone which are prominent on aerial photographs. Thickness ranges from about 90 to 175 ft. Unit is conformable with and perhaps intertongues with the overlying Mowry Shale. Upper contact is placed at the top of the uppermost quartzose sandstone beneath the Mowry Shale. Formation is generally well exposed and forms conspicuous cliffs. Unit locally crops out along the Grand Hogback as a window of steeply dipping sandstone surrounded by basalt flows. 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). Formation is an important producer of oil and gas in the Piceance Basin west of the quadrangle.

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). Formation includes thin, gray limestone beds up to about 10 ft thick which contain abundant specimens of Charophyta (Peck, 1957). Thickness is variable, but averages about 400 to 500 ft. Formation is very poorly exposed in the mapped area, where it is frequently covered by residuum, colluvium, sheetwash, or basalt. Contact is with overlying Dakota Sandstone is sharp and unconformable, but is difficult to precisely locate except where well exposed. Contact is drawn below the quartzose sandstone and carbonaceous beds of the Dakota. The Morrison Formation was probably deposited in a lacustrine-dominated fluvio-lacustrine environment (Fairer and others, 1993).

Je

Entrada Sandstone (Upper Jurassic)—Light-gray to light-orange, cross-bedded, medium to very fine-grained, well-sorted sandstone. Sand grains are mostly subrounded to well rounded quartz grains. Contact with overlying Morrison Formation is sharp and conformable and is placed at the top of the bold outcrop of the lighter colored Entrada Sandstone. Thickness averages about 50 to 100 ft, but it may vary significantly over a short distance. Formation is poorly exposed in the quadrangle. It occasionally forms a smooth, slick outcrop, but commonly is covered by residuum, colluvium, sheetwash, or basalt. 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.

TRc

Chinle Formation (Upper Triassic)—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. An excellent exposure of the Chinle Formation is in South Canyon Creek about 2 mi west of quadrangle. It was described by Stewart and others (1972a) as including the 208-ft-thick upper Chinle Red Siltstone Member and a 17-ft-thick basal unit correlated with the lower Chinle Mottled Member. Dubiel (1992) recognized a very thin, basal sandstone in the Chinle Formation along South Canyon Creek and correlated it with the Gartra Member. He stated that contacts between the Gartra Member and mottled strata are gradational, as is the contact between the mottled strata and the overlying red siltstone.

The Chinle Formation is very poorly exposed in the quadrangle. It is partially exposed in a roadcut in Threemile Creek canyon, but is covered by residuum, colluvium, sheetwash, or basalt in other areas. Total formation thickness is about 225 ft in South Canyon Creek, but appears to be much thinner in the exposure along Threemile Creek. 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, while the basal conglomerate and sandstone of the Gartra Member were deposited as active channel-fill and valley-fill deposits. Dubiel (1992) describes numerous paleosols within the formation.

TRPsb

State Bridge Formation (Lower Triassic? and Permian)—Pale-red, grayish-red, reddish-brown, and greenish-gray, micaceous siltstone, clayey siltstone, shale and minor sandstone with a prominent, thin bed of sandy dolomite and sandy limestone. Bass and Northrup (1950) named the carbonate bed the South Canyon Creek Dolomite Member and included it in the Maroon Formation. Murray (1958) proposed that the South Canyon Creek Dolomite Member of the Maroon Formation be included within the State Bridge Formation. Stewart and others (1972b) also included the South Canyon Creek Dolomite in the State Bridge Formation and used it to divide the State Bridge Formation into three members: an upper member and lower member separated by the South Canyon Creek Member.

The formation is very poorly exposed in the quadrangle, but an excellent exposure occurs along South Canyon Creek about 2 mi west of the quadrangle, a location which has been examined by several investigators. Stewart and others (1972b) indicate the upper member is 55.6 ft thick, the South Canyon Creek Member is 5.6 ft thick, and the lower member is 98.5 ft thick, for a total formation thickness of 159.7 ft. They describe the South Canyon Creek Member as including a 4 ft-thick, greenish-gray to light-olive gray dolomite and a 1.6 ft-thick, light- to dark-gray limestone (color is dependant on amount of solid hydrocarbon) with prominent wavy or crinkled laminae. Bass and Northrop (1950; 1963) collected fossils from the South Canyon Creek Member that were of Permian age and suggested the wavy structure indicated an algal origin. Upper and lower members are dominantly pale-red and grayish-red siltstone with minor claystone and sandstone. The only exposure of the State Bridge Formation within the Glenwood Springs quadrangle is a roadcut in Threemile Creek canyon that is mostly covered by colluvium and sheetwash. At this location the formation is either very thin (less than about 50 ft thick) or is partially removed by an unrecognized fault. The South Canyon Creek Dolomite Member was not observed at this location.

Contact with overlying Chinle is unconformable (Freeman, 1971a), but is often difficult to accurately locate unless the Gartra Member of the Chinle is present. The top of the upper member of the State Bridge coincides with the base of the Gartra Member or with the base of the Mottled Member if the Gartra is absent. There usually is a distinct color change from the orange-red color of the Mottled Member of the Chinle to the brick-red and gray-red color of the upper State Bridge. According to Bryant (1979) parallel oscillation ripple marks are diagnostic of the State Bridge Formation. The formation abruptly thickens south and east of the Glenwood Springs–El Jebel area (Freeman, 1971). Unit was probably mainly deposited in a fluvio-lacustrine environment dominated by lacustrine processes, but the South Canyon Creek Member suggests a short-lived encroachment of an environment favorable for carbonate deposition.

PIPm **Maroon Formation (Lower Permian and Pennsylvanian)**—Mainly red beds of sandstone, conglomerate, mudstone, siltstone, and claystone with minor, thin beds of gray limestone. Includes the Schoolhouse Member at the top of the formation (Johnson and others, 1990), which was previously called the Schoolhouse Tongue of the Weber Sandstone (Bass and Northrop, 1963; Stewart and others, 1972b). Conglomerate beds contain subangular to rounded pebble- and cobble-sized clasts of quartz, feldspar, and granitic rock fragments. Unit 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 which contain locally abundant interstitial and grain coatings of solid hydrocarbon. Marcasite nodules are occasionally present in the middle of Schoolhouse Member. Total thickness is about 3,000 to 4,000 ft, including the 150- to 175-ft-thick Schoolhouse Member.

Maroon Formation red beds crop out in the southwestern part of the quadrangle and are particularly well exposed on the valley walls of the Roaring Fork River. Exposures are generally poor near Lookout Mountain. The Schoolhouse Member is typically poorly exposed in the quadrangle, except in a roadcut along Threemile Creek where it is partially exposed. Contact with the overlying State Bridge Formation is sharp, and it is placed where the light-colored beds of the Schoolhouse Member are overlain by the red beds of the State Bridge. Johnson and others (1988) suggest the contact is an angular unconformity. The Maroon Formation was deposited in fluvial and perhaps eolian envionments in the Central Colorado Trough between the ancestral Front Range and Uncompahgre highlands.

Formation is prone to rockfall and rockslide hazards, especially where prominent bedding and cross-bedding planes are developed in the red beds. Numerous landslides appear to have originated in the unit, particularly in the vicinity of Lookout Mountain and along the west side of the Roaring Fork River north of Threemile Creek.

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 1,000 ft. Formation is generally poorly exposed. It is conformable and intertonguing with the overlying Maroon Formation and underlying Eagle Valley Evaporite. Contact with Maroon Formation is placed at the top of the uppermost evaporite bed or light-colored clastic bed below the thick sequence of red beds. The Eagle Valley Formation was deposited in the Eagle Basin on the margin of an evaporite basin at the distal end of a coalescing alluvial fan complex and in a submarine environment within the evaporite basin.

The formation may be susceptible to subsidence, sinkhole development, compaction, piping, and corrosion problems where evaporitic rocks occur near the land surface.

IPee **Eagle Valley Evaporite (Middle Pennsylvanian)**—Sequence of evaporitic rocks consisting of massive to laminated gypsum, anhydrite, halite, and beds of light-colored mudstone and fine-grained sandstone, thin limestone and dolomite beds, and black shale. Formation may include eolian deposits similar to those reported by Schenk (1987). Beds commonly are intensely folded, faulted, and ductily deformed by diapirism, flowage, dissolution-related subsidence or collapse, load metamorphism, hydration of anhydrite, and Laramide tectonism. The formation is generally poorly exposed except in recent alluvial cuts, man-made exposures, and stacks, which are unique chimney-like landforms that are well developed west of Roaring Fork River. Stacks are typically composed of yellowish-brown, calcareous sandstone breccia and sandy limestone breccia cemented by orangish-yellow to greenish-yellow-brown calcareous siltstone, sandstone, and claystone.

Total thickness of the Eagle Valley Evaporite ranges from about 1,200 to perhaps as much as 9,000 ft (Mallory, 1971) where it is tectonically thickened along the axis of the Cattle Creek Anticline. Presence of a thick halite sequence near the mouth of Cattle Creek on the adjacent Cattle Creek quadrangle was reported by Mallory (1966) on the basis of 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 thickness of neither halite nor the formation is known. The well was spudded near the axis of the Cattle Creek Anticline, a Laramide structure that has been modifed by salt flowage and diapirism during the Neogene, as evidenced by deformed Pleistocene deposits.

Contact with the 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.

The Eagle Valley Evaporite contains cavernous voids as much as several feet in diameter and tens of feet deep that have resulted from near-surface dissolution of halite and gypsum. It is prone to development of sinkholes into which overlying deposits may subside or be piped. Surficial deposits derived from the Eagle Valley Evaporite may be subject to compaction, settlement, sinkhole, and corrosion problems. Gypsum and halite in the formation may be economic resources.

IPeu **Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian)**—Includes the Eagle Valley Formation and Eagle Valley Evaporite on the south wall of Glenwood Canyon where heavy forest cover and a thick veneer of surficial deposits obscure the contact between units. Thickness is highly variable, but averages about 2,000 ft. Unit may be prone to subsidence, sinkholes, compaction, settlement, and piping where evaporitic rocks lie near land surface.

IPb **Belden Formation (Lower Pennsylvanian)**—Predominantly gray to black, calcareous shale and fossiliferous gray limestone with minor beds of fine- to medium-grained, micaceous sandstone, micaceous siltstone, and a few beds of faintly cross-bedded arkose. Formation contains thin beds of gray to brown and black chert in very lowermost part of unit. It may contain discontinuous and localized beds of evaporite which can occur anywhere in the formation. The upper portions of the unit include intertonguing beds of coarse-grained clastic rocks which are thought to be Minturn Formation equivalent. These intertonguing beds of lithic wacke and subarkose occurring near the top of the Belden Formation are well exposed and described in detail by Streufert and others

(1997a). Rocks of the Belden Formation were deposited in a low-energy marine environment at a distance from their source over a widespread area in the Central Colorado Trough between the Ancestral Uncompahgre and Front Range Highlands. Minturn Formation equivalent rocks were most likely deposited in a series of coalescing alluvial fans, the distal ends of which intertongue with rocks of the Belden Formation. Unit is approximately 500 to 750 ft thick across the map area but may be thickened or thinned by bedding-plane faulting. Unit is highly prone to landsliding, especially on north-facing slopes.

Ml

Leadville Limestone (Mississippian)—Light- to medium-gray, bluish-gray, massive, coarsely to finely crystalline, fossiliferous micritic, limestone and dolomite. Formation contains lenses and nodules of dark gray to black chert as much as 0.3 ft thick in the lower one-third of the formation. Upper half of the formation contains coarse-grained oölites. Carbonate veins with disseminated silt-sized quartz grains are common. The top of the unit contains collapse breccias, filled solution cavities, and a red to reddish-purple claystone regolith (Molas Formation), all of which formed on a paleokarst surface. The Leadville Limestone is very fossiliferous, with abundant crinoid and brachiopod fragments. It forms a prominent cliff and is frequently the caprock of outcrops within Glenwood Canyon and tributary canyons. Upper contact is irregular and unconformable with the overlying Belden Formation. Unit is 200 ft thick across the study area. It formed in a marine environment in the sublittoral zone by chemical precipitation and through the accumulation of biogenic and oölitic sediment.

Unit can be chemically pure and has been mined as metallurgical grade limestone in the northern half of the quadrangle. It also is a source of riprap and aggregate. Modern solution features including caves and solution pockets are common in these rocks. Unit may be susceptible to sinkholes and subsidence where karst features occur near the land surface. It may be a source of rockfall debris where exposed in cliffs.

Dc

Chaffee Group (Upper Devonian)—Sequence composed of green shale, quartzite, dolomite, limestone, and dolomitic sandstone. It consists of three named formations which from top to bottom are the Gilman Sandstone, Dyer Dolomite, and Parting Formation. Total thickness of the Chaffee Group in Glenwood Canyon is 252.5 ft (Soule, 1992).

Gilman Sandstone consists of tan to yellow, laminated, fine- to very fine-grained quartz arenite and dedolomitic limestone. It is variable in lithology and thickness across the study area. On the southeast flank of the White River Uplift the Gilman is predominantly a 16-ft thick calcareous sandstone. It becomes an oxidized dolomite (dedolomite) with thickness less than 1 ft near Glenwood Springs. Sandstone phase consists of rounded to sub-rounded quartz grains which are well sorted. Laminae are generally less than 1 inch in thickness and consist of zones of fine sand which locally display weak planar-tabular cross-bedding and minor load structures. Some laminae contain discontinuous lenses of quartz arenite with visible relict casts of carbonate rhombohedron. Limestone beds in the Gilman consist of a greater than 99 percent pure calcite-bearing dedolomitic limestone with minor hematite and quartz. Contact with the overlying Mississippian Leadville Limestone is unconformable. Tweto and Lovering (1977) suggest a water reworked, eolian origin for the Gilman Sandstone near Gilman. Most likely it was deposited in a changing environment of very shallow water and periodic subaerial exposure in the supratidal (tidal flat) zone.

Dyer Dolomite is divided into two members on the White River Plateau, an upper Coffee Pot Member and a lower Broken Rib Member. Coffee Pot Member consists of crystalline, micritic dolomite, dolomitic gray shale, and micritic limestone. It is somewhat sandy, especially near the top and is fossiliferous in places. The Coffee Pot Member is characterized by abundant rip-up clasts, intraformational breccia, and bioturbated bedding (Soule, 1992). Together with the Gilman Sandstone it forms blocky slopes beneath the prominent cliff of overlying Leadville Limestone in canyon outcrops. It was deposited predominantly in the uppermost intertidal to supratidal (tidal flat) zones in a changing environment of periodic subaerial exposure with influxes of shallow marine conditions. The Broken Rib Member consists of gray nodular crystalline limestone. The Dyer Dolomite is abundantly fossiliferous with brachiopods dominant (34 species) (Bass and Northrop, 1963). It forms a very distinctive "knobbly-weathering" gray ledge above blocky slopes of the underlying Parting Formation in canyon outcrops. The Dyer Dolomite formed in a shallow marine environment in the sub-littoral zone.

Parting Formation is variable in lithology across study area. In Glenwood Canyon it consists of white to buff, well-cemented orthoquartzite with minor feldspar and rock fragments, micaceous green shale with discontinuous lenses of orthoquartzite, and sandy micritic dolomite. The formation contains limestone breccia and sandy, green shale on the north end of the quadrangle in the vicinity of Windy Point. Thicknesses of orthoquartzite beds are consistent across study area, ranging from 0.5 to 1.0 ft. Other beds show much greater variation in thickness. The Parting Formation forms a blocky slope with distinct ledges above the prominent cliffs of the underlying Manitou Formation. Bass and Northrop (1963) collected fish fossils from the Parting in Glenwood Canyon. It formed in a shallow marine environment.

MDr **Mississippian and Devonian rocks, undivided (Mississippian and Upper Devonian)**—Includes rocks of the Leadville Limestone and Chaffee Group where it is not practicable to separate formations due to poor outcrop exposure, inaccessibility, or poorly defined marker horizons. Thickness of the combined unit is about 450 ft. Combined unit may be susceptible to sinkholes and subsidence where karst features occur near land surface.

Om **Manitou Formation (Lower Ordovician)**—Consists predominantly of medium-bedded brown dolomite at the top with thin beds of gray flat-pebble limestone interbedded with greenish-gray calcareous shale, sandstone, and brown-weathering limestone and dolomite in the lower portions. In Glenwood Canyon the unit is 155.8 ft thick according to Bass and Northrop (1963) and 167.3 ft thick as measured by Soule (1992).

The upper or Tie Gulch Member consists of massive, micritic, brown and orange-weathering, crystalline, somewhat siliceous dolomite and minor limestone. It becomes somewhat sandy near the top. The Tie Gulch Member forms a consistent 50- to 90-ft thick, brown to orange colored cliff in Glenwood, No Name, and Grizzly Canyons which rises distinctly above a gentler slope produced on the lower Manitou and Dotsero Formations. Some beds are glauconitic although considerably less so than the underlying beds of the Dead Horse Conglomerate Member. No fossils are known to occur in the Tie Gulch Member. Contact with the overlying Devonian Chaffee Group is unconformable, occurring at a thin shale bed which may be the remains of a paleosol (Soule, 1992). Strong dolomitization and lack of marine fossils suggests that sediments of the Tie Gulch Member accumulated in the upper intertidal and/or lowermost supratidal (tidal flat) environments.

The lower or Dead Horse Conglomerate Member consists mostly of thin-bedded, gray, flat-pebble limestone conglomerate, thin-bedded limestone, shaly limestone, and two beds of massive dolomitic orthoquartzite. It is somewhat glauconitic, especially in the bottom portion. A diverse Lower Ordovician fossil fauna has been described from the member by Bass and Northrop (1963) from outcrops in Glenwood Canyon. Base of the member generally forms a continuous slope with underlying rocks of the Dotsero Formation. Upper portions of the member frequently form an unbroken cliff with overlying rocks of the Tie Gulch Member in Glenwood, No Name, and Grizzly Canyons, rendering close inspection of the upper contact difficult. The Dead Horse Conglomerate Member most likely was deposited under fluctuating conditions and varying water depths in the intertidal and shallow marine environments. It may be a source of rockfall debris.

€d **Dotsero Formation (Upper Cambrian)**—Thinly-bedded, tan to gray, silty and sandy dolomite, dolomitic sandstone, green dolomitic shale, limestone and dolomite conglomerate, limestone, and pinkish-light-gray to very light-gray and white to lavender-weathering algal limestone.

The upper or Clinetop Member of the Dotsero Formation is a 5-ft-thick sequence of matrix-supported limestone pebble conglomerates with abundant rip-up clasts which occurs below a bed of stromatilitic limestone with well preserved algal-head crinkle structure. In Glenwood Canyon the Clinetop Member contains an upper Cambrian fossil assemblage. A limestone-pebble conglomerate in the Manitou Formation that conformably overlies and is only 3 ft above the Clinetop Member contains a Lower Ordovician fossil assemblage (Bass and Northrop, 1953). The Clinetop algal biostrome and overlying limestone-pebble conglomerates occur throughout a 400-square-mile area across the White River Plateau suggesting periods of high energy characteristic of the intertidal environment separated by a period of remarkable, wide-spread quiescence at the close of Cambrian time indicative of the uppermost intertidal to supratidal environment.

The Glenwood Canyon Member consists of thinly bedded dolomite, dolomitic sandstone, conglomeratic limestone, coarse-grained fossiliferous limestone, and dolomitic shale. Dolomitic beds contain abundant glauconite, giving the beds a greenish hue. Worm tracks and worm burrows (fucoids) are common, especially in the middle third of the member. Desiccation cracks are less common. These rocks generally form a vegetated slope above the prominent cliffs of the Sawatch Quartzite, however, they can be a cliff-former, especially in the deeper portions of Glenwood, No Name, and Grizzly Canyons. Member is 90 ft thick. Variation in lithologies and sedimentary structures in the member indicate a period of widely fluctuating depositional patterns ranging from near-shore shallow marine through intertidal to supratidal (tidal flat) environments.

Ꞓs

Sawatch Quartzite (Upper Cambrian)— White and buff to gray-orange, brown-weathering, vitreous orthoquartzite in beds from 1 to 3 ft thick. Locally the Sawatch Quartzite contains beds of arkosic quartz-pebble conglomerate at the base of the unit which rest unconformably on highly weathered Precambrian rocks. Basal hematite-stained, planar to tabular cross-bedded sandstone interbedded with quartzite is also present in the map area. The formation includes beds of massive, brown, sandy dolomite, which are a suggested equivalent of the Peerless Formation described by Tweto and Lovering (1977) and Bryant (1979) at Minturn and Aspen, respectively, and overlying beds of unnamed sandy dolomite and white dedolomitic quartzite. These upper beds are possibly disconformable with sediments of the Sawatch Quartzite below and the overlying Dotsero Formation. These sediments form a continuous cliff with the Sawatch Quartzite in Glenwood Canyon and cannot be mapped separately at a scale of 1:24,000. Fossils are extremely rare to non-existent in these rocks. Total thickness of this combined unit is 500 ft. Primary sedimentary structure is poorly preserved in the Sawatch Quartzite which most likely originated as beach deposits or in shallow water of the littoral zone from sediment eroding off a highland in the vicinity of the Front Range (Tweto and Lovering, 1977). Peerless-equivalent rocks and unnamed overlying dolomitized sediments possibly formed in the intertidal or lowermost supratidal (tidal-flat) environment characterized by fluctuating water depth. Formation prone to rockfalls, rockslides, and rock avalanches. It may be a source of aggregate.

O-Ꞓr

Ordovician and Cambrian rocks, undivided (Upper Cambrian and Lower Ordovician)— Includes rocks of the Sawatch Quartzite, Dotsero Formation, and Manitou Formations where it is not practicable to separate these rocks due to poor outcrop exposure, inaccessibility, or poorly defined marker horizons. Combined unit is 745 ft in thickness.

PRECAMBRIAN ROCKS

Xg

Biotite Granite (Proterozoic)—Generally dark-gray and white-speckled, medium to coarse-grained, equigranular granite and granodiorite; however, in the upper reach of No Name Canyon the granite is fine- to medium-grained. Primary constituents are soda-rich anhedra of plagioclase, anhedra of microcline and perthite, and severely strained anhedra of quartz. Small blebs of quartz also occur within the feldspar crystals. Accessory minerals include interstitial anhedra of biotite and hornblende. Trace minerals are magnetite, apatite, sphene, epidote, chlorite, and zircon. Mafic xenoliths averaging about a foot in diameter are common in the granite. Samples of the granite examined under the petrographic microscope have a weak gneissic foliation defined by the alignment of the biotite and hornblende crystals.

Unit forms spectacular, well-jointed outcrops in Glenwood Canyon; however, in No Name Canyon exposures are more subdued in comparison to the surrounding foliated rocks. The granite contains numerous dikes and sills of white to pink pegmatite and aplite. Dikes and sills range from an inch to 10 ft wide and have lengths as much as a few hundred feet.

Lithological similarity of the biotite granite to granites exposed in the Aspen area (Bryant, 1979) and Sawatch Range (Wetherill and Bickford, 1965) indicate that the biotite granite are of 1.6 to 1.7 Ga (Precambrian X age). Presence of foliation in these rocks indicates a syn- or post-metamorphic origin for the biotite granite.

Unit is subject to rockslides and rockfalls in the canyons where it is exposed. It may be a source of aggregate and riprap.

Xpgd **Porphyroblastic biotite granodiorite of No Name Canyon (Proterozoic)**—Matrix of the granodiorite is coarse-grained, inequigranular, and speckled in appearance; and consists of light-reddish-pink orthoclase anhedra, white anhedra of plagioclase often dusted with secondary white mica and lesser amounts of epidote and strained anhedra of quartz. The porphyroblasts consist of light-red to pink, fresh euhdral twinned orthoclase crystals; they have diameters of 2 to 4 in.

Biotite is the only accessory mineral, constituting about 20 percent by volume of the rock. Magnetite, apatite, and zircon occur in trace amounts. Petrographic examination indicates that the granodiorite has a gneissic texture.

In outcrops at Horseshoe Bend, a prominent bend in the Colorado River about 2,000 ft west of the junction of No Name Creek and the Colorado River, the orthoclase porphyroblasts are strongly aligned in a northwest-southeast direction. At this locality a purple to dark-gray regolith is developed in the granodiorite for approximately 20 ft below the contact with the overlying Cambrian Sawatch Quartzite.

Rocks of similar lithology and texture have been described near Aspen (Bryant, 1979) and in the Sawatch Range (Stark and Barnes, 1935) and are thought to be approximately 1.6 to 1.7 Ga.

The porphyroblastic granodiorite may be a border phase of the syn- to post-metamorphic, intrusive granites as it is the only unit that has been observed to have intrusive contacts with the older biotite-muscovite gneiss.

Unit may be subject to rockfalls and rockslides. Locally it may be suitable for use as aggregate and riprap.

Xqm **Gneissic quartz monzonite of Mitchell Creek (Proterozoic)**—Predominantly light-red to pink, fine- to medium-grained, equigranular, foliated, quartz monzonite. Anhedra of microcline, microperthite, plagioclase, and severely strained, irregular shaped anhedra of quartz are the primary constituents. Quartz also occurs as chains of small blebs within discontinuous and anastomosing cataclastic microshears. Biotite, commonly replaced by chlorite, and muscovite are accessory minerals. The muscovite occurs predominately in the cataclastic microshears. Trace minerals include magnetite, hematite, leucoxene, and apatite. This unit, like the above described igneous rocks, is thought to be 1.6 to 1.7 Ga. It may be a source of rockfalls and rockslides and locally may be acceptable for use as aggregate and riprap.

Xmgn **Biotite-muscovite gneiss (Proterozoic)**—Dark-gray to black, well to poorly foliated, biotite-muscovite gneiss composed primarily of fine-grained quartz, orthoclase, plagioclase, and as much as 35 percent biotite and muscovite. Biotite is commonly partially replaced by chlorite. In some localities the gneiss is coarse grained and contains distinct 1 inch diameter aggregates of white muscovite.

Quartz and feldspar podiform segregations that range from a few inches to 3 ft long and from less than an inch to 0.5 ft wide are common throughout the gneiss. Migmatitic layers of granite gneiss in bands ranging from approximately 1 inch to 3 ft thick are locally abundant.

White and pink pegmatite and aplite zones are common within the gneiss and can locally comprise most of the mapped gneiss unit. Where pegmatite units are mappable they are shown by a stippled pattern. Pegmatite units within the biotite-muscovite gneiss are generally composed of large, white, euhedral feldspars; muscovite; anhedral to euhedral red garnets; dendritic aggregates and solitary crystals of black tourmaline; and oxidized specular hematite.

Several studies of the Precambrian in Colorado have established an accepted chronology (Bryant, 1979). Sedimentary rocks, most likely shales and graywackes, were deposited in this area from about 2.0 to 1.7 Ga. The sediments were metamorphosed and, during the waning stages of metamorphism, intruded by granitic rocks of variable composition and texture about 1.6 to 1.7 Ga. Biotite-Muscovite gneiss may be subject to rockfalls and rockslides. It may be acceptable for use as aggregate and riprap.

ECONOMIC GEOLOGY

Mineral commodities with possible economic potential in the quadrangle include high-calcium limestone, and to a lesser degree, base metals. Limestone has been quarried in the quadrangle from three principal locations, all of which are less than one mile from the city of Glenwood Springs. One of these limestone quarries retains an active permit status (1994) even though there has been no mining in recent years. One small occurrence of oxidized lead-zinc ore was evaluated in 1944 by the United States Bureau of Mines under the War Minerals Program. This property is located near Windy Point on the north end of the quadrangle.

The Mississippian Leadville Limestone crops out extensively on the White River Plateau and has been suggested as a source of high-calcium limestone. CF & I Steel Corporation, Pueblo, has identified an area near Willow Peak on the adjacent Broken Rib Creek quadrangle that has been proven by core drilling to contain a sizeable resource of metallurgical limestone (Wark, 1980). Specific quality parameters pertaining to limestone feedstock for steel making applications (high calcium content—over 97 percent $CaCO_3$ and low silica content—less than 1 percent SiO_2) are frequently attainable in the Leadville Limestone, particularily in its upper part where dolomitization is less prevalent and away from the chert-bearing lower zones.

It is possible that zones of high-calcium limestone exist in the Devonian age Chaffee Group, but this is less likely. Any area within the quadrangle where the Leadville Limestone or other high-calcium rocks occur without appreciable overburden may be a target area for limestone development.

Lead and zinc minerals with minor copper and silver have been identified within the quadrangle near Windy Point (Strong Mine). The deposit was assayed at 24 percent zinc, 8.7 percent lead, 0.17 percent copper, and 0.81 troy ounces per short ton silver (Heyl, 1964). The minerals occur in small but rich "pods" within a fissure vein which strikes N. 50° E. and dips 44° NW. The mineralization is hosted in carbonate rocks of the Devonian Chaffee Group and the Mississippian Leadville Limestone. The ore consists of a mixture of lead and zinc minerals which are generally oxidized. At the time of the initial assessment of this deposit in 1944 by the U.S. Bureau of Mines, the ore was observed to occur only above a caved adit and in two small open cuts. When this site was visited in 1994 for this mapping project no ore was apparent in one recently driven adit (20 ft) nor was any of the described mineralization observable in surface exposures. This suggests a very discontinuous nature for these occurrences and, at best, a minor resource for this site. Other areas of lead-zinc-silver mineralization may occur in the quadrangle, however, none was observed during the course of field mapping. Other deposits similiar to those at Windy Point, if they do exist, are expected to be small and most likely sub-economic.

There are several thermal springs mostly associated with the Leadville Limestone and other carbonate rocks. Thermal springs near the city of Glenwood Springs are characterized by their high salinity, 18,000 to 22,0000 ppm sodium, temperatures ranging from 44° to 52°C, and flow rates of up to 5,000 liter per minute (Cappa and Hemborg, 1995).

Table 1. Major element, whole-rock analyses of the Glenwood Springs quadrangle.

Sample ID	Percent											
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	Cr_2O_3	P_2O_5	TiO_2	LOI*
GL-100	47.0	14.0	8.83	6.53	3.15	1.42	13.40	0.16	0.02	1.05	2.550	0.25
GL-146	47.3	14.4	7.40	8.35	2.92	2.05	11.40	0.15	0.03	0.67	1.770	1.95
GL-165B	49.5	15.1	8.11	6.76	2.96	1.23	11.80	0.15	0.03	0.46	1.520	1.70
GL-221	49.2	15.7	7.72	7.05	2.70	1.26	12.00	0.16	0.03	0.45	1.520	2.20
GL-306	50.2	15.2	7.17	6.62	3.12	2.31	11.10	0.15	0.03	0.66	1.810	0.75
GL-25	51.1	14.9	7.69	6.69	2.92	2.10	10.30	0.14	0.03	0.55	1.570	1.85
GMC-2	73.7	13.0	1.12	0.47	3.10	4.44	2.89	0.02	0.04	0.05	0.288	0.50
GNN-5	65.1	15.8	3.17	2.58	3.78	2.34	4.76	0.07	0.01	0.24	0.508	0.80
GCR-1	64.5	15.5	1.32	2.87	2.84	3.19	6.79	0.06	0.03	0.16	0.670	1.70
GNN-1	62.8	15.6	3.51	2.22	3.35	2.71	6.48	0.08	0.01	0.42	0.945	1.10

* Loss On Ignition

SAMPLE DESCRIPTIONS

GL-100: Coarse grained basalt flow exposed in roadcut at northwest end of Spring Valley: NW1/4NE1/4SE1/4 Sec. 24; T. 6 S.; R.89 W.

GL-146: Aphanitic basalt flow on ridge crest east of Glenwood Springs: SE1/4NE1/4SE1/4 Sec. 15; T. 6 S.; R. 89 W.

GL-165B: Aphanitic basalt flow exposed in quarry on Lookout Mountain: SE1/4SE1/4SE1/4 Sec. 12; T. 6 S.; R. 89 W.

GL-221: Vesicular, aphanitic basalt flow capping hilltop south of road into Paradise Valley from Mountain Springs Ranch: S1/2SW1/4NE1/4 Sec. 18; T. 6 S.; R. 89 W.

GL-306: Basalt flow exposed in roadcut in 10 acre subdivision west of north end of Spring Valley: NW1/4SE1/4SE1/4 Sec. 24; T. 6 S.; R. 89 W.

GL-25: Outcrop of basalt adjacent to road to Hughes Reservoir from Mountain Springs Ranch: SE1/4SW1/4SE1/4 Sec. 19; T. 6 S.; R. 89 W.

GMC-2: Gneissic quartz monzonite, Mitchell Creek: NE1/4NE1/4 Sec. 27; T. 5 S.; R. 89 W.

GNN-5: Medium-grained granite, 2.9 mi up No Name Creek just before aqueduct.

GCR-1: Biotite muscovite gneiss from outcrop on north side of Colorado River between No Name and Grizzly Canyons.

GNN-1: Coarse-grained, porphyroblastic granodiorite, Horseshoe Bend: SW1/4NE1/4 Sec. 3; T. 6 S.; R. 89 W.

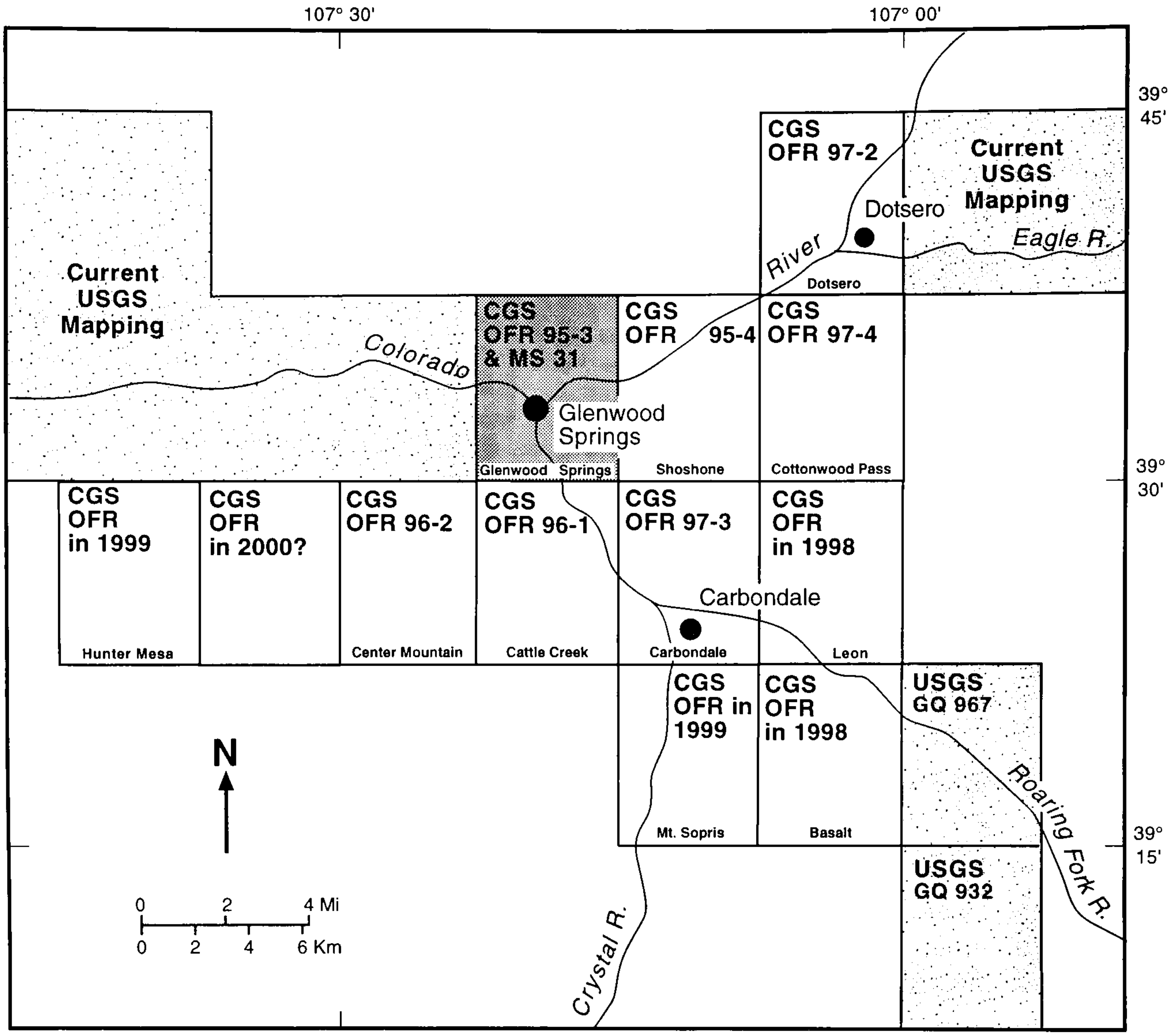


Figure 1. Status of geologic mapping of 7.5-minute quadrangles in the vicinity of Glenwood Springs. Glenwood Springs quadrangle is shaded.

SELECTED 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.

_____1953, Dotsero and Manitou Formations, White River Plateau, Colorado, with special reference to Clinetop algal limestone member of Dotsero Formation: American Association of Petroleum Geologists Bulletin, v. 37, no. 5, p. 889–912.

_____1963, Geology of Glenwood Springs quadrangle and vicinity, northwestern Colorado: U.S. Geological Survey Bulletin 1142-J, 74 p.

Bowen, T. 1988, Engineering geology of Glenwood Canyon, *in* Holden, G.S., ed., Geological Society of America Fieldtrip Guidebook, Centennial Meeting: Colorado School of Mines Professional Contributions 12, p. 408–418.

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

Bryant, B., and Shroba, R.R., 1997, Revised preliminary geologic map of the Storm King Mountain quadrangle, Garfield County, Colorado: U.S. Geological Survey Open-File Report (in preparation).

Campbell, J.A., 1970a, Stratigraphy of Chaffee Group (Upper Devonian), west-central Colorado: American Association of Petroleum Geologists Bulletin, v. 54, p. 313–325.

_____1970b, Petrology of Devonian shelf carbonates of west-central Colorado: The Mountain Geologist, v. 7, p. 89–97.

_____1972, Petrology of the quartzose sandstone of the Parting Formation in west-central Colorado: Journal of Sedimentary Petrology, v. 42, p. 263–269.

Cappa, J.A. and Hemborg, H.T., 1995, 1992–1993 low temperature geothermal assessment program, Colorado: Colorado Geological Survey Open File Report 95-1, 19 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.

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' x 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 Schroba, 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.

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. F1–17.

_____1971b, Permian deformation in the Eagle Basin, Colorado: U.S. Geological Survey Professional Paper 750-D, p. D80–D83.

Gale, H.S., 1910, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 415, 265 p.

Gerhard, L.C., 1972, Canadian depositional environments and paleotectonics, central Colorado, *in* DeVoto, R.H., ed., Paleozoic stratigraphy and structural evolution of Colorado: Colorado School of Mines Quarterly, v. 67, no. 4, p. 1–36.

Hallgarth, W.E., and Skipp, B.A., 1962, Age of the Leadville Limestone in the Glenwood Canyon, western Colorado: U.S. Geological Survey Professional Paper 450-D, p. D37–D38.

Heyl, A.V., 1964, Oxidized zinc deposits of the United States, Part 3, Colorado: U.S. Geological Survey Bulletin 1135-C, 98 p.

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, 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. 1–18.

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., Bryant, Bruce, Streufert, R.K., and Shroba, R.R., 1996a, Fieldtrip guidebook on the geology and geologic hazards of the Glenwood Springs area, Colorado, *in* Thompson, R.A., Hudson, M.R., and Pillmore, C.L., eds., Geologic excursions to the Rocky Mountains and beyond; Fieldtrip guidebook for the 1996 annual meeting of the Geological Society of America: Colorado Geological Survey Special Publication 44.

Kirkham, R.M., and Streufert, R.K., 1996, Neogene deformation in the Glenwood Springs–Carbondale–Gypsum area, Colorado [abs.]: Geologic Society of America Abstracts with Program, 1996 Annual Meeting, p. A-517.

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., Streufert, R.K., Hemborg, T.H., and Stelling, P.L., 1996b, Geologic map of the Cattle Creek quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 96-1.

Kirkham, R.M., and Widmann, B.L., 1997, Geologic map of the Carbondale quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 97-3.

_____in preparation, Geologic map of the Leon quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report.

Kirkham, R.M., Streufert, R.K., Scott, R.B., Lidke, D.J., Bryant, B., Perry, W.J., Jr., Kunk, M.J., Driver, N.E., and Bauch, N.J., 1997, Active salt dissolution and resulting geologic collapse in the Glenwood Springs region of west-central Colorado [abs.]: Geological Society of America Abstracts with Program, 1997 Annual Meeting, v. 29, no. 6, p. A-416.

Kunk, M.J., Kirkham, R.M., Streufert, R.K., Scott, R.B., Lidke, K.J., Bryant, B., and Perry, W.J., Jr., 1997, Preliminary constraints on the timing of salt tectonism and geologic collapse in the Carbondale and Eagle collapse centers, Colorado [abs.]: Geological Society of America Abstracts with Program, 1997 Annual Meeting, v. 29, no. 6, p. A-416.

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.

Lincoln-Devore Testing Laboratory, 1978, Geologic hazards of the Glenwood Springs metropolitan area, Garfield County, Colorado: Colorado Geological Survey Open-File Report 78-10, 27 p.

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.

Mears, A.I., 1977, Debris-flow-hazard analysis and mitigation—An example from Glenwood Springs, Colorado: Colorado Geological Survey Information Series 8, 45 p.

Mejia-Navarro, M., Wohl, E.E., and Oaks, S.D., 1994, Geological hazards, vulnerability, and risk assessment using GIS: model for Glenwood Springs, Colorado: Geomorphology, v. 10, p. 331–354.

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.

Murray, H.F., 1958, Pennsylvanian stratigraphy of the Maroon trough, *in* Curtis, B.F., ed., Symposium on Pennsylvanian rocks of Colorado and adjacent areas: Rocky Mountain Association of Geologists, p. 47–58.

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 [abs.]: 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: Geological 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., 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.

Soule, J.M., 1992, Precambrian to earliest Mississippian stratigraphy, geologic history, and paleogeography of northwestern Colorado and west-central Colorado: U.S. Geological Survey Bulletin 1787-U, 35 p.

Soule, J.M., and Stover, B.K., 1984, 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.

Stark, J.T., and Barnes, F.F., 1935, Geology of the Sawatch Range, Colorado: Colorado Scientific Society Proceedings, v. 13, no. 8., p. 467–479.

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.

Streufert, R.K. and Kirkham, R.M., 1996, Structural styles and age of deformation on the southern flank of the White River Uplift [abs.]: Geological Society of America Abstracts with Program, 1996 Annual Meeting, p. A-116.

Streufert, R.K., Kirkham, R.M., Schroeder, T.S., and Widmann, B.L., 1997a, Geologic map of the Dotsero quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 97-2.

Streufert, R.K., Kirkham, R.M., Widmann, B.L., and Schroeder, T.S., 1997b, Geologic map of the Cottonwood Pass quadrangle, Eagle and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report 97-4.

Streufert, R.K., Widmann, B.L., and Kirkham, R.M., in preparation, Geologic map of the Basalt quadrangle, Pitkin, Eagle, and Garfield Counties, Colorado: Colorado Geological Survey Open-File Report.

Tweto, Ogden and Lovering, T.S., 1977, Geology of the Minturn 15-minute quadrangle, Eagle and Summit Counties, Colorado: U.S. Geological Survey Professional Paper 956, 96 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, I.G., 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.

Wark, J.G., 1980, Development of a metallurgical limestone deposit, *in* Schwochow, S.D., ed., Proceedings of the Fifteenth Forum on Geology of Industrial Minerals: Colorado Geological Survey Resource Series 8, p. 53–62.

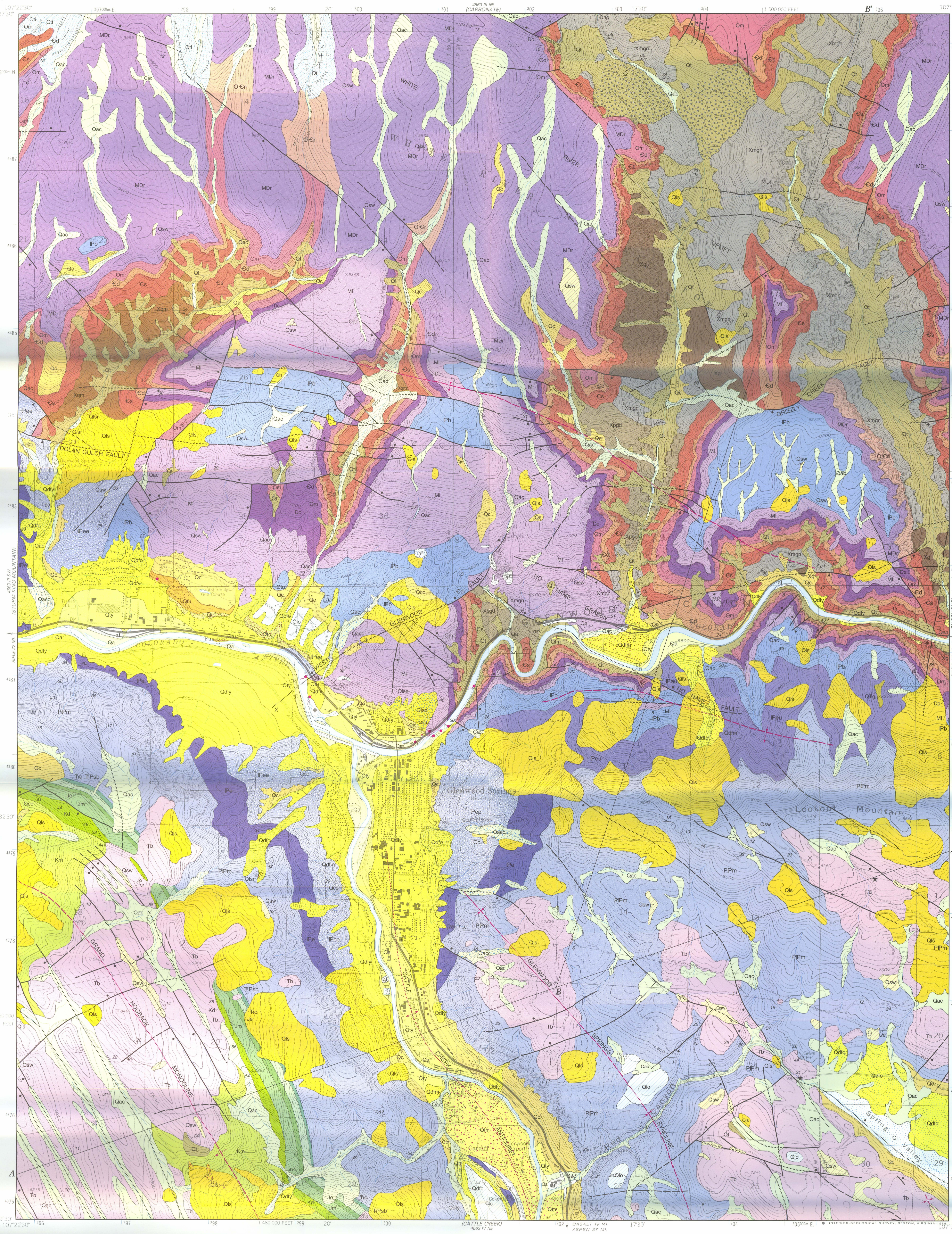
Wetherill, G.W., and Bickford, M.E., 1965, Primary and metamorphic Rb-Sr chronology in central Colorado: Journal of Geophysical Research, v. 70, no. 18, p. 4669–4686.

COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES

MAP SERIES 31

GEOLOGIC MAP OF THE GLENWOOD SPRINGS QUADRANGLE, GARFIELD COUNTY, COLORADO

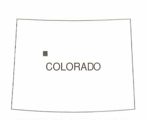
Booklet accompanies map



Base from U.S. Geological Survey, 1987
10,000-foot grid based on Colorado coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 13

UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
1°29′ 26 MILS
12½° 222 MILS

SCALE 1:24,000
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



QUADRANGLE LOCATION

Geology mapped in 1993, 1994 and 1996; assisted by Peter L. Stelling in 1994

CONDENSED DESCRIPTION OF MAP UNITS

The complete description of map units and references is in the accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**

ALLUVIAL DEPOSITS—Sediments deposited in stream channels, flood plains, terraces, debris fans, and sheet-wash areas

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix up to about 15 ft above modern rivers

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Gravelly sand, sandy silt, and clayey silt deposited on gentle hillslopes, in small basins, and in stream valleys

Qty — **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel with a sand matrix. May include fine-grained overbank deposits. Underlies terraces about 19-56 ft above modern rivers

Qtm — **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally similar to younger terrace alluvium (Qty). Underlies terraces about 58-95 ft above modern rivers

Qto — **Older terrace alluvium (middle Pleistocene)**—Deposits texturally similar to younger terrace alluvium (Qty). Underlies terraces about 110-160 ft above modern rivers

Qtt — **Oldest terrace alluvium (middle Pleistocene)**—Deposits similar in texture to younger terrace alluvium (Qty). Underlies a terrace west of Glenwood Springs airport about 220-360 ft above the Roaring Fork River

QTg — **High-level gravel (early Pleistocene or Pliocene)**—Includes a single, very poorly exposed deposit of rounded river gravel found about 1,500 ft above the Colorado River near the north quarter-corner of sec. 7, T. 6 S., R. 88 W

COLLUVIAL DEPOSITS—Sediments on valley sides, valley floors, and hillslopes mobilized, transported, and deposited primarily by gravity

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes active and recently active landslides with fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified rock debris, gravel, sand, silt and clay

Qc — **Colluvium (Holocene and late Pleistocene)**—Matrix-and clast-supported, pebble to boulder gravel in a sandy silt matrix. Locally fine grained

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from bedrock outcrops and transported by rockfalls, rockslides, rock avalanches, and rock topples. Deposits marked by triangular pattern in No Name Creek indicate two very large, rapid rotational rockslides or rock topples

Qls — **Landslide deposits (Holocene and Pleistocene)**—Similar in texture to recent landslide deposits (Qlsr). Ranges in age from recently active landslides to long-inactive Pleistocene landslides

Qco — **Older colluvium (Pleistocene)**—Highly variable deposits texturally similar to colluvium (Qc), but generally not subject to future deposition

Qlso — **Older landslide deposits (Pleistocene and late Pliocene?)**—Landslide deposits dissected by erosion that lack distinctive landslide morphology. Similar in texture to recent landslide deposits (Qlsr)

ALLUVIAL AND COLLUVIAL DEPOSITS—Sediments in debris fans, stream channels, flood plains, and hillslopes along tributary valleys

Qdfy — **Younger debris-flow deposits (Holocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported, pebble, boulder, and cobble gravel in a sandy silt or silty sand matrix. Distal fan areas are finer grained. Deposited as debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans

Qac — **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Moderately well-sorted to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt

Qdfm — **Intermediate debris-flow deposits (Holocene and late Pleistocene)**—Similar in texture and depositional environment to younger debris-flow deposits (Qdfy), but found 15-40 ft above adjacent streams

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally similar to alluvium and colluvium, undivided (Qac), that underlie terraces and hillslopes above the floor of tributary valleys

Qdfo — **Old debris-flow deposits (late, middle, and early? Pleistocene)**—Remnants of long-inactive debris fans found on ridge lines, mesas, and valley floors 40-320 ft above adjacent streams. Similar in texture to younger debris-flow deposits (Qdfy)

GLACIAL DEPOSITS

Qti — **Till (late and/or middle? Pleistocene)**—Heterogenous deposits of gravel, sand, silt, and minor clay deposited in lateral, end, and ground moraines

LACUSTRINE DEPOSITS

Ql — **Lacustrine deposits (Quaternary)**—Well stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, and medium-red-brown, well-sorted, coarse sand deposited in Spring Valley

EOLIAN DEPOSITS

Qlo — **Loess (late and middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind on level to gently sloping surfaces. Usually unstratified, friable, and plastic or slightly plastic when wet

SINTER DEPOSITS

Qtu — **Tufa (Holocene and Pleistocene?)**—Low density, porous calcium carbonate deposits precipitated from mineral-charged spring water. A conventional radiocarbon age of 12,410 ± 60 ^{14}C years BP was obtained from peat interbedded with tufa that overlies younger terrace alluvium near Funston (D. Trimble, 1995, written commun.).

UNDIFFERENTIATED DEPOSITS

Q — **Undifferentiated surficial deposits (Quaternary)**—Shown only on cross sections

BEDROCK

Tb — **Basalt (Miocene)**—Multiple flows of basalt and trachybasalt interbedded with fluvial and lacustrine sediments. A whole rock sample of basalt exposed in a roadcut at the northwest end of Spring Valley was dated at 22.4 ± 0.3 Ma using the $^{40}Ar/^{39}Ar$ method (L. Snee, written commun., 1995)

Kmv — **Mesaverde Group (Upper Cretaceous)**—Shown only on cross section A-A′

Km — **Mancos, Niobrara, Frontier, and Mowry Formations, undivided (Upper Cretaceous)**—Includes in ascending order: siliceous, gray to black shale of the Mowry Shale; the calcareous Frontier Sandstone, a calcareous shale zone equivalent to the Niobrara, and the dominantly light- to dark-gray, sometimes bentonitic, carbonaceous shale unit that comprises the Mancos Shale

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

Jm — **Morrison Formation (Upper Jurassic)**—Pale-green and maroon mudstone and shale and gray limestone. Thin beds of silty sandstone in lower part

Je — **Entrada Sandstone (Upper Jurassic)**—Light-gray to light-orange, cross-bedded sandstone. Medium to very fine grained and well sorted

TRc — **Chinle Formation (Upper Triassic)**—Thin, even bedded, 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

TRPsb — **State Bridge Formation (Lower Triassic? and Permian)**—Includes upper and lower members composed of pale-red, grayish-red, reddish-brown, and greenish-gray, micaceous siltstone, clayey siltstone, and minor sandstone that are separated by the South Canyon Creek Member, a prominent, thin bed of sandy dolomite and sandy limestone

PIPm — **Maroon Formation (Permian and Pennsylvanian)**—Mainly reddish-brown sandstone, conglomerate, mudstone, siltstone, and claystone with minor, thin beds of gray limestone. Includes Schoolhouse Member at top of formation

IPe — **Eagle Valley Formation (Middle Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and perhaps intertonguing with the Maroon Formation and Eagle Valley Evaporite

IPee — **Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and plastically deformed

IPeu — **Eagle Valley Formation and Eagle Valley Evaporite, undivided (Middle Pennsylvanian)**—Includes Eagle Valley Formation and Eagle Valley Evaporite where contact between units is not mappable

IPb — **Belden Formation (Lower Pennsylvanian)**—Medium-gray to black, calcareous shale and fossiliferous limestone with interbeds of fine-grained micaceous sandstone, gritstone, coaly shale, and gypsum

Ml — **Leadville Limestone (Mississippian)**—Gray to bluish-gray, coarse to finely crystalline limestone and dolomite. Abundant chert nodules in lower part of formation

Dc — **Chaffee Group (Upper Devonian)**—Includes in ascending order: Parting Formation-white to buff orthoquartzite, green shale, and gray dolomite; Dyer Dolomite-limestone and dolomite; and Gilman Sandstone-tan to yellow, fine-grained dolomitic sandstone

MDr — **Mississippian/Devonian rocks-undivided (Mississippian and Upper Devonian)**

Om — **Manitou Formation (Lower Ordovician)**—Flat-pebble limestone conglomerate, brown and tan crystalline dolomite, and greenish-gray calcareous shale

€d — **Dotsero Formation (Upper Cambrian)**—Thin-bedded, brown to tan sandy dolomite and dolomitic sandstone with abundant glauconite, and pinkish light-gray to light-gray algal limestone

€s — **Sawatch Quartzite (Upper Cambrian)**—White to buff, massive, medium-grained orthoquartzite and arkosic quartz-pebble conglomerate. Unit includes possible Peerless Formation equivalent sandy dolomites, and unnamed beds of white quartzite and quartzose sandstone

O-€r — **Ordovician and Cambrian rocks, undivided (Upper Cambrian-Lower Ordovician)**

PRECAMBRIAN ROCKS

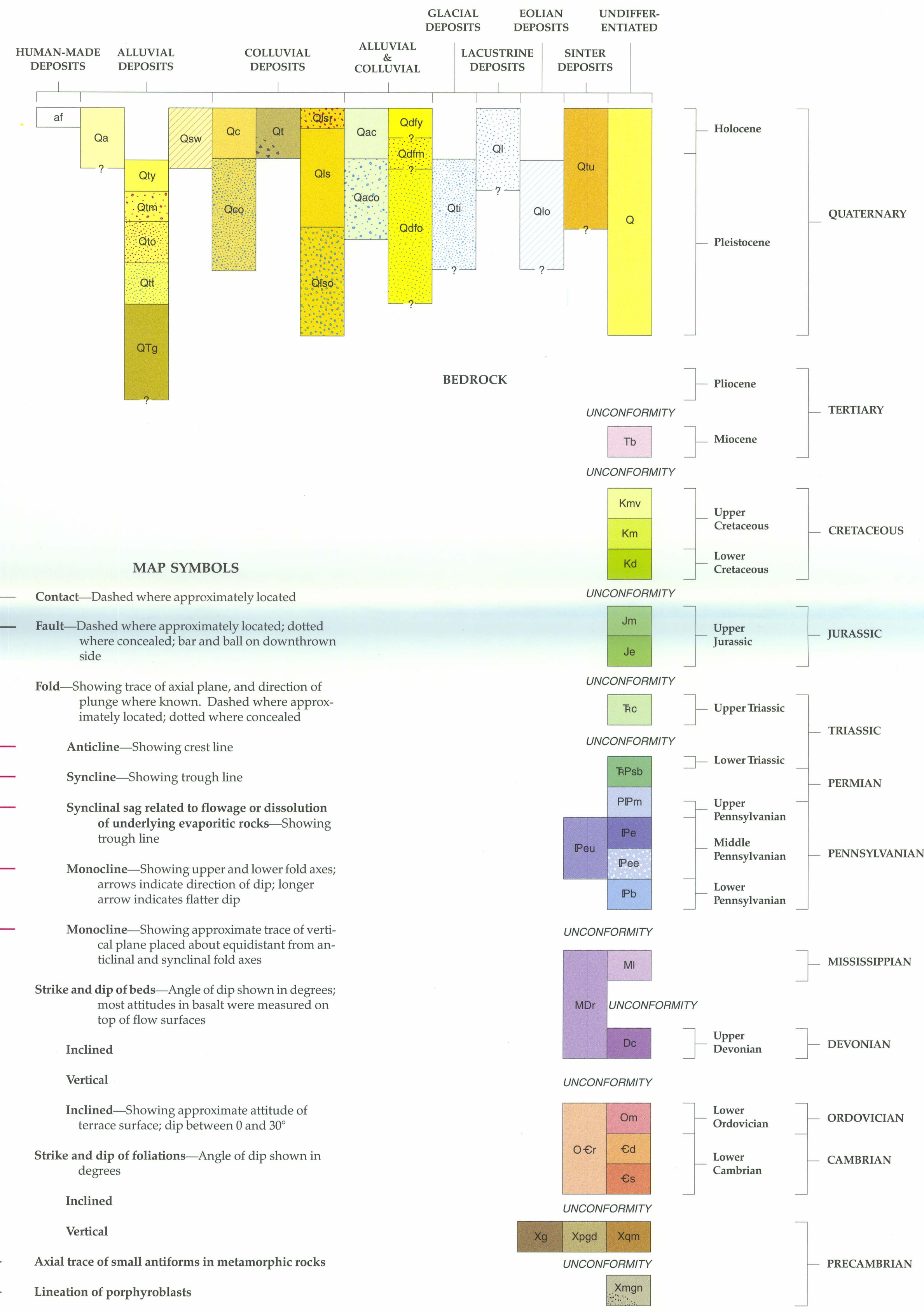
Xg — **Biotite granite (Proterozoic)**—Dark-gray and white-speckled, fine- to coarse-grained, equigranular granite and granodiorite

Xpgd — **Porphyroblastic biotite granodiorite of No Name Canyon (Proterozoic)**—Coarse-grained, inequigranular, granodiorite with large, pink euhedral porphyroblasts of orthoclase

Xqm — **Gneissic quartz monzonite of Mitchell Creek (Proterozoic)**—Fine- to medium-grained, equigranular, foliated, quartz monzonite

Xmgn — **Biotite-muscovite gneiss (Proterozoic)**—Well to poorly foliated biotite-muscovite gneiss. Stipple pattern indicates areas where locally pegmatitic

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side

Fold—Showing trace of axial plane, and direction of plunge where known. Dashed where approximately located; dotted where concealed

Anticline—Showing crest line

Syncline—Showing trough line

Synclinal sag related to flowage or dissolution of underlying evaporitic rocks—Showing trough line

Monocline—Showing upper and lower fold axes; arrows indicate direction of dip; longer arrow indicates flatter dip

Monocline—Showing approximate trace of vertical plane placed about equidistant from anticlinal and synclinal fold axes

Strike and dip of beds—Angle of dip shown in degrees; most attitudes in basalt were measured on top of flow surfaces

14 **Inclined**

Vertical

Inclined—Showing approximate attitude of terrace surface; dip between 0 and 30°

Strike and dip of foliations—Angle of dip shown in degrees

7 **Inclined**

Vertical

62 **Axial trace of small antiforms in metamorphic rocks**

37 **Lineation of porphyroblasts**

Moraine crest—Crest of lateral and end moraines

Thermal spring

Gravel pit

Quarry

Locality of rock sample—Radiometrically dated using the $^{40}Ar/^{39}Ar$ method

Locality of radiocarbon sample—Radiometrically dated using the ^{14}C method

Sinkhole in surficial deposits.

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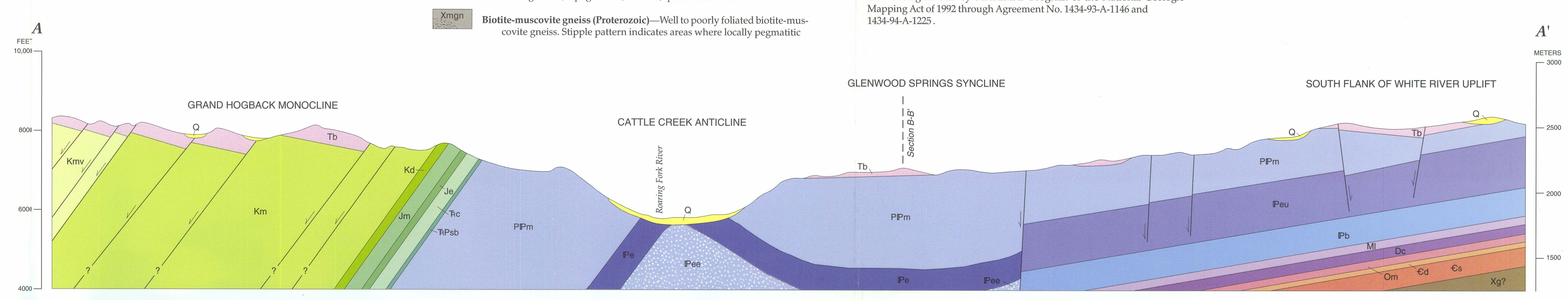

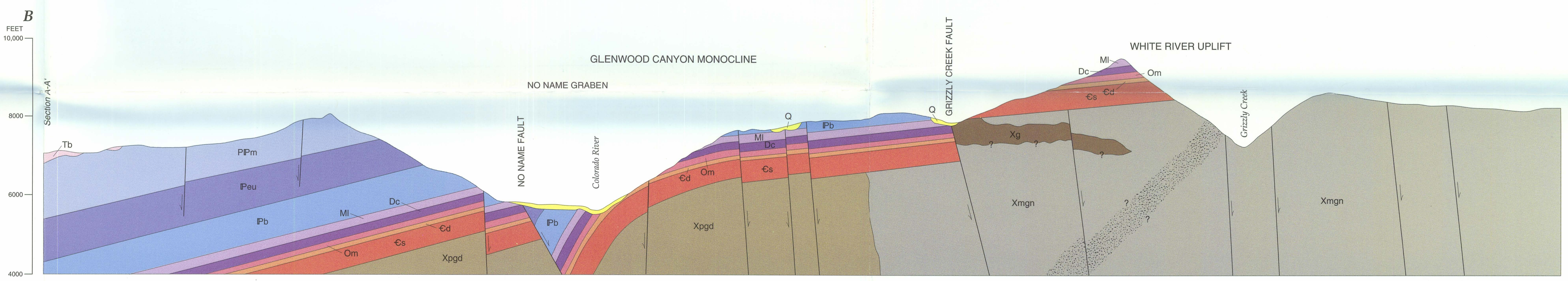

GEOLOGIC MAP OF THE GLENWOOD SPRINGS QUADRANGLE, GARFIELD COUNTY, COLORADO

By
Robert M. Kirkham, Randall K. Streufert, and James A. Cappa
1997