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Geologic Map of the Carbondale Quadrangle, Garfield County, Colorado

Geologic Setting, Description of Map Units, Economic Geology, and References

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GEOLOGIC SETTING

Over the past four years the Colorado Geological Survey has mapped the geology of several 7.5-minute quadrangles in the Glenwood Springs-Carbondale-Dotsero area, and additional quadrangles are scheduled to be mapped in future years (Figure 1). The U.S. Geological Survey is mapping 7.5-minute quadrangles in adjacent areas.

This region is geologically fascinating and at times has been very perplexing. Interpretation of widespread evidence of Neogene deformation has been especially challenging. It is becoming increasingly apparent to us that salt tectonism and salt dissolution play major roles in the pervasive Neogene deformation found in this region.

Evaporitic diapirism in this area was first proposed by Mallory (1966). Murray (1969) suggested that flexural slip along the Grand Hogback Monocline was responsible for faulting of Neogene lava flows that unconformably overlie

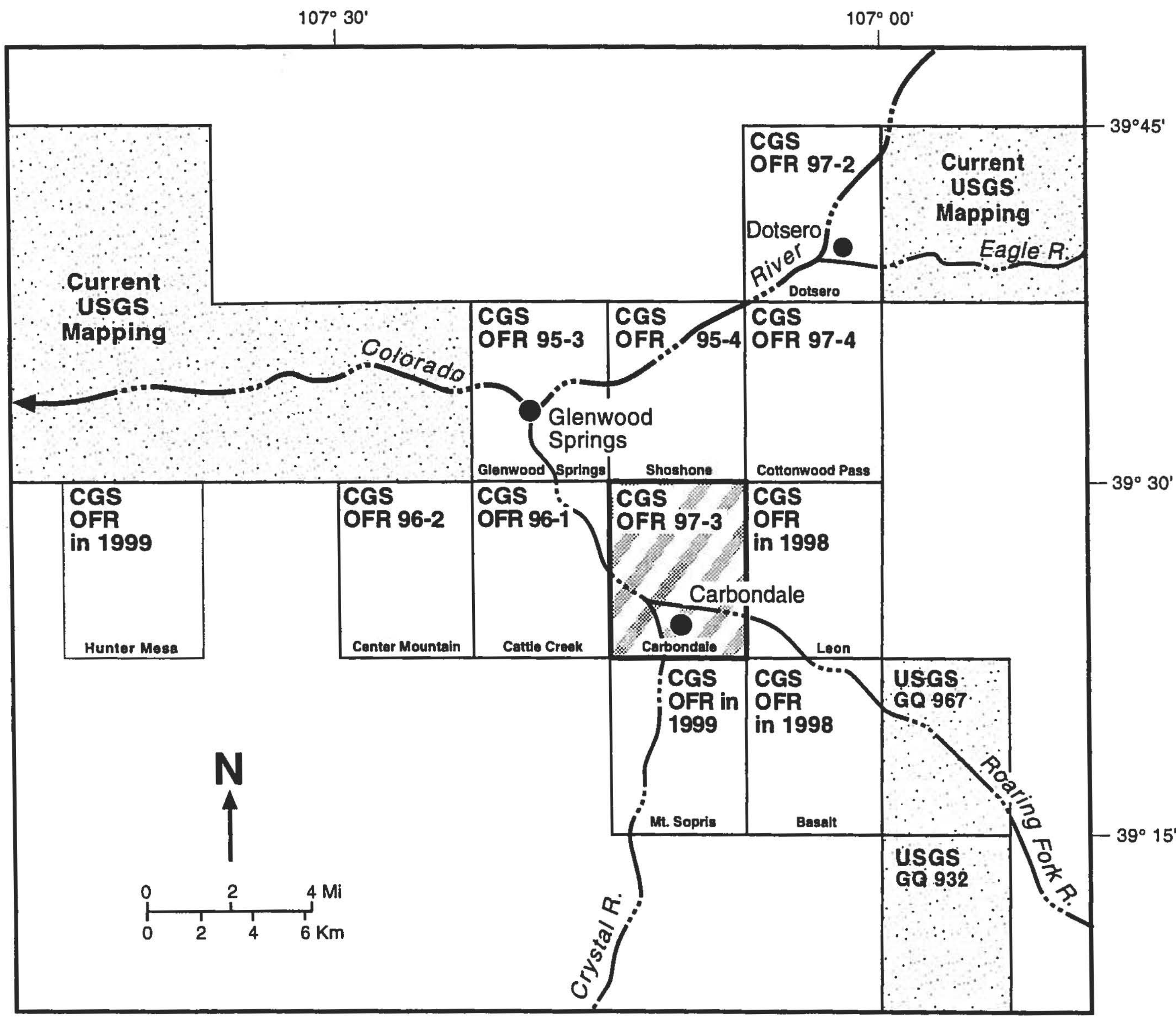

Figure 1. Status of geologic mapping of 7.5-minute quadrangles in the vicinity of Glenwood Springs.

the monoclinally folded early Cenozoic and older rocks. Tweto (1977) concluded that evaporite flowage initiated during Late Permian time and was responsible for abrupt local thickening of the State Bridge and Chinle Formations and possibly the Maroon Formation and for several structural features in the region. Stover (1986) described evidence of late Quaternary deformation at a few locations and proposed evaporitic diapirism and dissolution as possible causative mechanisms. Unruh and others (1993) confirmed much of the prior work, found other young structures, and reported that flowage, diapirism, and dissolution of evaporites could cause the deformation.

In the following paragraphs we describe and interpret some of the unusual shallow structural features within the upper crust of the area. Our mapping program is ongoing, so this discussion should be considered a progress report; our theories may evolve as further studies are completed, particularly studies of deeper crustal structure.

A map showing the tectonic setting of the region is shown in Figure 2. The Carbondale quadrangle is in part on a shallow structural

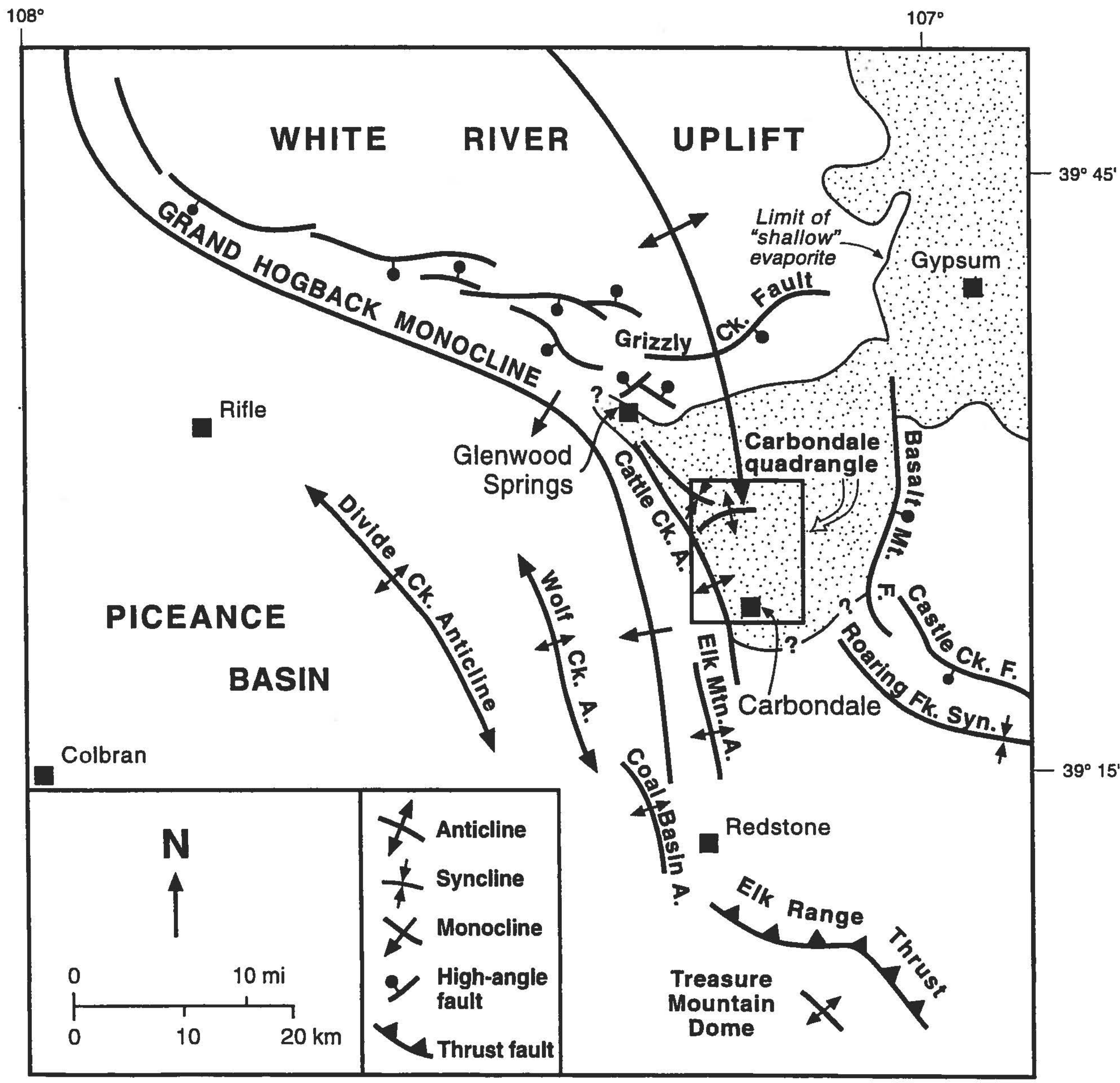

Figure 2. Regional tectonic map. (modified from Tweto, 1979; Tweto and others, 1978.) Stipple pattern indicates area where evaporite rocks lie at or near the ground surface.

bench that lies between several well-known folds, faults, and uplifts. On the west it is bounded by the Cattle Creek Anticline, which is the upper limb or anticlinal flexure of the Grand Hogback Monocline, a late Laramide structure that forms the east flank of the Piceance Basin. The Grand Hogback Monocline has experienced renewed structural activity since the middle Miocene; however its Neogene movement is opposite in direction from its Laramide (Murray, 1966; Kirkham and others, 1996b). The Cattle Creek Anticline at least locally has been modified by diapirism (Mallory, 1966; Kirkham and others, 1996b). On the east the shallow structural bench is bordered by the Basalt Mountain Fault, a high-angle, down-to-the-east, probably reverse fault (Streufert and others, 1997b). The Basalt Mountain Fault is primarily a Laramide structure, but it also has been reactivated during the Neogene in a reverse fashion from its Laramide movement. To the north the shallow structural bench merges with the gently southward-dipping south limb of the White River Uplift, another late Laramide feature. The south boundary of the structural bench is less well understood; for this report we assume it terminates against the northwest end of the Roaring Fork Syncline. The shallow structural bench lies within and is in part responsible for an area where evaporitic rocks either crop out or occur at shallow depths beneath the ground surface (Figure 2).

Since most of the Carbondale quadrangle lies on the shallow structural bench or on the southern, gently dipping end of the south flank of the White River Uplift, one would expect bedrock within it to be relatively undeformed; broad folds, gently dipping homoclines, and minor faults should be the norm. However, bedrock exposed in the quadrangle (which includes only the Eagle Valley Evaporite and younger formations) is moderately to severely deformed. Much of the deformation is of Neogene age and consists of unusual structures such as 1) linear or arcuate synclinal sags, some with faulted limbs, 2) intrusive contacts between sedimentary formations, 3) sets of orthogonal faults, 4) circular, elliptical, rectangular, and irregularly shaped bowl-like structural troughs of varying sizes, 5) a large, arcuate, half graben whose floor was occupied by a lake until drained by homesteaders, 6) valley anticlines, and 7) complexly deformed, highly broken and brecciated blocks of randomly oriented bedrock which we classify as Pleistocene and/or late Tertiary collapse debris.

As shown in Figure 3, these distinctive structures are pervasive wherever evaporitic rocks lie at or near the land surface both on the structural bench and on the gently dipping south flank of the White River Uplift (Kirkham and others, 1995a; Kirkham and others, 1996a, b; Streufert and others, 1997b). Many of the structural sags, troughs, and bowls contain locally derived sediments eroded from adjacent uplands; we have named these deposits the Sediments of Missouri Heights on Carbondale quadrangle. They also are deformed, but much less so than underlying bedrock formations. We contend that this unusual deformation is restricted to the Eagle Valley Evaporite and overlying deposits. Bedrock older than the Eagle Valley Evaporite has not been affected by the salt tectonism and dissolution. Geomorphically these unusual structures have combined to create a landscape that has the classic characteristics of karst topography. Open voids and caverns can be seen in many outcrops of the Eagle Valley Evaporite, and sinkholes, some quite large, have developed in bedrock formations overlying the evaporitic rocks.

As first reported by Mallory (1966), Quaternary deposits may be affected by this unusual type of deformation. River terraces are upwarped away from modern river channels. Large, broad, closed or nearly closed depressions and swales that we interpret as subsidence troughs have developed in many outwash terraces. Sinkholes are locally abundant in surficial deposits. Drainage patterns and the extent of many of the basin-filling surficial deposits are influenced by the sinkholes and subsidence troughs, folded river terraces, folded and faulted bedrock, and collapse debris.

A prominent regional topographic depression coincides in part with the area where evaporitic rocks lie at or near the ground surface. The topographic depression is as much as 4,000 ft lower in elevation than surrounding terrane. We interpret the topographic depression as a large collapse block that has resulted from dissolution and flowage of evaporitic rocks from beneath the area. Neogene igneous rocks are well preserved within

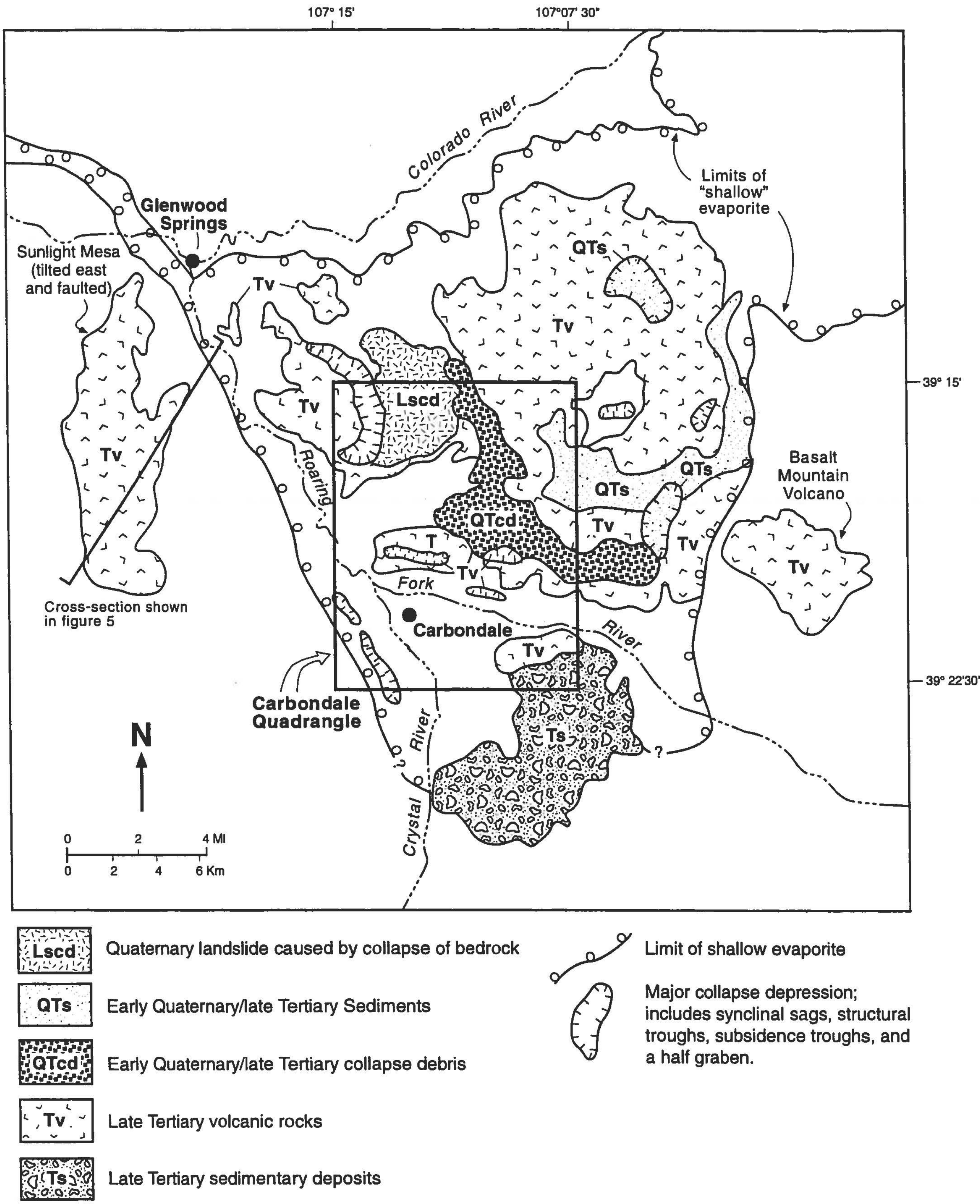

Figure 3. Distribution of shallow evaporites, Neogene volcanic rocks, collapse debris, and major collapse depressions (modified from Tweto and others, 1978; Kirkham and others, 1996a, 1996b; Streufert and others, 1997a, 1997b). Some map units are not labeled.

the down-dropped collapse block (Figure 4). Both the lateral extent and amount of vertical collapse is defined by structural deformation within the Neogene igneous rocks. The synclinal sags, intrusive contacts between sedimentary formations, orthogonal fault sets, bowl-like structural

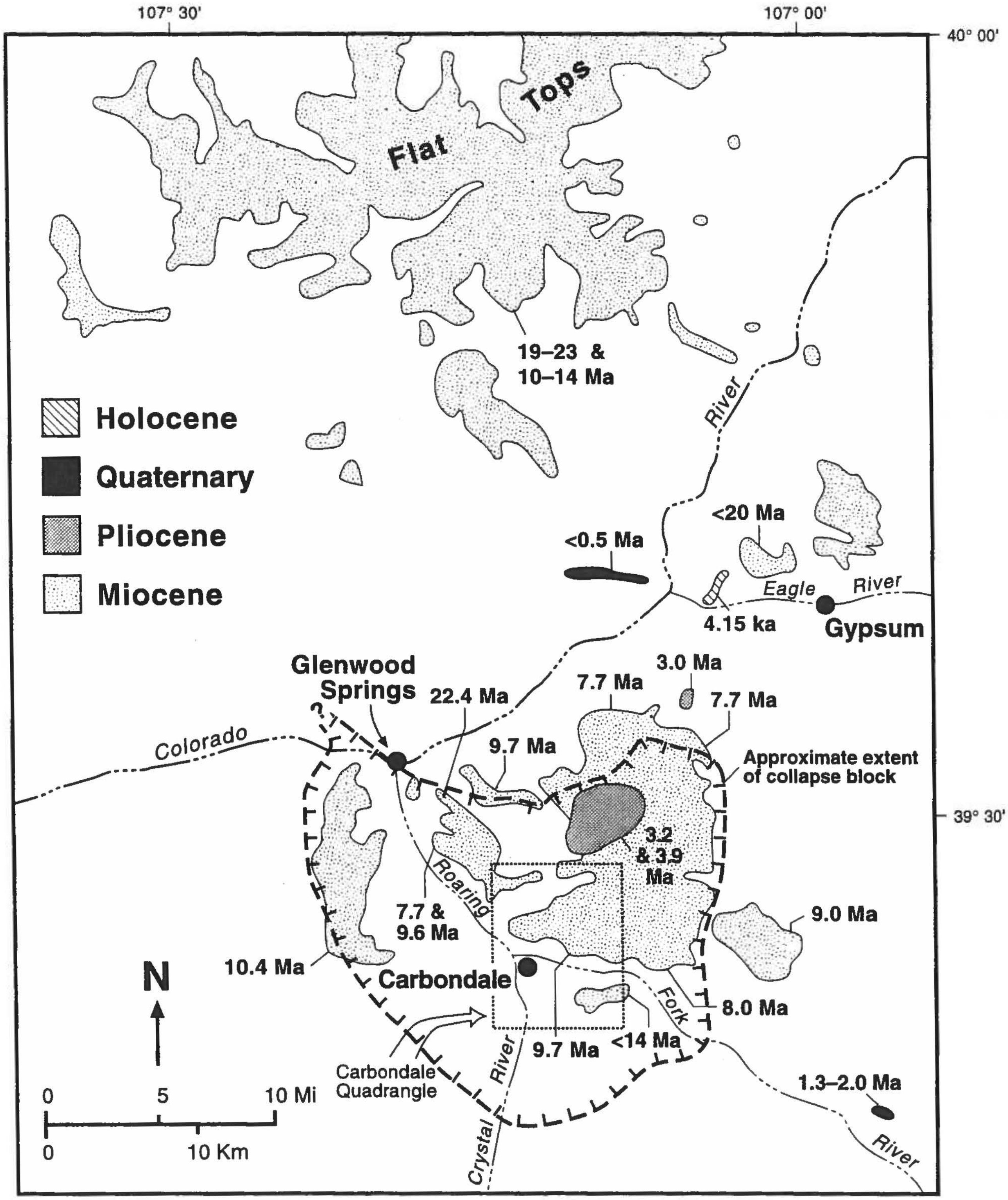

Figure 4. Generalized distribution of Neogene igneous rocks (after Tweto, 1978; Tweto and others, 1978; Larson and others, 1975; Kirkham and others, 1995a, b; Carroll and others, 1996; Streufert and others, 1997a, 1997b). Dashed line with barbs indicates approximate extent of collapse block.

troughs, arcuate half graben, valley anticlines, collapse debris, and folded Pleistocene outwash terraces occur within the collapse block.

Existence of thick sequences of halite in the subsurface beneath this region is best documented by the Shannon Oil Rose No. 1 well, which was drilled on the Cattle Creek Anticline near the confluence of Cattle Creek and the Roaring Fork River about 1.4 miles west of the Carbondale quadrangle (Mallory, 1966, 1971; Kirkham and others, 1996b). The lower 900 ft of this well was drilled in almost pure halite, and drilling stopped without penetrating through the evaporite sequence. We suspect that halite and gypsum within the Eagle Valley Evaporite have been tectonically thickened beneath the Cattle Creek Anticline. Evaporitic rocks may well have been trapped against the Grand Hogback Monocline as Laramide compressional stresses shortened the crust in this region. Tweto (1977) described other areas in the region where evaporite flowage played a major role influencing depositional patterns and structures.

Evidence for dissolution includes the widespread occurrence of voids and caverns within the Eagle Valley Evaporite and sinkholes, subsidence troughs, and synclinal sags in deposits overlying it. Hot springs in the region, such as those at Glenwood Springs and Dotsero, have sodium, chloride, calcium, and sulfate concentrations ranging from about 9 to 20 grams per liter and combined discharges around 3,000 gallons per minute (Barrett and Pearl, 1976). These high salt concentrations also indicate the dissolution process is active today. On the basis of analyses and flow rates in Barrett and Pearl (1976), Yampa Spring, which supplies water for Glenwood hot springs pool, discharges about 260 tons or about

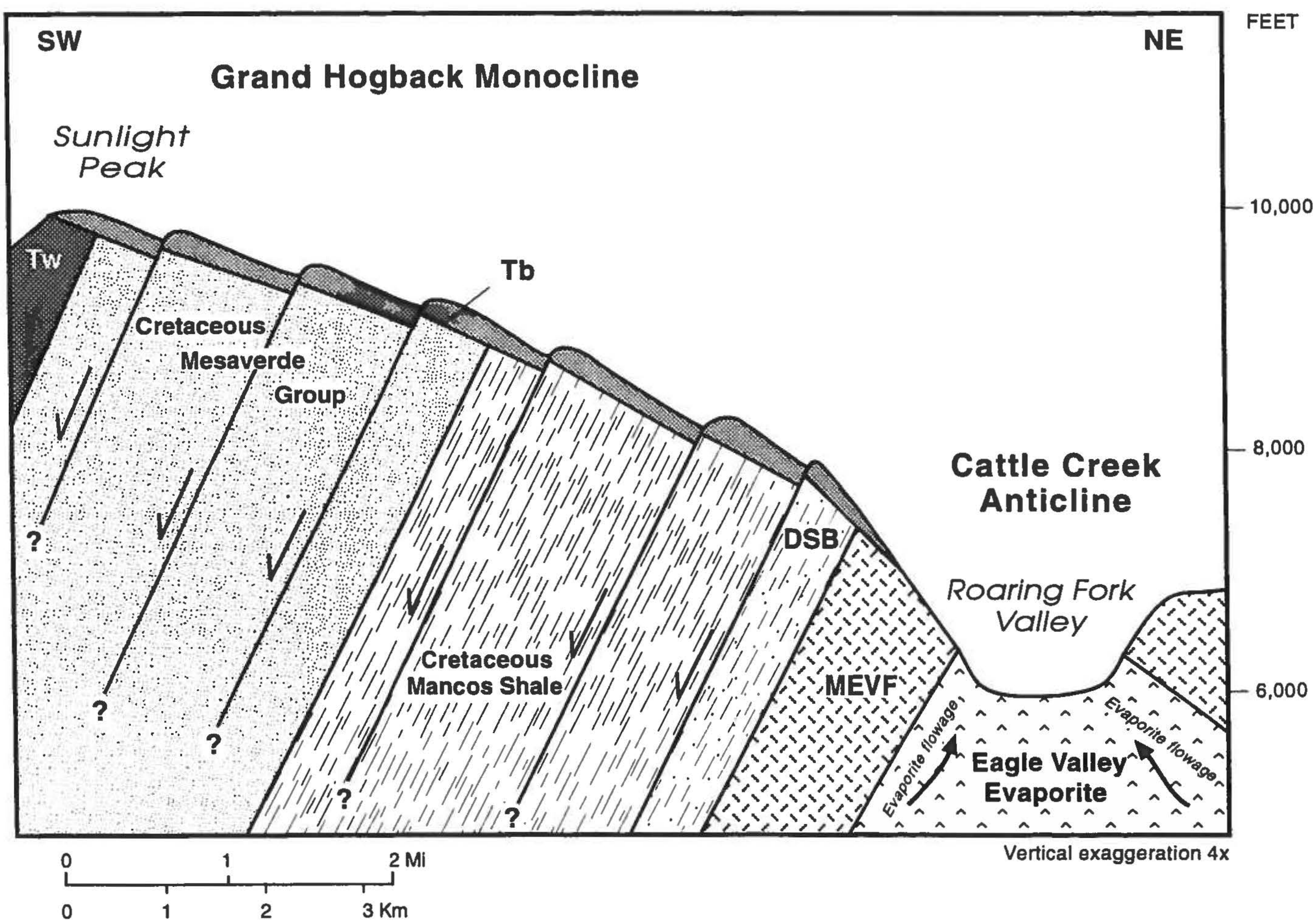

Figure 5. Schematic cross section from Sunlight Peak to the Roaring Fork Valley. ***MEVF****—Pennsylvanian Maroon and Eagle Valley Formations;* ***DSB****—Cretaceous Dakota Sandstone through Triassic–Permian State Bridge Formation;* ***TW****—Paleocene and Eocene Wasatch Formation;* ***Tb****—Miocene basalt.*

120 cubic yards of salt each day to the Colorado River system. Yampa Spring alone would be responsible for the dissolution of one cubic mile of salt in about 110,000 years. Similar types of springs existed for much of the Pleistocene and perhaps since late Miocene or early Pliocene time when rivers began eroding deeply into the evaporitic rocks. Over a period of several million years salt loadings from the numerous springs and from saline ground water directly entering alluvial aquifers could account for the dissolution of well over one hundred cubic miles of halite and gypsum. This process may explain the volume loss required to generate a collapse block the size of which we are herein proposing.

Neogene deformation along the Grand Hogback Monocline involves 1) regional down-to-the-east tilting of Miocene basalt flows that unconformably overlie moderately west-dipping sedimentary formations within the monocline and 2) a series of subparallel bedding plane faults that closely follow the bedding of the moderately west-dipping sedimentary beds and offset overlying Neogene deposits (Murray, 1966, 1969; Kirkham and others, 1995a, 1996a, b; Carroll and others, 1996). As shown in Figure 5, the bedding plane faults are downthrown to the west, but blocks of basalt between the faults dip as much as about 30° eastward, opposite that of the underlying pre-Laramide sedimentary formations. This type of deformation can be explained by dissolution of evaporitic rocks that underlie the monocline or by flowage of them towards the Roaring Fork Valley. As the evaporites are removed, the monocline relaxes or "unfolds", causing regional tilting to the east. Dips of sedimentary rocks within the monocline decrease as relaxation progresses. While the monocline relaxes strain also occurs as differential slippage on bedding planes, creating a series of subparallel faults along which the unconformably overlying Neogene deposits are downdropped to the west. Neogene deposits between the faults are also tilted eastward.

Synclinal sags, the bowl-like structural troughs in bedrock, the half graben of Spring Valley, and the presence of collapse debris all can be explained by locally intense subsidence within the regional collapse block. Features such as valley anticlines and intrusive sedimentary contacts are probably a result of diapirism. Folded outwash terraces are a product of either dissolution-induced, localized subsidence and/or diapiric processes focused along river channels where overburden pressures are at a minimum.

As demonstrated by Larson and others (1975), Neogene igneous rocks are prevalent across much of this part of west-central Colorado (Figure 4), which leads one to assume that the crust in this region must have been fractured and probably was faulted during the Neogene. Igneous activity has occurred as recently as 4,150 years B.P. at Dotsero volcano (Giegengack, 1962; Streufert and others, 1997a). However, much and perhaps all the demonstrable Neogene deformation within the area where evaporitic rocks are at shallow depths and in the adjoining Grand Hogback Monocline appears to be directly due to salt tectonism and salt dissolution. Neogene crustal tectonism related to regional extension, if present within this area, is masked by the salt-related deformation.

A critical element in understanding the timing and rates of collapse involves accurate correlation of the various Neogene volcanic rocks which lie within and adjacent to the collapse block. A cooperative effort to unravel the volcanic stratigraphy of the area using petrography, geochemistry, paleomagnetism, and $^{40}Ar/^{39}Ar$ dating has recently been undertaken by the Colorado Geological Survey and U.S. Geological Survey.

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 and by the deformation which affects many of terraces, altering their relative heights above stream level. Morphological stages of secondary calcium carbonate used herein are those described by Gile and others (1966).

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**—Composed mostly of unsorted silt, sand, and rock fragments deposited during the construction of dams, sewage treatment plants, and tunnels and of trash placed in landfills. Maximum thickness is estimated at 50 ft. Artificial fill may be subject to settlement when loaded, if not adequately compacted. Landfills may have environmental concerns such as venting of methane gas and contaminated ground water.

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

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Includes modern alluvium and other deposits underlying the Roaring Fork and Crystal Rivers, adjacent flood-plain deposits, and low-terrace alluvium that is as much as about 12 ft above modern stream level. Mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel in a sandy or silty matirx 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. Deposits along the Roaring Fork River above Carbondale are rich in clasts of Proterozoic plutonic rocks, whereas those along the Crystal River are rich in middle Tertiary hypabyssal rocks and contain distinctive clasts of green hornfels, probably derived from metamorphosed Morrison Formation. Unit may locally include organic-rich deposits. It may be interfingered with younger debris-flow deposits where the distal ends of fans extend into modern river channels. Maximum thickness is estimated at about 50 ft. Flood-plain and terrace deposits included in this unit correlate with deposits in terrace T8 of the Carbondale-Glenwood Springs area of Piety (1981). Low-lying areas are subject to flooding. Unit 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 shale, basalt, red beds, collapse debris, 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 14 to 45 ft above modern stream level. May be capped by a single, thin loess sheet. Stream alluvium is mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand matrix, but unit may include fine-grained overbank deposits. Clasts are mainly subrounded to rounded and are comprised of a variety of lithologies reflecting the diverse types of bedrock found in the drainage basin. Deposits along the Crystal River generally are rich in clasts of middle Tertiary hypabyssal rocks and contain distinctive clasts of green hornfels, whereas deposits along the Roaring Fork River above Carbondale are rich in coarse-grained Precambrian plutonic clasts. Clasts generally are unweathered or only slightly weathered. Thickness ranges widely but probably averages 30 to 40 ft.

North of the quadrangle at the rest area on Highway I-70 in West Glenwood Springs, peat interbedded with tufa that overlies a terrace deposit 19 ft above the Colorado River yielded a ^{14}C date of 12,410 ± 60 years B.P. (Kirkham and others, 1995a; 1996a), providing a minimum age for that terrace. This dated deposit correlates in part with younger terrace alluvium (Qty) in the Carbondale quadrangle. Unit includes deposits in terrace T7 in the Carbondale-Glenwood Springs area described by Piety (1981) and may also correlate with terrace A of Bryant (1979) in the Aspen area and in part with younger terrace alluvium of 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. Younger terrace deposits are locally very slightly tilted away from the Roaring Fork River by upwarping believed to be related to evaporitic diapirism and/or to collapse or subsidence induced by dissolution of underlying evaporitic rocks. Unit is a good source of sand and gravel.

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Composed of stream alluvium underlying terraces about 55 to 110 ft above modern stream level. Locally the unit is capped by a thin loess sheet. It consists of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand matrix. Fine-grained overbank deposits are locally present. Clasts are chiefly subround to round and consist of various lithologies that reflect the types of bedrock found in their drainage basins. Deposits along the Roaring Fork River above Carbondale are rich in coarse-grained Precambrian plutonic clasts, whereas those along the Crystal River are rich in clasts of middle Tertiary hypabyssal rocks and contain distinctive clasts of green hornfels probably derived from metamorphosed Morrison Formation. Clasts generally are only slightly weathered at shallow depths. Thickness averages about 20 to 50 ft.

Unit correlates with deposits in terrace T6 of the Carbondale-Glenwood Springs area of Piety (1981), who suggested they were of Pinedale age (12 to 35 ka; Richmond, 1986). Piety (1981) reported what appeared to be two different terrace deposits exposed near the present (1996) location of the active gravel pit west of the mouth of Crystal Spring Creek. Clasts within an underlying terrace alluvium was distinctly more weathered than in an overlying terrace deposit. She correlated the upper deposit with her T6 terrace unit and the lower deposit with her terrace T4 or T5 unit. Due to safety concerns we did not inspect the exposures in the presently tall and very steep highwalls in the gravel pit. Unit may also 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. Intermediate terraces may be slightly tilted away from the river, probably by upwarping related to evaporitic diapirism along the axis of the modern river channel or by collapse or subsidence of the terrace surface due to dissolution of underlying evaporitic rocks. The prominent, broad, topographic depression nearly 30 ft deep in the terrace east of the mouth of Crystal Spring Creek is mapped as a subsidence trough. Unit is a good source of sand and gravel and currently (1996) is being mined at two locations.

Qto **Older terrace alluvium (middle Pleistocene)**—Includes deposits of stream alluvium in terraces on the west side of the confluence of the Roaring Fork and Crystal Rivers and on the east side of the Crystal River southeast of Carbondale. Upper surface of unit ranges from about 160 to 200 ft above stream level. Unit is generally a clast-supported cobble or pebble gravel in a sand matrix, but may range to a matrix-supported gravelly sand or silt. Locally it may include fine-grained overbank deposits. Clasts are chiefly subround to round, with varied lithologies that reflect the rock types found in the drainage basin. Clasts are slightly to moderately weathered at shallow depths. Older terrace alluvium has been locally deformed, probably by subsidence or collapse associated with dissolution of underlying evaporitic rocks or by evaporitic diapirism. In places the older terraces now dip several degrees away from modern river channels, affecting the height of terraces above modern river level and making correlations between terraces based solely on height above the river tenuous. The presence of small closed or nearly closed depressions and sinkholes on their depositional surfaces, particularly the terrace south-southwest of the confluence of the rivers, indicates dissolution likely played or is playing a major role in the deformation. Folded and faulted older terrace alluvium and overlying older alluvium and colluvium (Qaco) associated with a subsidence trough are well exposed in the roadcut along County Road 108 near the mouth of Edgerton Creek.

Exposed thickness ranges from 28 to 39 ft; maximum thickness is estimated at about 60 ft. Unit is tentatively correlated with terraces T4 and T5 in the Carbondale-Glenwood Springs area of Piety (1981), with terrace C of Bryant (1979) in the Aspen-Woody Creek area, and with older terrace alluvium of Bryant and Shroba (1997). Unit 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 deposits (Qto) on the east valley wall of the Roaring Fork River 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. Unit may be a potential source of sand and gravel.

Qtt

Oldest terrace alluvium (middle and early? Pleistocene)—Consists of stream alluvium in terraces that range from about 240 to 480 ft above adjacent rivers. Unit underlies an extensive terrace southwest and west of Carbondale and caps two small bedrock knolls that extend above the level of the older terrace alluvium (Qto) north of Edgerton Creek, a small terrace remnant south of Mulford, and an eroded, dissected terrace that caps several hills southeast of White Hill. Unit is poorly sorted to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. Locally it includes thin lenses and beds of sandy silt and silty sand. Gravel clasts are commonly moderately to strongly weathered, even at moderate depths. Exposed thickness ranges from 33 to 88 ft. May be as much as 120 ft thick. Locally the deposits are slightly to moderately well cemented with carbonate.

Unit is correlative with T1, T2, and T3 terrace deposits in the Carbondale-Glenwood Springs area of Piety (1981). A large subsidence trough with maximum dimensions of about 0.4 miles wide by 2 miles long has formed in oldest terrace alluvium southwest and west of Carbondale. Within this trough the terrace gravels are overlain by the 620 ka Lava Creek B volcanic ash (Izett and Wilcox, 1982), demonstrating that this deposit of oldest terrace alluvium is older than 620 ka. It may be a potential source of sand and gravel.

QTg

High-level gravel (early Pleistocene and/or late Tertiary)—Occurs on hills and ridges 580 to 720 ft above the Crystal and Roaring Fork Rivers as eroded remnants of formerly extensive fluvial sediments. It caps three hills in the southwest corner of the quadrangle and the prominent ridge between the Roaring Fork and Crystal Rivers east-southeast of Carbondale. Unit consists of clast-supported, sandy and silty pebble and cobble gravel and gravelly sand and silt that locally is moderately well cemented with carbonate. Clasts are subround to well rounded and composed chiefly of middle Tertiary hypabyssal rocks and lesser amounts of quartzite, basalt, quartz, chert, red sandstone, and hornfels. Clasts are moderately to very highly weathered.

The deposits in the southwest corner of the quadrangle comprise the northern end of a large deposit of high-level gravel found in the Mount Sopris quadrangle. The apparent original depositional surface on these deposits is preserved in the Mount Sopris quadrangle, where it lies 1,000 to 1,100 ft above the Crystal River and 240 to 320 ft above adjacent oldest terrace alluvium (Qtt). Relationships between high-level gravel deposits and Miocene basalt are not definitive anywhere within the Carbondale quadrangle. High-level gravels on the ridge east-southeast of Carbondale either were deposited in a channel cut through the basalt or they originally lay beneath the basalt and should be correlated with Miocene sedimentary deposits (Ts). Measured thickness is 168 ft on ridge east-southest of Carbondale; may be 200 ft thick in southwest corner of quadrangle. Unit is a possible source of sand and perhaps gravel.

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

Qlsr

Recent landslide deposits (latest Holocene)—Includes two small, recently active landslides with fresh morphological features. Deposits consist of unsorted, unstratified gravel, sand, and silt. Maximum thickness is probably about 20 ft. Both recent landslides on this quadrangle occurred on moderately steep slopes mantled with a thin veneer of colluvium. They initiated in gravel deposits overlying either the Eagle Valley Evaporite or Eagle Valley Formation. Recent landslides may be prone to renewed or continued landsliding, and they are suggestive of the type of conditions which may produce future landslides in the current climatic regime.

Qc

Colluvium (Holocene and late 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 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. 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. 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 was derived from outcrops of basalt (Tb) or basalt-rich collapse debris (QTcd) and transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Unit commonly lacks matrix material. Locally it is underlain by or incorporated into landslides. Maximum thickness is estimated at about 40 ft. Areas mapped as talus are subject to severe rockfall, rockslide, and rock-topple hazards. Basalt-rich talus deposits usually are a source of high quality riprap and aggregate. Usually 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 active landslides to long-inactive middle or early Pleistocene landslides. Unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Also includes collapse debris in which there appears to be a significant horizontal component in the direction of movement, such as the large landslide on the east side of Spring Valley. Maximum thickness is probably around 200 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). Locally is cemented by tufa. Deposits mapped as older colluvium near the mouth of Fisher Creek may be collapse debris (QTcd). Unit averages 10 to 25 ft thick, with a maximum thickness about 60 ft. Generally is not subject to significant future colluvial deposition, except where adjacent to eroding hillslopes. Unit may be subject to collapse, piping, and settlement where fine grained and low in density. May be difficult to excavate where it contains large boulders of basalt.

Qlso **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion that lack distinctive landslide geomorphic 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 deposits. Maximum thickness locally may exceed 80 ft. Unit probably is not prone to future landsliding unless it is significantly disturbed by construction activities.

ALLUVIAL AND COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay in debris fans, stream channels, flood plains, and adjacent hillslopes along tributary valleys. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes are prevalent on debris fans, 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 is about 50 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. Studies of debris fans at Bowles and Holland Gulches and an unnamed fan between the two named gulches by Dames & Moore (1996) suggests a debris-flow recurrence interval of 103 to 154 years for Bowles Gulch, 200 to 266 years for Holland Gulch, and 265 to 342 years for the unnamed gulch. Younger debris-flow deposits are prone to settlement, piping, and hydrocompaction where fine grained and low in density, subject to sinkhole development by piping where underlain by cavernous evaporitic rocks, and corrosive if derived from evaporitic rocks.

Qac **Alluvium and colluvium, undivided (Holocene and latest Pleistocene)**—Unit is chiefly stream-channel, low-terrace, and flood-plain deposits along 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, but colluvium may range to unsorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt. Clast lithologies are dependant upon type of rock within source area. Thickness is commonly 5 to 20 ft, with its maximum thickness estimated at about 40 ft. Low-lying areas are subject to flooding. Valley sides are prone to 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.

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate. Refer to unit descriptions for colluvium (Qc) and sheetwash deposits (Qsw) for genetic, textural, and lithologic characteristics and for engineering properties and hazards.

Qdfm **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similar in texture, lithology, and depositional environment to younger debris-flow deposits (Qdfy). Geomorphic character of original depositional surfaces are commonly recognizable, but the surfaces are topographically about 20 to 100 ft above active channels. Occurs only along Edgerton Creek, where two distinctly different age of deposits are preserved. The numeric subscripts on the unit symbol depict the relative age of the two deposits, with $Qdfm_1$ being older than $Qdfm_2$. Within the map area the older of the intermediate debris-flow deposits could be mapped as older debris-flow deposits; however, upstream on Cattle Creek quadrangle the surface on these deposits is only 10 to 20 ft above Edgerton Creek. 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)**—Deposits of alluvium and colluvium ranging from about 10 to 200 ft above adjacent small perennial, intermittent, and ephemeral streams. Texture, bedding, clast lithology, sorting, and genesis are similar to alluvium and colluvium (Qac). Unit locally includes debris-flow and sheetwash deposits. It also includes locally derived sediments deposited within a large subsidence trough developed in oldest terrace alluvium (Qtt) southwest of Carbondale. Within this trough along Barbers Gulch a well stratified, 3-ft-thick bed of volcanic ash overlies the terrace gravel. The best exposure of the ash is indicated on the map, and it is less well exposed on the opposite wall of Barbers Gulch. The ash has been identified as the 620 ka Lava Creek B ash by Izett and Wilcox (1982). Bedding in the ash has an apparent strike of N16°E and dip of 3° northwest, suggesting subsidence occurred both before its deposition (to create the trough in which the ash is preserved) and afterwards (to tilt the ash). The ash is overlain by 30 to 35 ft of locally derived older alluvium and colluvium (Qaco) which accumulated within the subsidence trough. Unit also includes a series of three terraces on the southside of Cattle Creek near the west edge of the quadrangle and a deposit that overlies intermediate terrace alluvium (Qtm) at the mouth of Crystal Spring Creek. Thickness is as much as 50 feet. Area is subject to active colluvial and sheetwash deposition where adjacent to hillslopes. Unit may be a potential source of sand and gravel.

Qdfo **Older debris-flow deposits (Holocene? and Pleistocene)**—Occurs as remnants of debris fans found on mesas and adjacent to tributaries of Cattle Creek and the Roaring Fork and Crystal Rivers. Unit is genetically, texturally, and lithologically similar to younger debris-flow deposits (Qdfy). Boulders within older debris-flow deposits (Qdfo) are commonly 1 to 3 ft in diameter. Clasts range from unweathered to moderately weathered. Elevation differences between original depositional surfaces and adjacent modern drainages range from about 20 to 160 ft. Unit may in part be age equivalent to intermediate debris-flow deposits (Qdfm) on Edgerton Creek. Thickness is generally about 20 to 40 ft. Where fine grained and low in density, unit may be prone to piping, settlement, and perhaps hydrocompaction. It is corrosive when derived from evaporitic bedrock. May be a potential source of sand and gravel.

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

Qlo **Loess (late and middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind and preserved on level to gently sloping surfaces. Typically is unstratified, friable, and plastic or slightly plastic when wet. Sand grains are sometimes frosted. Thickness ranges from about 5 to 20 ft. Deposition occurred during at least two periods of eolian activity. At least one and perhaps multiple sheets of loess overlie older terrace deposits (Qto) and basalt (Tb) along the west edge of the quadrangle. Mapped distribution of loess is very approximate due to the poor geomorphic expression of loess. Remnant deposits of loess are locally preserved within collapse debris (QTcd). Low-density loess may be prone to settlement when loaded and to piping and hydrocompaction when wetted. Sinkholes in loess along Crystal Springs Creek appear to be the result of piping failure. Loess is highly erodible.

LACUSTRINE DEPOSITS—Sediments deposited in lakes.

Ql_2&Ql_1 **Lacustrine deposits (Holocene and Pleistocene)**—Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, yellow-brown clayey silt, and medium-red-brown, well-sorted, fine to coarse sand. Unit is very poorly exposed in quadrangle, but it appears to consist predominantly of lacustrine deposits. Unit underlies the central floor of Spring Valley (Ql_2), and it also crops out along the margins of the valley in bluffs that are 20 to 40 ft higher than the central valley floor (Ql_1). Although we have little supportive data other than the elevation difference, we consider Ql_1 deposits to be older than Ql_2 deposits. Exposed thickness up to about 40 ft, but may be much thicker beneath the valley floor.

According to Calvin Cox (1994, oral commun.), a lake existed in Spring Valley until the turn of the 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 when the 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.

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

ALLUVIAL, COLLUVIAL, LACUSTRINE?, AND DELTAIC? DEPOSITS

QTm **Sediments of Missouri Heights (Early Pleistocene and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Coulter Creek region in alluvial, colluvial, and either lacustrine or deltaic environments. Usually ranges from sandy and silty pebble, granule, or cobble gravel to gravelly silty sand. At the northern end of Missouri Heights in the hills south of the sharp, right-angle bend of Cattle Creek below its confluence with Coulter Creek, however, the unit is predominantly gravelly sandy silt, clayey silt, and crossbedded fine-grained to very fine-grained sands. Clasts are mostly subangular to subround basalt, red sandstone, and quartzite, but many other rock types can be found within these deposits in small quantities. Fine-grained sediments in the northern Missouri Heights area are well exposed in a few drainages and irrigation ditches. In these exposures they are slightly to moderately oxidized, slightly to moderaterly indurated, and dip 6 to 9 degrees to the south or southwest.

Sediments of Missouri Heights were deposited in areas topographically lowered by collapse or subsidence related to dissolution of salt deposits in the underlying Eagle Valley Evaporite. Their maximum thickness is estimated at 150 ft. Unit usually overlies Miocene basaltic rocks (Tb) and overlies or is interbedded with Pliocene trachyandesitic rocks (Tta). Underlying volcanic rocks are commonly more deformed than are the sediments of Missouri Heights suggesting significant salt-related collapse and deformation occurred before deposition of the sediments. Tilting of the sediments indicates that deformation has continued since their deposition. Unit is similar in origin to the Sediments of Cottonwood Bowl (QTc) mapped by Streufert and others (1997b) on Cottonwood Pass quadrangle, but their age relationship is not known. Fine-grained deposits within the unit may be prone to settlement problems.

COLLAPSE DEPOSITS

QTcd **Collapse debris (Pleistocene and late Tertiary)**—Heterogeneous deposits of moderately to severely deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Formed in response to differential vertical collapse or regional subsidence resulting from dissolution of underlying thick beds of evaporite, primarily halite, and/or flowage of the evaporitic rocks out from beneath the area.

Highly fractured and locally brecciated basalt and small, intact but strongly tilted blocks of basalt ranging up to about 20 acres in size comprise the predominant type of bedrock within the collapse debris at the ground surface. Lesser amounts of deformed Maroon Formation locally occur within the collapse debris. Unit probably includes broken rock debris from the Eagle Valley Formation at depth. Various types of surficial deposits, including loess, may be incorporated into the collapse debris.

Unit grades to folded and faulted bedrock where less deformed and to landslide deposits where there appears to be a significant horizontal component to the direction of collapse, such as on the east side of Spring Valley. Contacts between collapse debris and basalt or landslide deposits are gradational. May be prone to settlement problems where fine-grained, low-density deposits of loess occur and to differential settlement where these deposits abut basalt rubble. Unit may be difficult to excavate because of the abrupt changes in lithology and presence of large blocks of basalt.

BEDROCK

Tta

Trachyandesite (Pliocene)—Multiple flows of moderately dense to highly vesicular basaltic trachyandesite and trachyandesite. Locally includes volcaniclastic deposits. Petrographically most flows are olivine basalt with xenocrysts of quartz, sanidine, and plagioclase as much as about 0.3 inches in diameter. Quartz xenocrysts are rounded, corroded anhedra. Sanidine xenocrysts range from fairly fresh to moderately weathered and have inclusions of plagioclase and quartz. Plagioclase occurs as rounded, zoned, corroded anhedra and euhedra. Olivine phenocrysts are euhedral and subhedral crystals generally altered to hematite and iddingsite. Groundmass consists of fine, fresh laths of plagioclase and olivine and pyroxene similar to that of Miocene basalt (Tb). Accessory minerals include biotite, hematite, and magnetite. Thickness of individual flows generally ranges from about 5 to 30 ft, whereas the maximum thickness of the entire flow sequence is about 60 ft. Possible equivalent rocks from Little Buck Point in Shoshone quadrangle have an $^{40}Ar/^{39}Ar$ age of 3.94 ± 0.02 Ma (Kirkham and others, 1995b); a sample from Buck Point in Cottonwood quadrangle has an $^{40}Ar/^{39}Ar$ age of 3.17 Ma (Streufert and others, 1997b). Steep cliffs composed of this unit may pose rockfall hazards. Excavation into the unit may be difficult and require blasting.

Tb

Basalt (Miocene)—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesit. In places the unit includes slightly indurated sediments. Petrographically most flows are olivine basalt; many are porphyritic. Flow rocks range from massive to highly vesicular and locally contain amygdules of calcite and iron-rich clay. 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. 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 300 ft, but generally is 20 to 40 ft.

Preliminary whole rock $^{40}Ar/^{39}Ar$ dating has been completed for three samples from this quadrangle (M. Kunk, 1997, written commun.). Flow exposed in roadcut on Catherine Store Road about 1 mile north of Catherine yielded an age of 9.7 Ma; Larson and others (1975) report a whole-rock K-Ar age of 8.68 ± 0.4 Ma for this same flow. Upper flow in a sequence of four exposed flows in NE1/4 Sec. 22, T. 7 S., R. 88 W. north of the east end of Heuschkel Park was about 10 Ma. Upper exposed flow in the west end of "The A's" in SE1/4 Sec. 1, T. 8 S., R. 88 W. yielded an Ar/Ar age of less than 14 Ma.

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.

Ts

Sedimentary deposits (Miocene?)—Mostly clast-supported, fluvial, silty, sandy pebble and cobble gravel but locally contains silty and sandy deposits of probable alluvial and/or colluvial origin. Unit is poorly exposed in quadrangle. Clast lithology ranges widely. Coarse-grained Precambrian plutonic rocks, middle Tertiary hypabyssal rocks, quartzite, and red sandstone are the most common rock types; basalt clasts are rare. Most clasts are well rounded to moderately well rounded. Clasts are moderately to very highly weathered. Appears to underlie Miocene basaltic rocks in hills south of Catherine. Fine-grained sediments are locally slightly to moderately indurated. Thickness ranges from about 40 ft to at least a few hundred feet. Fine-grained deposits are prone to landsliding. May be a source of sand and perhaps gravel.

PIPm

Maroon Formation (Lower Permian? and Upper Pennsylvanian)—Reddish-brown beds of sandstone, conglomerate, siltstone, mudstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle. Conglomerate contains pebble- and cobble-sized clasts of quartz, feldspar, and granitic rock fragments. Commonly is arkosic and very micaceous. Exposed thickness only about 800 ft. In adjacent quadrangles where the entire formation is present, it is 3,000 to 5,000 ft thick (Kirkham and others, 1995a; 1996b). Clastic rocks in the lower part of the Maroon Formation were deposited in basin-margin, alluvial fan and fan-delta environments in the Central Colorado Trough, whereas the limestones were deposited in shallow marine environments (Johnson and others, 1990). The upper part of the formation was deposited in the Central Colorado Trough in fluvial and eolian environments (Johnson and others, 1988). Formation is prone to rockfall where exposed in steep cliffs.

IPe

Eagle Valley Formation (Middle Pennsylvanian)—Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks. Unit represents a stratigraphic interval in which the red beds of the Maroon Formation grade into and intertongue with the predominantly evaporitic rocks of the Eagle Valley Evaporite. It includes rock types of both formations. Thickness is variable, ranging from about 500 to perhaps as much as 3,000 ft on the west side of the Cattle Creek Anticline. The Eagle Valley Formation is conformable and intertongues with the overlying Maroon Formation and underlying Eagle Valley Evaporite. Contact with Maroon Formation is placed at the top of uppermost evaporite bed or light-colored clastic bed below the predominantly red bed sequence of the Maroon Formation. It was deposited in the Central Colorado Trough on the margin of an evaporite basin in fluvial, eolian, and marine environments. Unit may be susceptible to subsidence and sinkholes. Surficial deposits derived from it are prone to collapse, compaction, piping, and corrosion problems.

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. 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 diapirs. Occurrence of prominent gypsum outcrops on hillslopes may be evidence of recent or on-going diapiric activity. Contact with overlying Eagle Valley Formation is both conformable and intertonguing and is defined as the base of the lowest red bed within the Eagle Valley Formation.

The Eagle Valley Evaporite was deposited in a marine evaporitic basin known as the Eagle Basin that formed as the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1989) recognized multiple transgressive-regressive sedimentary cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment rather than in a sabkha.

Base of formation not exposed in quadrangle. Thickness may range from about 1,200 ft to perhaps 9,000 ft (Mallory, 1971), where it is tectonically thickened along the axis of the Cattle Creek Anticline. Formation is at least 2,700 ft thick near Catherine, on the basis of the 2,320 ft of Eagle Valley Evaporite penetrated by the Champlin Oil Blue No. 1 well and the additional 400 ft of formation exposed on the hillslope north of the well. 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.

The Eagle Valley Evaporite contains cavernous voids as much as several feet in diameter and tens of feet deep that 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.

ECONOMIC GEOLOGY

Gypsum beds within the Eagle Valley Evaporite are potentially valuable as an industrial mineral, particularly in the manufacture of wall board. Halite within the formation may also be an economic resource. One oil test well has been drilled in the Carbondale quadrangle. Champlin Oil and Refining Company spudded the Blue No. 1 well in 1962. The objective was the Leadville Limestone and Dyer Dolomite, which they anticipated encountering at depths of 4,300 and 4,450 ft. They drilled through 280 ft of what appeared to be surficial deposits and 2,040 ft of shale, siltstone, and gypsum described as Minturn Formation, a name previously used for the Eagle Valley Evaporite. The well lost circulation at a depth of 2,320 ft and was abandoned. Other economic resources include sand, gravel, aggregate, and riprap. Refer to the unit descriptions for sources of these materials.

Table 1. Whole-rock analyses of the Carbondale Quadrangle

Sample ID	PERCENT										
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	LOI*
CD5	52.4	15.4	7.77	7.13	3.23	1.03	11.5	0.16	1.42	0.32	-0.28
CD6	51.3	15.1	7.88	7.76	2.86	1.08	12.4	0.16	1.45	0.31	-0.28
CD8	55.1	15.4	5.99	4.30	3.28	3.57	8.4	0.11	1.36	0.54	1.00
CD12	51.0	15.5	8.40	6.23	3.01	1.54	10.7	0.15	1.44	0.41	1.06
CD17	52.4	15.6	7.94	6.97	3.07	0.99	11.1	0.15	1.37	0.29	-0.09
CD19	51.0	15.5	7.61	7.18	3.09	1.45	11.6	0.16	1.54	0.50	0.10
CD23	50.5	17.0	9.46	2.79	3.48	2.12	9.1	0.09	1.98	0.70	2.10
CD31	52.0	15.3	8.09	6.80	2.85	0.83	11.1	0.14	1.38	0.29	1.38
CD42	51.5	15.5	8.03	7.02	3.04	1.21	11.4	0.15	1.43	0.35	0.09
CD45a	51.0	15.2	8.23	6.89	2.90	1.08	10.9	0.14	1.41	0.36	1.40
CD45b	51.0	15.2	8.30	6.79	2.90	1.04	11.0	0.14	1.41	0.34	1.58
CD51a	51.5	15.1	8.21	6.68	2.80	0.83	10.7	0.14	1.37	0.28	2.32
CD51b	52.5	15.5	8.10	6.79	2.97	1.02	11.0	0.15	1.37	0.29	0.36
CD53a	51.5	15.5	7.38	6.95	2.99	1.73	11.2	0.15	1.60	0.55	0.16
CD53b	52.2	15.4	7.92	6.96	3.14	1.04	11.3	0.15	1.43	0.31	-0.01
CD53c	52.2	15.4	7.99	6.96	3.07	1.06	11.3	0.15	1.41	0.31	0.05
CD53d	52.4	15.4	7.87	6.92	3.04	0.95	12.0	0.16	1.38	0.29	-0.44
CD59	51.7	15.5	8.18	7.13	3.05	0.95	11.3	0.15	1.40	0.31	0.52
CD65	52.2	15.4	8.03	6.97	3.11	0.96	11.2	0.15	1.41	0.31	0.20
CD109	52.4	15.9	8.02	6.27	3.08	1.62	10.5	0.15	1.47	0.43	0.09
CD124a	51.3	15.8	8.16	7.00	2.96	0.98	11.4	0.15	1.38	0.29	0.03
CD124b	51.7	15.4	8.00	7.33	2.92	1.09	11.6	0.16	1.45	0.30	-0.13
CD135	52.2	15.7	7.10	6.11	3.19	2.18	10.5	0.14	1.60	0.69	-0.02
CD138	51.3	15.7	8.25	6.80	2.98	1.42	11.1	0.15	1.43	0.39	0.46
CD150a	51.6	15.6	7.33	5.82	2.93	2.10	10.1	0.13	1.59	0.67	1.52
CD150b	51.6	16.2	7.29	6.08	3.13	2.08	10.7	0.15	1.64	0.70	0.28
CD150c	51.0	16.0	8.00	6.68	2.99	1.29	11.4	0.17	1.48	0.40	0.49
CD152	55.2	16.0	6.38	4.46	3.64	2.84	9.2	0.15	1.38	0.47	-0.14
CD156	51.4	15.2	8.25	6.85	2.88	0.99	10.8	0.14	1.37	0.31	1.79
CD179	52.4	15.5	8.05	6.73	3.05	0.98	11.2	0.15	1.38	0.30	0.29
CD180	52.3	15.7	8.09	6.80	3.05	0.96	11.2	0.15	1.39	0.29	0.04
CD181a	51.9	15.7	7.22	6.94	3.11	1.81	11.2	0.15	1.59	0.43	-0.06
CD181b	52.4	15.5	7.90	6.89	3.20	1.06	11.3	0.15	1.44	0.32	-0.05
CD181c	52.5	15.6	7.95	6.90	3.05	0.91	11.1	0.15	1.37	0.30	0.19
CD187	51.6	15.5	7.37	7.21	3.08	1.73	11.4	0.15	1.60	0.55	0.04
CD191b	52.4	15.6	8.14	6.70	3.06	1.04	11.2	0.15	1.39	0.30	0.39
CD192	52.1	15.6	8.08	7.00	3.10	1.05	11.4	0.16	1.41	0.31	0.00
CD193a	51.4	15.4	7.44	7.15	2.99	1.67	11.4	0.15	1.55	0.52	0.09
CD193b	52.1	15.6	7.94	6.68	3.04	1.06	11.5	0.16	1.44	0.31	0.26
CD193c	51.8	15.6	8.06	6.92	3.01	1.02	11.6	0.15	1.42	0.31	0.30

Table 1. Continued

Sample ID	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	LOI*
	PERCENT										
CD193d	51.8	15.5	8.05	7.11	3.02	0.98	11.4	0.15	1.38	0.30	0.30
CD197	56.0	15.8	5.95	4.94	3.28	3.63	8.0	0.13	1.40	0.43	0.07
CD199	54.7	15.7	5.89	5.11	3.37	3.44	8.3	0.13	1.39	0.31	0.75
CD203	51.5	15.9	7.89	6.67	3.00	1.34	11.0	0.15	1.42	0.32	0.73
CD204	51.2	16.1	7.93	6.50	2.96	1.25	11.2	0.15	1.46	0.27	0.59
CD206	54.2	16.0	6.36	5.40	3.36	3.57	8.3	0.13	1.44	0.40	0.18
CD209	54.0	16.0	6.35	5.30	3.34	3.56	8.4	0.12	1.45	0.47	0.38
CD215	54.7	15.9	5.98	4.86	3.27	3.45	8.5	0.12	1.45	0.35	0.71
CD216	55.9	15.6	5.98	4.72	3.23	3.50	7.9	0.12	1.37	0.46	0.60
CD218	51.5	15.8	8.28	6.61	2.99	0.91	10.8	0.15	1.37	0.30	0.74

[* loss on ignition; negative LOI indicates sample gained mass on ignition]

Above analyses performed by U.S. Geological Survey, Denver, Colorado

Sample ID	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	Cr_2O_3	LOI*
	PERCENT											
CD6	51.3	14.8	7.90	7.16	2.88	1.21	11.65	0.16	1.47	0.27	<0.01	0.01
CD53d	51.8	14.8	7.96	6.65	3.04	1.05	11.19	0.15	1.39	0.25	<0.01	0.01
CD152	55.7	15.7	6.25	4.26	3.57	3.05	8.39	0.14	1.38	0.42	<0.01	0.64
CD216	55.1	15.1	6.00	4.81	3.21	3.75	7.89	0.13	1.36	0.49	0.01	0.59

[* loss on ignition]

Sample ID	Rb	Sr	Y	Zr	Nb	Ba
	PERCENT					
CD6	122	312	20	261	20	690
CD53d	106	290	34	357	12	925
CD152	126	358	42	324	8	575
CD216	90	314	22	177	12	430

Above analyses performed by Chemex Labs, Inc., Sparks, Nevada

Sample Descriptions:

CD5— Highest Tb flow exposed in roadcut on Colorado Mountain College Road below the college; Lat. 39.46160°, Long. 107.24453°

CD6— Tb flow in roadcut on Catherine Store Road about 1 mile north of Catherine; K-Ar dated by Larson and others (1975) at 8.68 Ma; Lat. 39.42140°, Long. 107.15111°

CD8— Flow exposed in roadcut near Coulter Creek; Lat. 39.47295°, Long. 107.14085°

CD12— Tb at west end of Nieslanic irrigation tunnel; Lat. 39.49122°, Long. 107.20612°

CD17— Lower of two flows on north rim of Cattle Creek, west of Fisher Cemetery; Lat. 39.46865°, Long. 107.21386°

Sample Descriptions Continued:

CD19— Flow along road to Colorado Mountain College water tank; Lat. 39.47574°, Long. 107.22530°

CD23— First Tb flow above Eagle Valley Evaporite in roadcut on Colorado Mountain College road; highly fractured and moderately weathered; Lat. 39.46257°, Long. 107.24664°

CD31— Tb on east wall of Roaring Fork River, south of Cattle Creek, near intrusive contact of Eagle Valley Evaporite into Eagle Valley Formation; Lat. 39.43899°, Long. 107.24291°

CD42— Tb on Red Hill between Carbondale junction and Heuschkel Park; Lat. 39.42376°, Long. 107.22615°

CD45a— Lower of two flows on west end of Red Hill; Lat. 39.42327°, Long. 107.23244°

CD45b— Upper flow of two flows on west end of Red Hill; Lat. 39.42324°, Long. 107.23248°

CD51a— Lowest of at least two and perhaps three flows on high knob on ridge north of west end of Heuschkel Park; Lat. 39.42340°, Long. 107.23213°

CD51b— Second flow from bottom of at least two and perhaps three flows on high knob on ridge north of west end of Heuschkel Park; Lat. 39.42338°, Long. 107.23198°

CD53a— Lowest of four Tb flows exposed on high knob on ridge north of the east end of Heuschkel Park; Lat. 39.43510°, Long. 107.20037°

CD53b— Second Tb flow up from bottom of four flows exposed on high knob on ridge north of the east end of Heuschkel Park; Lat. 39.43516°, Long. 107.20057°

CD53c— Third Tb flow up from bottom of four flows exposed on high knob on ridge north of the east end of Heuschkel Park; Lat. 39.43525°, Long. 107.20073°

CD53d— Upper flow of four Tb flows exposed on high knob on ridge north of the east end of Heuschkel Park; Lat. 39.43538°, Long. 107.20090°

CD59— Tb flow exposed in bottom of east end of Heuschkel Park; Lat. 39.42683°, Long. 107.20573°

CD65— Flow on prominent hill east of Heuschkel Park; Lat. 39.43110°, Long. 107.19021°

CD109— Poorly exposed slope with only one outcrop of a Tb flow; on Sterling Ranch, north side of Roaring Fork River near east edge of quadrangle; Lat. 39.41448°, Long. 107.12911°

CD124— Middle exposed flow on ridge in southern part of Panorama subdivision; Lat. 39.44371°, Long. 107.12550°

CD124b— Upper exposed flow on ridge in southern part of Panorama subdivision; Lat. 39.44347°, Long. 107.12581°

CD135— Flow on south side of Te-Ke-Ki landing strip; Lat. 39.38647°, Long. 107.16541°

CD138— Flow on north side of Te-Ke-Ki landing strip; Lat. 39.39178°, Long. 107.16530°

CD150a— Lower flow on Te-Ke-Ki landing strip; Lat. 39.39826°, Long. 107.14548°

CD150b— Middle flow on Te-Ke-Ki landing strip; Lat. 39.39764°, Long. 107.14556°

CD150c— Upper flow on Te-Ke-Ki landing strip; Lat. 39.39727°, Long. 107.14593°

CD152— Upper Tb flow exposed on the west end of the ridge locally known as "The A's"; about 1.4 miles southwest of Mulford; Lat. 39.38270°, Long. 107.16593°

CD156— Basal flow at west end of Heuschkel Park; Lat. 39.43007°, Long. 107.23368°

CD179— Pinion Peaks subdivision; Upper site above Cattle Creek; Lat. 39.45748°, Long. 107.18920°

CD180— Pinion Peaks subdivision; Lower site above Cattle Creek; Lat. 39.45758°, Long. 107.18389°

CD181a— Pinion Peaks subdivision; Top site-lower flow; Lat. 39.44748°, Long. 107.18564°

CD181b— Pinion Peaks subdivision; Top site-middle flow; Lat. 39.44798°, Long. 107.18590°

CD181c— Pinion Peaks subdivision; Top site-Upper flow; Lat. 39.44858°, Long. 107.18662°

CD187— Flow exposed on hillslope on Raven Ridge Ranch above Cattle Creek; Lat. 39.46003°, Long. 107.18345°

CD191b— Middle flow along tributary on south side of Cattle Creek; Lat. 39.45740°, Long. 107.17233°

CD192— On ridge east of McNulty home on south side of Cattle Creek; Lat. 39.45987°, Long. 107.16202°

CD193a— Lowest flow on north side of Cattle Creek road below junction with Catherine Store road; Lat. 39.46050°, Long. 107.15147°

CD193b— Second flow from bottom on north side of Cattle Creek road below junction with Catherine Store road; Lat. 39.46171°, Long. 107.14965°

Sample Descriptions Continued:

CD193c— Third flow from bottom on north side of Cattle Creek road below junction with Catherine Store road; Lat. 39.46309°, Long. 107.14844°

CD193d— Uppermost flow on north side of Cattle Creek road below junction with Catherine Store road; Lat. 39.46473°, Long. 107.14729°

CD197— Flow on east side of Cattle Creek west of Williams' ranch; Lat. 39.46851°, Long. 107.14030°

CD199— Flow near east edge of quadrangle north of east end of Williams' ranch house; Lat. 39.47175°, Long. 107.12720°

CD203— Flow between Mesa and Coulter Creeks; Lat. 39.49681°, Long. 107.14411°

CD204— Flow at north edge of quadrangle immediately west of West Coulter Creek; Lat. 39.49938°, Long. 107.13806°

CD206— Flow on high knob on Buck Point ranch; Lat. 39.49132°, Long. 107.15166°

CD209— Flow on high hill on Max Donnell ranch; Lat. 39.49137°, Long. 107.15407°

CD215— Flow near confluence of Cattle Creek and Coulter Creek; Lat. 39.47383°, Long. 107.14144°

CD216— Tta along Spring Valley road on east side of Coulter Creek; Lat. 39.47247°, Long. 107.13933°

CD218— Flow on Catherine Store road above where it drops down into Cattle Creek; Lat. 39.45709°, Long. 107.15136°

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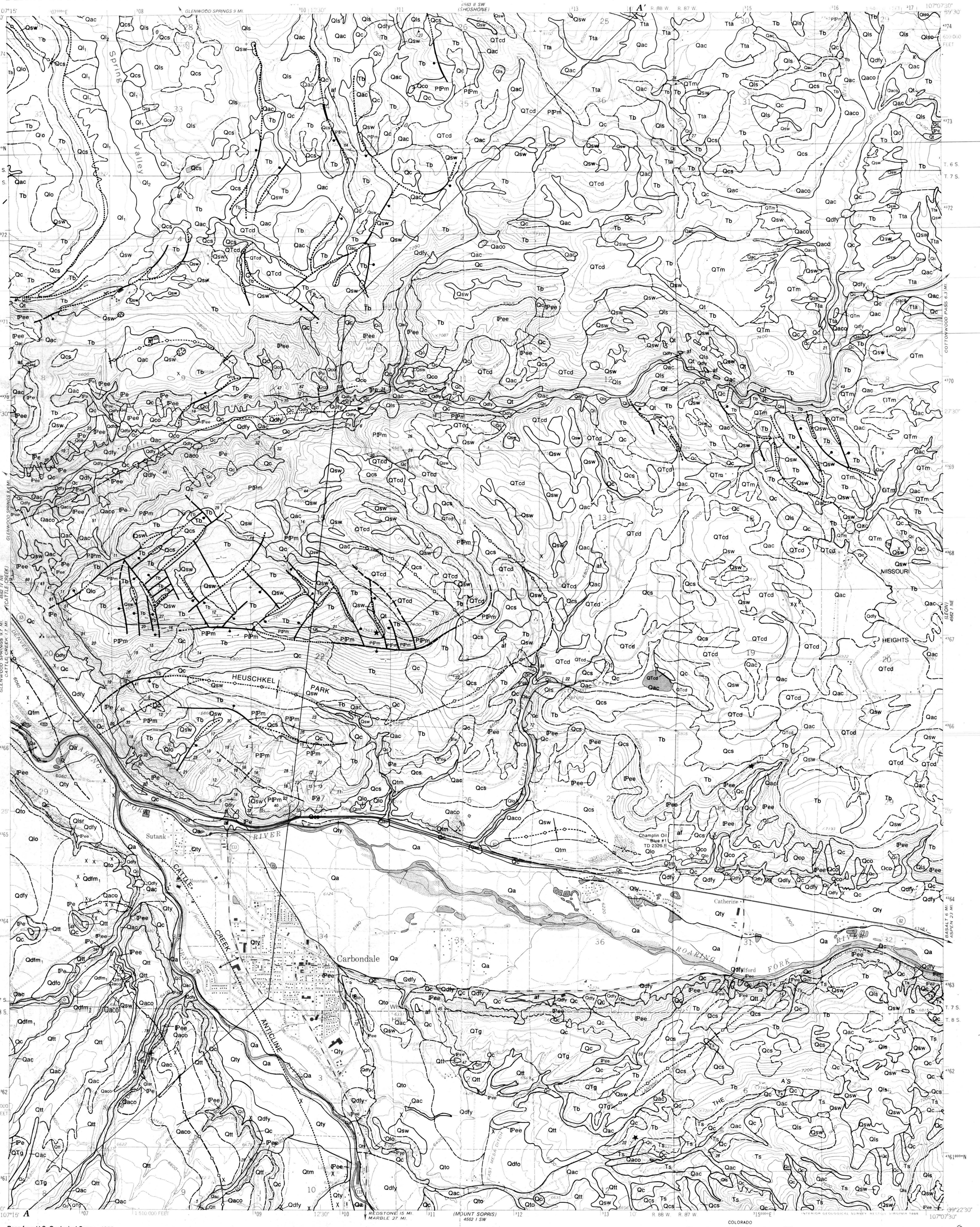
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES

OPEN FILE MAP 97-3
GEOLOGIC MAP OF THE CARBONDALE
QUADRANGLE, GARFIELD COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1982

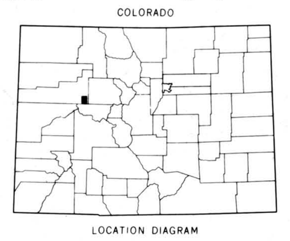
Geology mapped in 1996

SCALE 1:24,000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER



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, glacial outwash terraces, and sheetwash areas

Qa **Stream-channel, flood-plain, and low-terrace deposits (Holcene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. Includes terraces up to about 12 ft above modern river level

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, and in basinal areas

Qty **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 14–45 ft above modern stream level. May include fine-grained overbank deposits

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55–110 ft above modern streams

Qto **Older terrace alluvium (middle Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts slightly to moderately weathered. Underlies terraces 160–200 ft above modern streams

Qtt **Oldest terrace alluvium (middle and early? Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Deposit southwest of Crystal River is locally overlain by Lava Creek B volcanic ash. Clasts moderately to highly weathered. Underlies terraces about 240–480 ft above rivers

QTg **High-level gravel (early Pleistocene and/or late Tertiary)**—Chiefly clast-supported, sandy, silty, cobble and pebble gravel occurring on hills and ridges 580–720 ft above Crystal and Roaring Fork Rivers. Clasts are moderately to very highly weathered

COLLUVIAL DEPOSITS—Sediments on valley sides, valley floors, and hillslopes 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 gravel, sand, and silt

Qc **Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Usually coarser grained in upper reaches of colluvial slopes and finer grained in distal areas

Qt **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of basalt or basalt-rich collapse debris (QTcd)

Qls **Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris. Ranges from recently active landslides to long-inactive Pleistocene landslides

Qco **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. Generally not subject to future deposition.

Qlso **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion that lack distinctive landslide geomorphology. Similar in texture to landslide deposits (Qls)

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 deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels

Qac **Alluvium and colluvium, undivided (Holocene and latest 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

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate

Qdfm **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similar in texture and depositional environment to younger debris-flow deposits (Qdfy), but found 20-100 ft above Edgerton Creek. Numeric subscripts on unit symbol indicate relative ages of deposits, with $Qdfm_1$ being older than $Qdfm_2$. Generally not subject to future deposition except during unusually large events or when drainage channels plug with debris and are overtopped

Qaco **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes above the floor of tributary valleys. Includes locally derived sediments and the Lava Creek B volcanic ash that were deposited within a large subsidence trough developed in oldest terrace alluvium (Qtt) southwest of Carbondale

Qdfo **Older debris-flow deposits (Holocene? and Pleistocene)**—Remnants of inactive debris fans found on mesas and adjacent to stream drainages 20–160 ft above nearby streams. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

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

LACUSTRINE DEPOSITS

Ql_2 & Ql_1 **Lacustrine deposits (Holocene and Pleistocene)**—Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, yellow-brown clayey silt, and medium-red-brown, well-sorted, fine to coarse sand deposited in Spring Valley. Numeric subscripts indicate relative ages of deposits. Ql_1 deposits are older than and lie 20–40 ft above Ql_2

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

ALLUVIAL, COLLUVIAL, LACUSTRINE?, AND DELTAIC? DEPOSITS

QTm **Sediments of Missouri Heights (Early Quaternary and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Cottonwood Pass region in alluvial, colluvial, and either lacustrine or deltaic environments. Deposited in areas topographically lowered by collapse or subsidence related to dissolution or flowage of salt deposits in the underlying Eagle Valley Evaporite. Usually overlies Miocene basaltic rocks (Tb) and overlies or is interbedded with Pliocene trachyandesitic rocks (Tta). Typically is less deformed than underlying rocks

COLLAPSE DEPOSITS

QTcd **Collapse debris (Pleistocene and late Tertiary)**—Heterogeneous deposits of moderately to severely deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Formed in response to differential vertical collapse or regional subsidence resulting from dissolution of underlying thick beds of evaporite, primarily halite, and/or flowage of the evaporitic rocks out from beneath the area. Highly fractured and locally rubblized basalt and small, intact but strongly tilted blocks of basalt ranging up to about 20 acres in size comprise the predominant type of bedrock within the collapse debris at the ground surface. Deformed, rubblized, and/or brecciated materials derived from Maroon Formation locally crop out within the collapse debris. Various types of surficial deposits occur within the collapse debris. Unit grades to folded and faulted bedrock where less deformed and to landslide deposits where there appears to be a significant horizontal component to the direction of collapse

BEDROCK

Tta **Trachyandesite (Pliocene)**—Multiple flows of basaltic trachyandesite and trachyandesite. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts. Groundmass similar to that of Miocene basalt (Tb). $^{40}Ar/^{39}Ar$ ages of possibly equivalent rocks are 3.94 ± 0.02 Ma at Little Buck Point in Shoshone quadrangle (Kirkham and others, 1995b) and 3.17 Ma at Buck Point in Cottonwood quadrangle (Streufert and others, 1997b)

Tb **Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments. Preliminary whole-rock $^{40}Ar/^{39}Ar$ analyses are available for three samples from this quadrangle (M. Kunk, 1997, written commun.). Flow exposed in roadcut on Catherine Store Road about 1 mile north of Catherine yielded an age of about 9.7 Ma; Larson and others (1975) report a K-Ar age of 8.68 ± 0.4 Ma for this same flow. Upper flow in a sequence of four flows exposed in NE1/4 Sec. 22, T. 7 S., R. 88 W. is about 10 Ma. Upper exposed flow in SE1/4 Sec. 1, T. 8 S., R. 88 W. yielded an Ar/Ar age of less than 14 Ma

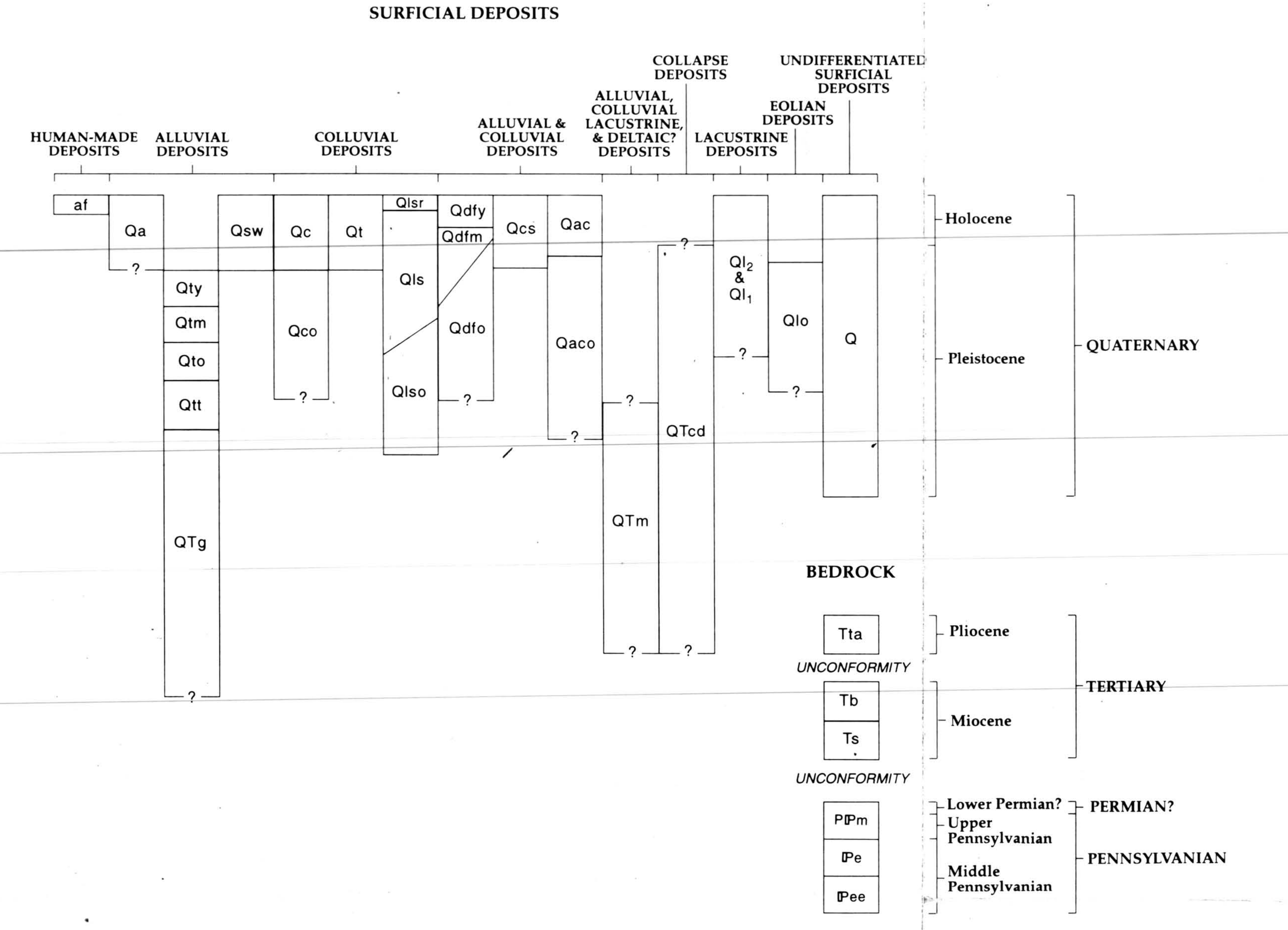
Ts **Sedimentary deposits (Miocene?)**—Mostly fluvial, clast-supported, silty, sandy pebble and cobble gravel, but locally contains silty and sandy deposits of probable alluvial and/or colluvial origin. Appears to underlie Miocene basaltic rocks in hills south of Catherine. Locally slightly to moderately indurated

PIPm **Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle

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 intertonguing with the Maroon Formation and Eagle Valley Evaporite

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

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximately located; queried where very uncertain

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; includes faults related to dissolution and flowage of evaporite

Anticline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axis indicates direction of plunge

Anticline—Showing approximate axial trace of late Pleistocene and Holocene? anticline which probably is due to diapirism, expansion related to hydration of anhydrite, dissolution-induced subsidence, or a combination thereof

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; these structures may be synclinal sags, but they lack supportive evidence for this origin

Synclinal sag or subsidence trough—Showing axial trace of synclinal sag or subsidence trough related to evaporite dissolution and/or flowage; synclinal sags occur in bedrock, subsidence troughs are in river terraces and overlying deposits; dashed where approximately located; dotted where concealed; limbs of synclinal sags and subsidence troughs may be faulted; closed and nearly closed depressions in collapse debris (QTcd), which likely are at least in part sags or troughs, are not mapped

X **Sinkhole**—Created by piping or collapse of surficial deposits, usually into dissolution caverns within underlying Eagle Valley Evaporite or by collapse or settlement of low-density surficial deposits; includes dissolution caverns in outcrops of Eagle Valley Evaporite; "X" denotes small sinkholes; many small sinkholes other than those shown on the map are probably present in the quadrangle

Strike and dip of beds—Angle of dip shown in degrees; most attitudes in basalt and terrace deposits were measured on top of apparent surface

Inclined beds

Vertical beds

Inclined beds—Showing approximate attitude of surface on terraces and basalt flows as determined from stereoscopic models set on a Kelsh PG-2 plotter; dip between 0 and 30°

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

Gravel pit

Locality of rock sample—Dated by the whole-rock $^{40}Ar/^{39}Ar$ method

\+ **Outcrop of Lava Creek B volcanic ash**

A ——— A′ **Alignment of cross section**

Oil or gas exploration test hole—Plugged and abandoned; operator, well name, and total depth shown

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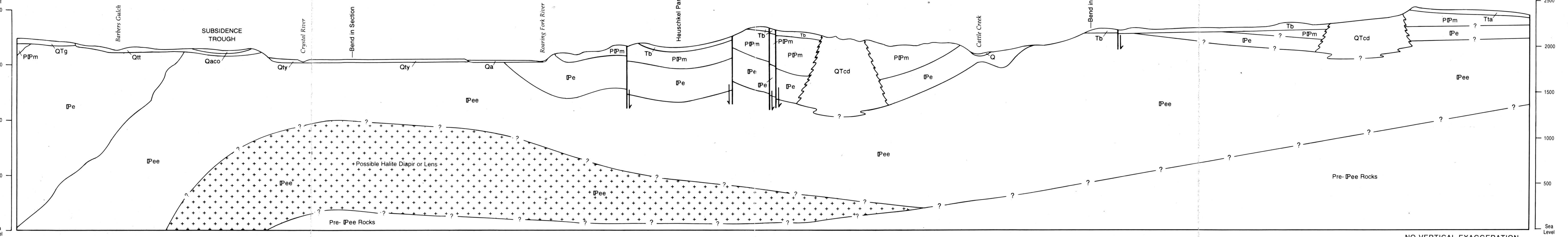

NO VERTICAL EXAGGERATION

GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE, GARFIELD COUNTY, COLORADO

By
Robert M. Kirkham and Beth L. Widmann
1997