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Geologic Map of the Leon Quadrangle, Eagle and Garfield Counties, Colorado

Description of Map Units, Structural Geology, 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 locally include deposits of another type. Divisions of the Pleistocene correspond to those of Richmond and Fullerton (1986). Relative 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 evaporite-related deformation that affects many of the terraces, altering their relative heights above stream level.

HUMAN-MADE DEPOSITS

af

Artificial fill (latest Holocene)—Composed mostly of unsorted silt, sand, and rock fragments deposited during the construction of dams and roads 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 Fryingpan Rivers and their tributaries.

Qa

Modern stream-channel, flood-plain, and low terrace deposits (Holocene and late Pleistocene)—Includes modern stream-channel deposits of the Roaring Fork and Frying Pan 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 matrix 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 includes clayey deposits in some subsidence troughs. Unit may locally include organic-rich deposits. It may interfinger 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 is a 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 valleys of ephemeral and intermittent streams, 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 or clayey silt. Locally they are gradational and interfingered with colluvium on steeper hillslopes and with lacustrine or slackwater deposits in closed depressions. Maximum thickness is 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)—Younger terrace alluvium (late Pleistocene)—Chiefly stream alluvium underlying terraces that range from about 15 to 52 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. Clasts generally are unweathered or only slightly weathered. Thickness ranges widely but averages about 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, 1998), providing a minimum age for that terrace. This dated deposit correlates in part with younger terrace alluvium (Qty) in the Leon quadrangle. Unit may correlate with 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. 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 deformed, a result of evaporitic diapirism and/or collapse or subsidence induced by dissolution of underlying evaporitic rocks. Unit is a source of sand and gravel.

Qtm

Intermediate terrace alluvium (late Pleistocene)—Composed of stream alluvium underlying terraces about 55 to 100 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 may locally be present. Clasts are chiefly subround to round and consist of various lithologies that reflect the types of bedrock found in their drainage basins. Clasts generally are only slightly weathered at shallow depths. Thickness averages about 20 to 50 ft.

Unit may correlate 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). It may also correlate with terrace B deposits of Bryant (1979) in the Aspen area. Intermediate terraces are locally deformed, perhaps a result of upwarping related to evaporitic diapirism along the axis of the modern river channel or, more likely, by collapse or subsidence of the terrace surface due to dissolution of underlying evaporitic rocks. Unit is a source of sand and gravel.

Qtt

Older terrace alluvium (middle and early? Pleistocene)—Consists of stream alluvium in a small terrace remnant about 380 to 400 ft above the Frying Pan River in the southeast corner of the quadrangle. Deposit is poorly exposed, but appears to be poorly sorted to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. Gravel clasts are predominantly red sandstone, coarse-grained Proterozoic plutonic rocks, quartz, and quartzite that are commonly moderately to strongly weathered. Thickness is about 15 to 25 ft.

Unit may be correlative with T2 terrace deposits in the Carbondale-Glenwood Springs area of Piety (1981). It may be a source of sand and gravel.

QTg

High-level gravel (early Pleistocene and/or late Tertiary)—Occurs on a subtle ridge line about 1 mile east of El Jebel about 1,300 to 1,350 ft above the Roaring Fork. Unit consists of clast-supported, sandy and silty, pebble and cobble gravel and gravelly sand and silt. Clasts are subround to subangular and composed chiefly of quartzite, white sandstone, red sandstone, quartz, and chert, with sparce rounded to well rounded pebbles of Proterozoic metamorphic and plutonic rocks. Clasts are moderately to very highly weathered. The high-level gravel deposit is about 20 to 30 ft thick. Unit is a possible source of sand and perhaps gravel, but is very limited in size.

QTm

Sediments of Missouri Heights (early Pleistocene and/or late Tertiary)—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights area in alluvial and perhaps localized colluvial environments. May include pediment deposits derived from and deposited on the sediments of Missouri Heights in area between Spring Park Reservoir and Cattle Creek. Unit is generally very poorly exposed in the quadrangle; however it is well exposed in an irrigation ditch north of Spring Park Reservoir. The sediments of Missouri Heights typically range from sandy and silty pebble, granule, or cobble gravel to gravelly silty sand. Kirkham and Widmann (1997) reported that in the Carbondale quadrangle this unit is predominantly gravelly sandy silt, clayey silt, and cross-bedded, fine-grained to very fine-grained sand. Clasts are mostly subangular to subround basalt, red sandstone, and quartzite, but many other rock types can be found within these deposits in trace amounts. Unit occurs about 1,000 to 1,650 ft above the Roaring Fork River.

Sediments of Missouri Heights were deposited in areas topographically lowered by collapse or subsidence related to dissolution or flowage of salt deposits in the underlying Eagle Valley Evaporite. Their maximum thickness may exceed 300 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.

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 one small, recently active landslide with very fresh morphological features near the northeast corner of the quadrangle. Deposits consist of unsorted, unstratified rock debris, sand, and silt. Maximum thickness is probably about 15 ft. The recent landslide on this quadrangle occurred on moderately steep slope underlain by the Entrada Sandstone and mantled with a thin veneer of colluvium. Recent landslides may be prone to renewed or continued landsliding.

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), sheetwash deposits (Qsw), and colluvium and sheetwash (Qcs) 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 50 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 hard, indurated outcrops of basalt (Tb), trachyandesite (Tta), or Dakota Sandstone (Kd), and transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Unit commonly lacks matrix material, because the outcrops that serve as source areas for talus seldom weather to fine-grained material. Locally it is underlain by or incorporated into landslides. Maximum thickness is estimated at about 60 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.

Qbf

Boulder-field deposits (Holocene and late Pleistocene)—Deposits of angular boulders and cobbles of basalt with little or no matrix on moderate to steep slopes. Boulder-field deposits are common on the flanks of Basalt Mountain, where they generally overlie landslide deposits or basalt flows. Many of the clasts within the boulder-field deposits originated as talus derived from steep cliffs of basalt and have been transported down slope by landslides. Locally the surface developed on these deposits has linear or sinuous ridges and swales that generally trend parallel to the slope of the surface. Such features are suggestive of movement as a rock glacier or periglacial processes, perhaps during the last glacial period. Thickness averages 20 to 50 ft. Area may be subject to future landsliding. Boulder-field deposits are difficult to excavate and are unstable, which reduces their suitability for foundations. Unit is a source of riprap, decorative rock, and crushed aggregate.

Qls

Landslide deposits (Holocene and Pleistocene)—Highly variable deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Clast lithology is dependent upon its provenance. Unit includes landslides that range in age from recently or currently active to long-inactive, middle or early Pleistocene landslides. Unit includes rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. The large landslide complex on the southwest side of Basalt Mountain includes prominent slump blocks with linear ridges that are underlain by highly permeable basalt rubble. The landslide deposits in that area are locally overlain by small, thin deposits of unmapped loess. Maximum thickness may exceed 400 ft. 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 15 to 20 ft thick, with a maximum thickness about 30 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. 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 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 and late Pleistocene?)—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 silty, sandy, or clayey matrix. It is commonly very bouldery, particularly near fan heads. Numeric subscripts indicate relative ages of younger debris fan deposits in the southwest corner of the quadrangle with deposits labeled Qdfy$_1$ being younger than and derived from deposits labeled Qdfy$_2$. 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 subrounded 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.

Areas mapped as younger debris-flow deposits are subject to flooding and to future debris-flow, hyperconcentrated-flood, and alluvial deposition following intense rainstorms, although mudflow and sheetwash processes prevail on the distal parts of some fans. All areas mapped as Qdfy1 are subject to future deposition, whereas only portions of the areas mapped as Qdfy$_2$ are prone to future deposition. 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. Unit is a potential source of gravel and sand, especially where derived from Tertiary sedimentary deposits (Ts).

Qac **Alluvium and colluvium, undivided (Holocene?)**—Unit chiefly consists of modern stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams and colluvium and sheetwash on valley sides. Deposits of alluvium and colluvium probably interfinger. Locally includes younger debris-flow deposits and earth-flow deposits. Unit 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 dependent upon type of rock within source area. Estimated thickness is commonly 5 to 20 ft; maximum thickness is 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. May include lacustrine sediments beneath Kodiak ski lake in the subsidence trough about one-half mile southeast of El Jebel. This unit is 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 nazards. Thickness averages 10 to 30 ft, but may be thicker in subsidence troughs.

Qaco **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits of alluvium and colluvium ranging from about 10 to 60 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. Thickness is as much as 60 feet. Area is subject to active colluvial and sheetwash deposition where adjacent to hillslopes. Unit may be a potential source of sand and gravel.

Qcso **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Deposits of colluvium and sheetwash that underlie surfaces 20 to 160 ft above adjacent drainages. Unit is texturally and depositionally similar to colluvium and sheetwash (Qcs). Thickness averages 20 to 40 ft. Areas mapped as older colluvium and sheetwash are generally not subject to future deposition except where adjacent to and below steep hillslopes.

Qdfo **Older debris-flow deposits (Pleistocene)**—Occurs as a single remnant of an old debris fan on a ridgeline in the southeast corner of the quadrangle about 80 to 160 ft above the adjacent stream bed. Unit is genetically, texturally, and lithologically similar to younger debris-flow deposits (Qdfy). Boulders within older debris-flow deposits (Qdfo) are up to 3 ft in diameter. Clasts range from unweathered to moderately weathered. Thickness is about 10 to 20 ft.

SINTER DEPOSITS—Chemical sediments deposited by a mineral spring

Qtu **Tufa (Holocene and late Pleistocene?)**—Low-density, porous, calcium carbonate deposited as chemical precipitate from a now inactive mineral spring. Tufa occurs as a massive ledge-forming deposit along the Basalt Mountain Fault in the northeast part of the quadrangle immediately north of where the fault crosses Cattle Creek. Thickness averages 6 to 7 ft.

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

COLLAPSE DEPOSITS

QTcd **Collapse debris (Quaternary and late Tertiary)**—Heterogeneous deposits of moderately to severely deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Unit formed west of the Basalt Mountain Fault in the central parts of the Carbondale collapse center in response to major 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 comprise the predominant type of bedrock within the collapse debris at the ground surface. The unit locally includes relatively small blocks of intact but tilted basalt up to about 20 acres in size. 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, alluvium, sheetwash, and colluvium, have been deposited over the collapsing debris at various times. These surficial deposits often were caught up within and incorporated into the deposit as it underwent further collapse.

Unit grades to folded and faulted bedrock where less deformed and to landslide deposits where the direction of collapse appears to have a significant horizontal component. Contacts between collapse debris and basalt or landslide deposits are very gradational and only very approximately located.

Two samples collected from a basalt flow exposed in a roadcut into collapse debris along Upper Cattle Creek road about 1 mile south of Spring Park Reservior were dated using $^{40}Ar/^{39}Ar$ methods by M. J. Kunk (1998, written commun). The samples had plateau ages of 10.62 ± 0.08 and 10.57 ± 0.07 Ma.

Collapse debris may be prone tosettlement 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 (Table 1; samples L-6 and L-7) perhaps erupted from more than one eruptive center. Includes flows along Cattle Creek above the confluence with Shippes Draw that geochemically are trachybasalt (Table 1; samples L-1 and L-4) but which appear to correlate with Pliocene trachyandesite because of their geomorphic setting, petrography, age, and trace-element geochemistry. Unit locally includes volcaniclastic deposits. Petrographically most flows are xenocrystic olivine basalt with xenocrysts of quartz, sanidine, and plagioclase up to 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 to subhedral crystals and are sometimes 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 25 ft, whereas the maximum thickness of the entire flow sequence is about 50 ft.

$^{40}Ar/^{39}Ar$ dating of trachyandesite exposed in a roadcut near Cattle Creek and south of the cinder quarries between Shippes Draw and Sleepy Creek yielded a plateau age of 3.094 ± 0.022 Ma (M. J. Kunk, 1998, written commun.). The correlation age for this sample agrees with the plateau age. $^{40}Ar/^{39}Ar$ ages of possibly equivalent rocks are 3.94 Ma at Little Buck Point in Shoshone quadrangle (Kirkham and others, 1995b) and 3.17 Ma at Buck Point and 3.0 Ma at Gobbler Knob in Cottonwood Pass quadrangle (Streufert and others, 1997b). Steep cliffs composed of this unit may pose rockfall hazards. Excavation into the unit may be difficult and require blasting.

Ttac **Cinder deposits of McNulty quarry (Pliocene)**—Dark-gray to black, scoriaceous, cinder deposits exposed in the McNulty cinder quarry on the north side of Cattle Creek. Deposit appears to be an eroded remnant of a tilted cinder cone. Petrographically this deposit is xenocrystic olivine basalt; geochemically it is basaltic trachyandesite (Table 1; sample L-3). Unit contains abundant xenocrysts of quartz and rare sanidine. Also contains sparse xenoliths of red sandstone and gypsum. Deposit generally is lightweight, unconsolidated to weakly consolidated, and very vesicular, but locally is dense, hard, and only slightly to moderately vesicular. Unit is a source of cinders and light-weight aggregate.

Tsb **Sediments of Basalt Mountain (Pliocene or Miocene)**—Chiefly clast-supported, medium-red-brown, weakly indurated pebble and cobble gravel or conglomerate with a sandy, silty, or sometimes clayey matrix. Unit locally is bouldery. Clasts are subrounded to angular and are composed chiefly of red sandstone and siltstone with lesser amounts of tan, brown, and white sandstone, suggesting that Red Table Mountain was the provenance. Unit occurs in three isolated, erosional remnants that overlie Miocene basalt (Tb) on the north flank of Basalt Mountain. This unit was probably deposited by ancestral Cattle Creek prior to incision of the modern valley of Cattle Creek through the Miocene basalt cap.

The stratigraphic relationship between the sediments of Basalt Mountain and flows from the Basalt Mountain shield volcano, along with the apparent low relief erosion surface beneath the Miocene basalt around Basalt Mountain, provide strong evidence of the paleogeomorphologic setting of this area during the late Tertiary. Basalt flows that erupted from Basalt Mountain shield volcano apparently flowed across an erosion surface with low relief onto the valley floor of ancestral Cattle Creek. The lava flows must have filled the low-relief paleovalley, causing ancestral Cattle Creek to then flow over the basalt cap. Maximum thickness is about 20 to 30 ft in the quadrangle, but may be much thicker east of the quadrangle. The sediments of Basalt Mountain are a potential sand and gravel resource suitable for surfacing roads on Basalt Mountain (T. Svatos, 1997, personal commun.).

Tspb **Basalt of Spring Park (Pliocene or Miocene)**—Medium-gray basaltic flows from an eruptive center about one-half mile east of the dam for Spring Park Reservoir. Petrographically the unit is xenocrystic olivine basalt, while geochemically it is basaltic trachyandesite (Table 1; sample L-246). Groundmass is predominantly plagioclase and pyroxene. Contains sparse phenocrysts of mainly olivine and rarely plagioclase. Locally contains abundant xenocrysts of quartz, sanidine, and plagioclase. Unit may consist of multiple flows, but only one flow was exposed in outcrops on the quadrangle. Exposed thickness ranges from about 10 to 40 ft. The largest remnant of this flow lies northeast of and as much as 200 ft higher in elevation than the cinder cone from which it was erupted. This suggests these rocks have undergone considerable down-to-the-west tilting since deposition, deformation that we attribute to dissolution or flowage-related collapse along the west side of the Basalt Mountain Fault.

Tspc **Cinder deposits of Spring Park (Pliocene or Miocene)**—Red and red-brown, scoriaceous, unconsolidated cinder deposits associated with an eroded eruptive center about one-half mile east of the dam for Spring Park Reservoir in the Griffith cinder quarry. This unit is mostly light-weight and highly vesicular, but locally is only slightly to moderately vesicular. Petrographically the rock is olivine basalt with locally abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically these rocks are basaltic trachyandesite (Table 1; sample L-245) (M. Kunk, 1998, written commun.).

Tb **Basalt (Miocene)**—Multiple flows of basalt, trachybasalt, basaltic andesite, and basaltic trachyandesite (Table 1; samples L-11 and L-12). In places the unit includes slightly indurated interflow 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 and hematite. Phenocrysts are chiefly olivine and less commonly plagioclase. Unit may contain rare xenocrysts or xenoliths of quartz or quartzite.

Basalt Mountain, the prominent mountain along the eastern edge of the quadrangle, is a partially eroded shield volcano and is perhaps the source of much of the Miocene basalt on Leon quadrangle. A former crater at the summit of Basalt Mountain is filled with thick, ponded lava flows, two of which are exposed in the cliff on the southwest side of the summit. The lower exposed flow may exceed 250 ft in thickness. Individual flows outside of the crater commonly are 5 to 50 ft thick. Thickness of the entire sequence of flows averages 40 to 80 ft in the quadrangle, but it may exceed 500 ft in the Basalt Mountain shield volcano. The base of the volcanic pile on Basalt Mountain is poorly exposed, but geomorphic relationships suggest the volcano and associated flows were erupted onto a low-relief erosion surface.

Several samples of basalt from Leon quadrangle have been dated using whole rock ^{40}Ar/^{39}Ar methods (M. J. Kunk, 1998, written commun), and ages for several more samples are pending. The lowermost flow in the steep cliff face at the southern edge of Basalt Mountain shield volcano had a plateau age of 10.49 ± 0.07 Ma. Correlation ages on two samples from this same flow support this age determination. The third basalt flow above the base of this stacked sequence of flows gave a plateau age of 10.18 ± 0.06 Ma, which is supported by a perferred age of 10.11 ± 0.06 Ma on a second sample collected from this same flow.

^{40}Ar/^{39} ages have been determined for both of the two thick, ponded basalt flows contained within the possible crater at the top of Basalt Mountain shield volcano (M. J. Kunk, 1998, written commun). The lower of the two flows had a plateau age of 9.83 ± 0.07 Ma, which is supported by its correlation age. The upper of the two ponded flows yielded a plateau age of 9.72 ± 0.06 Ma. Presently available dates suggest Basalt Mountain shield volcano was active at least between about 10.5 to 9.7 Ma.

^{40}Ar/^{39}Ar dating of the next to lowest basalt flow exposed in a roadcut along Upper Cattle Creek road about 1 mile northwest of El Jebel yielded a plateau age of 10.84 ± 0.06 Ma (M. J. Kunk, 1998, written commun). This age determination is supported by its inverse isotope correlation age.

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)—Weakly indurated to unconsolidated deposits of mostly clast-supported, fluvial, silty, sandy pebble and cobble gravel with occasional beds of silt and sand of probable alluvial and/or colluvial origin. Unit is poorly exposed in quadrangle. Includes two distinct deposits, one found in the southwest corner of the quadrangle and a second in the northeast part of the quadrangle west of the Basalt Mountain Fault. Deposits in the northeast part of the map area appear to have more fine-grained interbeds and clasts tend to be smaller. Isolated hills in the southwest corner of the quadrangle that are mapped as Tertiary sedimentary deposits may have been part of a landslide complex that subsequently has undergone intense erosion.

Clast lithology ranges widely. In the northeast part of the quadrangle clasts are mostly red sandstone, quartz, and coarse-grained plutonic rocks with minor metamorphic and hypabyssal rock types. The hypabyssal clasts in this area are similar to ones in late Pleistocene Colorado River deposits upstream of Dotsero (Streufert and others, 1997b), suggesting the ancestral Colorado River may have at one time flowed near modern-day Cottonwood Pass. In the southeast part of the quadrangle coarse-grained Proterozoic plutonic rocks, middle Tertiary hypabyssal rocks, quartzite, and red sandstone are the most common rock types; basalt clasts are sparse. Most clasts in both areas are well rounded to subrounded and moderately to very highly weathered.

Tertiary sedimentary deposits in the southwest corner of the quadrangle may have been deposited in a large structural depression on the northern side of Mount Sopris that was actively subsiding syndepositionally (Streufert and others, 1998). This structural depression is interpreted as a subsidence trough or synclinal sag due to dissolution or flowage of underlying evaporitic rocks. Dissolution rates in this area may have been enhanced by magmatic fluids associated with the intrusion of the Mount Sopris stock. The Tertiary sedimentary deposits may be over 2,000 ft thick in the central part of the structural depression. The Tertiary sediments appear to overlie a 36.3 Ma ash-flow tuff on Basalt quadrangle (Streufert and others, 1998; Marvin and Dodson, 1979) and underlie a basalt flow dated at less than 14 Ma south of Catherine on Carbondale quadrangle (Kirkham and Widmann, 1997). In the northeast part of the quadrangle the Tertiary sedimentary deposits underlie Miocene basalt flows. Maximum thickness of these deposits in the southwest corner of Leon quadrangle is about 600 ft, but they are much thicker to the west. In the northeast part of the quadrangle these deposits have a maximum thickness slightly in excess of 200 ft. Unit is prone to landsliding in the southwest corner of the quadrangle. Unit is a potential source of sand and perhaps gravel.

Km

Mancos Shale (Upper Cretaceous)— Predominantly light- to dark-gray and black, carbonaceous, silty to sandy shale with minor bentonite beds, limy gray shale, and thin light- to medium-gray, grayish-yellow-weathering, clayey sandstone. To the north on Cattle Creek and Glenwood Springs quadrangles Kirkham and others (1995a; 1996; 1998) report that formations such as the Niobrara, Frontier, and Mowry are present in this area. In some cases these rocks were mapped separately, but at other times they were included within the Mancos Shale. To the south and southeast of Leon quadrangle Streufert and others (1998) and Freeman (1972) recognized the Fort Hays Limestone Member, a thick-bedded, coarse-grained, gray limestone, and unnamed sandstone members in the Mancos Shale. These subdivisions of the Mancos Shale were not mappable in Leon quadrangle. This is largely due to the very poor and limited exposures in this area, because slopes underlain by Mancos Shale are frequently mantled with landslides and other surficial deposits.

Total thickness of the Mancos Shale in Woody Creek quadrangle to the southeast is 5,200 ft (Freeman, 1972). The upper part of the formation is not preserved in Leon quadrangle, therefore its thickness on the quadrangle is probably less than 5,200 ft. The Mancos Shale was deposited in a low-energy, off-shore marine environment. It is very prone to landsliding and is 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. Unit may include the Burro Canyon Formation in the southern part of the quadrangle. Sandstone beds within the formation commonly are well sorted, silica cemented, and have angular to subrounded sand grains. Conglomeratic clasts generally are pebble-sized chert and quartz. Thickness ranges from about 125 to 175 ft. Unit is conformable with overlying Mancos Shale. Upper contact is placed at the top of the uppermost quartzose sandstone beneath the Mancos Shale. Sandstone beds within the formation are often well exposed and in the northeast part of the quadrangle cap prominent flatiron dip slopes. 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). It is prone to rockfall where exposed in cliffs.

Jm

Morrison Formation (Upper Jurassic)— Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to tan sandstone, and gray limestone. Thin beds of sandstone in the lower half of the formation may be equivalent to the Salt Wash Member in nearby areas. A 10- to 20-ft-thick, coarse-grained, oolitic, tan- and white-weathering, medium- to dark-gray limestone is at the base of the formation and rests directly on the Entrada Sandstone. Thickness is variable but probably averages about 350 to 400 ft. The Morrison Formation is poorly exposed in much of the quadrangle, but is fairly well exposed on the steep hillslope south of Basalt Mountain. Contact with the overlying Dakota Sandstone is sharp and unconformable, but seldom is observed in the field. Unit was probably deposited in a lacustrine-dominated, fluvio-lacustrine environment (Fairer and others, 1993). Shale and claystone beds in the formation may be prone to landsliding.

Je

Entrada Sandstone (Upper Jurassic)— Light-gray, tan, and white, medium- to very fine-grained, well sorted, poorly indurated sandstone with large-scale crossbedding. Sand grains are mostly rounded to subrounded quartz. Thickness is about 50 to 75 ft. The Entrada Sandstone is poorly exposed in most areas, probably due to weak cementation; however it is fairly well exposed on the steep hillslope below the cliffs of basalt on the southern margin of Basalt Mountain shield volcano. Contact with overlying Morrison Formation is sharp and conformable, occurring at the top of the main sandstone and immediately below a gray, coarse-grained, oolitic limestone. Cross-bedding is large-scale, indicating an eolian origin probably in an extensive dune field (Fairer and others, 1993).

TRc

Chinle Formation (Upper Triassic)—Consists of thin, even-bedded, and structureless beds 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. May include a thin, basal conglomeratic sandstone, the Gartra Member (Dubiel, 1992), but this was not recognized in the quadrangle. Contact with overlying Entrada Sandstone is fairly sharp and unconformable. The Chinle Formation is well exposed on the steep hill slope south of Basalt Mountain. At this location the formation is an estimated 100 to 150 ft thick. To the southeast in Woody Creek quadrangle the Chinle thickens to over 1,000 ft (Freeman, 1972). The upper or red bed portions of the formation are possibly lateral-accretion and flood-plain deposits, while the lower coarse-clastic portion was probably mainly deposited as active channel-fill and valley-fill deposits (Dubiel, 1992).

TRPsb

State Bridge Formation (Lower Triassic and Permian)—Reddish-orange, grayish-red, and pale-reddish-pink silty sandstone, clayey siltstone, arkosic sandstone, conglomeratic sandstone, and very minor gray dolomite. Includes the lower subunit of Freeman (1971, 1972), which he called the lower siltstone and sandstone member, and perhaps the Toner Creek member. Included within Freeman's lower siltstone and sandstone member is a medium-gray, silty and sandy limestone and dolomite that he correlated with the South Canyon Creek Dolomite Member of Bass and Northrop (1950) and Stewart and others (1972). The South Canyon Creek Dolomite occurs about 200 ft above the base of the State Bridge Formation in Leon quadrangle. It is up to 18 inches thick, but appears to occur in lenses, as it could not be traced across hillslopes that are only partially covered by residuum and colluvium.

The section of rocks that may correlate with the Toner Creek member of Freeman (1971, 1972) lies immediately below the Chinle Formation and is well exposed on the steep hillslope south of Basalt Mountain. It consists of a sequence of red-brown, sandy, pebble and cobble conglomerate and conglomeratic sandstone, the basal part of which has been strongly bleached. Clasts are rounded to subrounded chert, quartz, potassium feldspar, red sandstone and siltstone, Proterozoic plutonics, and hornfels. Prominent, near-vertical veinlets of milky quartz are locally numerous within the bleached beds. The veinlets are up to 4 inches in width and 7 to 8 ft in length. Bleaching is locally very intense along the veinlets.

Sandstone beds in the formation are thin to thick bedded, well sorted, fine to medium grained, and laterally continuous without any obvious lensing. Sand grains have a high degree of sphericity. The State Bridge Formation contains several conglomeratic sandstone beds. They are up to about 10 ft thick and are massive to very slightly cross-bedded, contain mostly pebble-sized clasts of quartz, chert, sedimentary rock fragments, and Proterozoic plutonic rocks. The State Bridge Formation is micaceous, although generally less so than the underlying Maroon Formation. Contact with the overlying Chinle Formation is sharp and unconformable.

Where exposed in Leon quadrangle the State Bridge Formation is around 1,000 ft thick. In adjacent quadrangles the formation thickness varies tremendously. In the Cattle Creek quadrangle Kirkham and others (1996) indicated the combined thickness of the Chinle and State Bridge is only 150 to 200 ft. Thickness of the State Bridge Formation increases from about 200 to over 1,000 ft from east to west across Basalt quadrangle (Streufert and others, 1998). In the Woody Creek quadrangle Freeman (1971) reported it is up to 2,400 ft thick. These relatively abrupt thickness changes may result from basin subsidence synchronous with deposition of the formation. Basin subsidence could be related to syn-depositional tectonic movement on faults such as the Basalt Mountain Fault or to structural collapse related to flowage of underlying evaporitic rocks (Tweto, 1977; Streufert and others, 1998). The State Bridge Formation was deposited in a marginal-marine, fluvio-lacustrine environment (Dubiel, 1992). It is prone to rockfall where exposed in steep cliffs.

TRPcs

Chinle and State Bridge Formations, undivided (Triassic to Permian)—Includes the Chinle and State Bridge Formations in the northern part of the quadrangle where poor exposures prevent recognition of the contact between the two formations.

PIPm **Maroon Formation (Lower Permian and Upper Pennsylvanian)**—Pale-red to pinkish-red and grayish-red arkosic sandstone, conglomerate, siltstone, and mudstone, with shale and minor, thin beds of gray limestone. The Maroon Formation is very micaceous, noticeably more so than the overlying State Bridge Formation. It also contains more sand grains composed of feldspar than does the State Bridge Formation. Sandstone beds are coarse to fine grained and moderately to poorly sorted with grains that are generally angular to subrounded. This distinguishes the sandstones of the Maroon Formation from sandstones in the overlying State Bridge Formation, whose grains are consistently well sorted and high in sphericity. The color change from the pale-reddish-pink color of the Maroon Formation to the orange-red and brownish-red colors of the State Bridge Formation is sometimes useful in identifying the contact between the two formations. The entire Maroon Formation is not exposed in the quadrangle, but to the north Kirkham and others (1995a; 1996) reported a thickness of 3,000 to 5,000 ft and to the southeast Freeman (1972) indicated a thickness of about 3,000 ft. The formation was deposited in fluvial, eolian, alluvial fan, and fan-delta environments within the Central Colorado Trough (Johnson and others, 1988; 1990). 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, sandstone, shale, 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 of formation is not known in Leon quadrangle, but ranges from 500 to 3,000 ft thick to the northwest in the Carbondale quadrangle (Kirkham and Widmann, 1997). 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 the 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.

PIPme **Maroon and Eagle Valley Formations, undivided (Lower Permian and Upper and Middle? Pennsylvanian)**—Includes the Maroon and Eagle Valley Formations where the contact between the two formations is not mappable.

IPee **Eagle Valley Evaporite (Middle Pennsylvanian)**—Sequence of evaporitic rocks consisting of massive to laminated gypsum, anhydrite, halite, beds of light-colored mudstone and fine-grained sandstone, thin limestones, and black shale. 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. Part of formation is fairly well exposed in road cuts on Upper Cattle Creek Road north of El Jebel. Thickness of unit in the Leon quadrangle is poorly constrained, as the base of the formation is not exposed. In adjacent areas the thickness may be as much as 9,000 ft (Mallory, 1971). Kirkham and Widmann (1997) reported a minimum thickness of 2,700 ft to the northwest in the Carbondale quadrangle. 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, which formed as the outlet for the Central Colorado Trough was restricted (Mallory, 1971). Schenk (1989) recognized multiple transgressive-regressive cycles in the formation near Gypsum and Eagle and suggested the gypsum was deposited in a subaqueous environment. The Eagle Valley Evaporite contains cavernous voids caused by dissolution of halite and gypsum. The sinkhole along Upper Cattle Creek Road north of El Jebel is approximately 30 ft in diameter and 30 to 60 ft deep. The unit is prone to development of sinkholes into which overlying deposits may subside or be piped. Surficial deposits derived from the unit may be subject to compaction, settlement, sinkhole, and corrosion problems. Gypsum and halite within the formation are potential mineral resources.

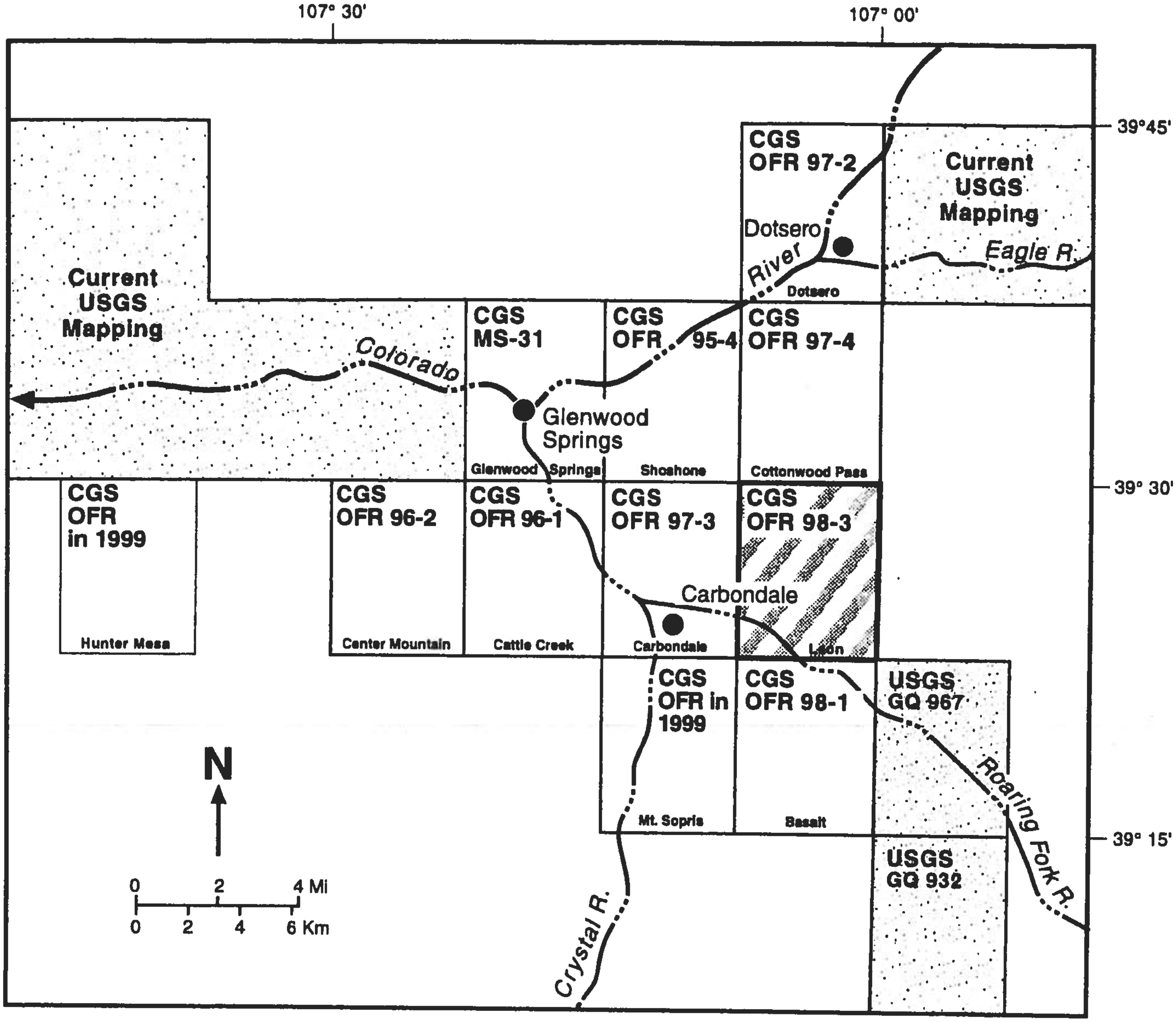

Figure 1. Status of geologic mapping of 7.5-minute quadrangles in the vicinity of Glenwood Springs.

STRUCTURAL GEOLOGY

The structural geology of Leon quadrangle is largely controlled by the Laramide-age Basalt Mountain Fault, a down-to-the-east, high-angle fault with a minimum of 5,600 ft of throw. Pennsylvanian evaporitic rocks are displaced against the Cretaceous Mancos Shale where the fault attains its greatest stratigraphic throw between Cattle Creek in the northern part of Leon quadrangle and near Emma in Basalt quadrangle. Depending on which part of the Eagle Valley Evaporite is faulted against which part of the Mancos Shale, maximum displacement on the Basalt Mountain Fault could exceed 10,000 ft. A prominent synclinal drag fold occurs on the east side of the fault at the north end of the quadrangle and continues into Cottonwood Pass quadrangle. Streufert and others (1997b) reported that this drag folding suggests the fault is a reverse fault. We are not aware of any conclusive evidence that defines the dip of the Basalt Mountain Fault in Leon quadrangle, but have chosen to show it as a high-angle reverse fault on cross section A—A'.

The structural juxtapositioning of readily dissolvable evaporite against shale highly prone to landsliding has created a perhaps unique geologic setting. Regional collapse due to dissolution and/or flowage of relatively shallow evaporite predominates on the western or upthrown side of the fault. On the downthrown eastern side large-scale landsliding that involves the Mancos Shale and overlying Miocene basalt prevails along and below the exposed edge of the protective cap of Basalt Mountain shield volcano.

The western half of the Leon quadrangle lies within the Carbondale collapse center defined by Kirkham and Widmann (1997). The Basalt Mountain Fault forms the eastern boundary of the Carbondale collapse center in Leon quadrangle. Exposures of Miocene basalt along the eastern margin of the Carbondale collapse center suggest that the Neogene deformation west of and immediatlely adjacent to the Basalt Mountain Fault is predominantly down-to-the-west tilting accompanied by minor faulting, which is opposite in direction to the down-to-the-east Laramide movement on the fault. Miocene basalts in the Missouri Heights area are about 2,000 ft lower than those on Basalt Mountain shield volcano, providing a minimum value for the amount of Neogene collapse along this eastern margin of the collapse center. The Neogene, salt-related, west tilting along the Basalt Mountain Fault is restricted to the Eagle Valley Evaporite and overlying deposits. Definitive evidence for deep-seated, basement-involved crustal deformation during the Neogene on the Basalt Mountain Fault has not been documented.

Features described by Kirkham and Widmann (1997) as being typical of the on-going collapse due to salt dissolution and/or flowage are widespread within the Carbondale collapse center in Leon quadrangle. Basalt flows from Basalt Mountain shield volcano are abruptly tilted downwards into the collapse area with only minor disruption by faulting. A cinder deposit and its associated flow east of Spring Park Reservoir serve as excellent marker beds that define the style of deformation along the eastern margin of the collapse center. Here, the eruptive center now lies at least 200 ft lower in elevation than a flow that was erupted from it. The dip direction of the flow indicates down-to-the-west tilting along the eastern margin of the Carbondale collapse center. Curiously, bedding in outcrops of the sediments of Missouri Heights (QTm) near the western edge of this tilted hinge zone dip as much as 65 degrees back to east, opposite in direction from the tilting that affects the Miocene basalts.

Volcanic rocks in Leon quadrangle are highly fractured and broken by small faults within the collapse area. Approaching the central portion of the collapse area these rocks grade into a heterogeneous deposit of complexly deformed and highly brecciated material that we classify as collapse debris (QTcd). These deposits consist largely of blocks and rubble of basalt with remnants of younger, wind-blown, alluvial, and colluvial deposits caught up in the collapsing debris. These deposits are sometimes overlain by less deformed surficial materials. Unusually thick deposits of Tertiary and early Quaternary sediments are locally preserved within the collapse center. They probably were deposited in large subsidence troughs or synclinal sags active at the time of sediment deposition. Tertiary sedimentary deposits may exceed 2,000 ft in thickness on the north and northeast side of Mount Sopris (Streufert and others, 1998).

Synclinal sags and subsidence troughs are locally common within the Leon quadrangle part of the Carbondale collapse center. Based on generally poorly exposed remnants of folded Miocene basalt flows, we interpret Shippes Bowl as a synclinal sag with 800 ft or more of structural collapse. Broad, low-amplitude sags deform Miocene basalt in Shippes Draw Sag and Polaris Sag. Other synclinal sags may occur within the vicinity of Spring Park Reservoir and in Missouri Heights.

At least one of the subsidence troughs, the one at Kodiak ski lake one-half mile southeast of El Jebel, contains a layer of sandy clay several feet thick (Chen-Northern, 1991). A more subtle subsidence trough lies across the highway southwest of Kodiak lake. It appears to have developed in younger terrace alluvium (Qty) and later partially filled with modern stream alluvium (Qa). Blue Creek makes an abrupt turn to the west and hugs the valley wall where it flows within an apparent subsidence trough north of El Jebel.

Sinkholes occur in several areas within the collapse center. The large sinkhole along Upper Cattle Creek road north of El Jebel is developed in a massive outcrop of gypsum. A nearby spring issues from a small void along a bedding plane in massive gypsum.

Recent mapping in the Dotsero-Eagle-Wolcott area by Streufert and others (1997a), Lidke (1998), and M. Hudson and R. Moore (1997, personal commun.) suggested a second regional collapse center, called the Eagle collapse center, exists in that area. Preliminary structure contouring of basalts by R. Scott (1997, written commun.) indicated the combined area of the two regional collapse areas is around 1,800 square miles, with a total collapse volume of approximately 550 cubic miles.

Water quality monitoring by the USGS from 1970 to 1993 provides loading values for total dissolved solids in the rivers above and below the collapse areas (N. Bauch, N. Driver, 1997, written commun; U. S. Department of Interior, 1997). Upstream of the collapse areas total dissolved solids loads in the Colorado River and its tributaries are very low. Yet at Cameo, about 65 miles downstream from the collapse centers, the mean annual dissolved solids load in the Colorado River has been around 1.5 million tons per year during the 24 year period of record, most of which has been dissolved sodium, chloride, calcium, and sulfate.

This data demonstrates that dissolution is active and on-going. Assuming the modern rate of salt dissolution was constant during the late Cenozoic and that the density of the dissolved evaporite averages 2.21, it would take about 3.7 million years to account for the 550 cubic miles of evaporite thought to have dissolved in the two collapse centers. Although the dissolved solids concentrations likely fluctuated with time, particularly with changes in climate, rates of downcutting by rivers, timing and location of magmatic intrusions, this analysis supports the geologic interpretation that salt dissolution is the ultimate manner in which evaporitic rocks are removed from the collapse areas and that the dissolution and associated collapse process has been ongoing for millions of years.

Table 1. Whole-rock analyses of volcanic rocks from the Leon quadrangle.

Sample ID No.	PERCENT												
	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI*	Total
L-1	14.76	9.18	0.00	9.40	2.82	6.05	0.15	3.01	0.57	49.58	1.41	2.44	99.37
L-3	14.98	8.00	0.00	9.95	3.04	6.30	0.15	3.12	0.58	51.49	1.35	0.47	99.43
L-4	14.80	8.95	0.00	10.74	2.20	6.75	0.16	3.07	0.68	48.82	1.75	1.66	99.58
L-6	15.07	6.66	0.00	8.54	3.55	6.09	0.13	3.25	0.62	54.08	1.41	–0.04	99.36
L-7	15.42	6.23	0.00	8.18	3.47	5.02	0.13	3.30	0.57	55.44	1.36	0.26	99.38
L-11	15.30	8.02	0.00	11.05	2.23	7.40	0.16	3.18	0.71	49.97	1.80	-0.24	99.58
L-12	15.70	4.43	0.00	6.63	4.00	1.55	0.08	3.95	0.38	60.45	1.14	0.98	99.30
L-245	14.50	7.07	0.03	9.15	3.00	4.75	0.14	3.41	0.59	52.80	1.52	0.69	97.65
L-246	14.20	7.10	0.03	9.07	2.96	5.87	0.14	3.27	0.60	52.65	1.48	0.61	97.98

*Loss on ignition

Note: Samples L-1, L-3, L-4, L-6, L-7, and L-11 analyzed by U. S. Geological Survey, Denver, Colorado; Samples L-12, L-245, and L-246 analyzed by Chemex Labs Inc., Sparks, Nevada

LEON QUADRANGLE

L-1: Trachybasalt flow exposed in road cut on north side of Cattle Creek. Lat. 39.462, Long. 107.091
L-3: Scoriaceous basaltic trachyandesite in the McNulty cinder quarry. Lat. 39.468, Long. 107.109
L-4: Trachybasalt flow on northeast side of junction of CR 113 and 122. Lat. 39.477, Long. 107.120
L-6: Basaltic trachyandesite flow on ridge near northwest corner of quadrangle. Lat. 39.498, Long. 107.119
L-7: Basaltic trachyandesite flow on northwest side of junction of CR 113 and 122. Lat. 39.477, Long. 107.123
L-11: Trachybasalt flow near center of north edge of quadrangle. Lat. 39.498, Long. 107.053
L-12: Remnant of trachyandesite flow in collapse debris in excavation about 0.5 mile north of El Jebel. Lat. 39.404, Long. 107.89
L-245: Scoriaceous basaltic trachyandesite in the Griffith cinder quarry. Lat. 39.433, Long. 107.080
L-246: Basaltic trachyandesite flow from eruptive center at Griffith cinder quarry. Lat. 39.436, Long. 107.076

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COLORADO GEOLOGICAL SURVEY
VICKI J. COWART, DIRECTOR
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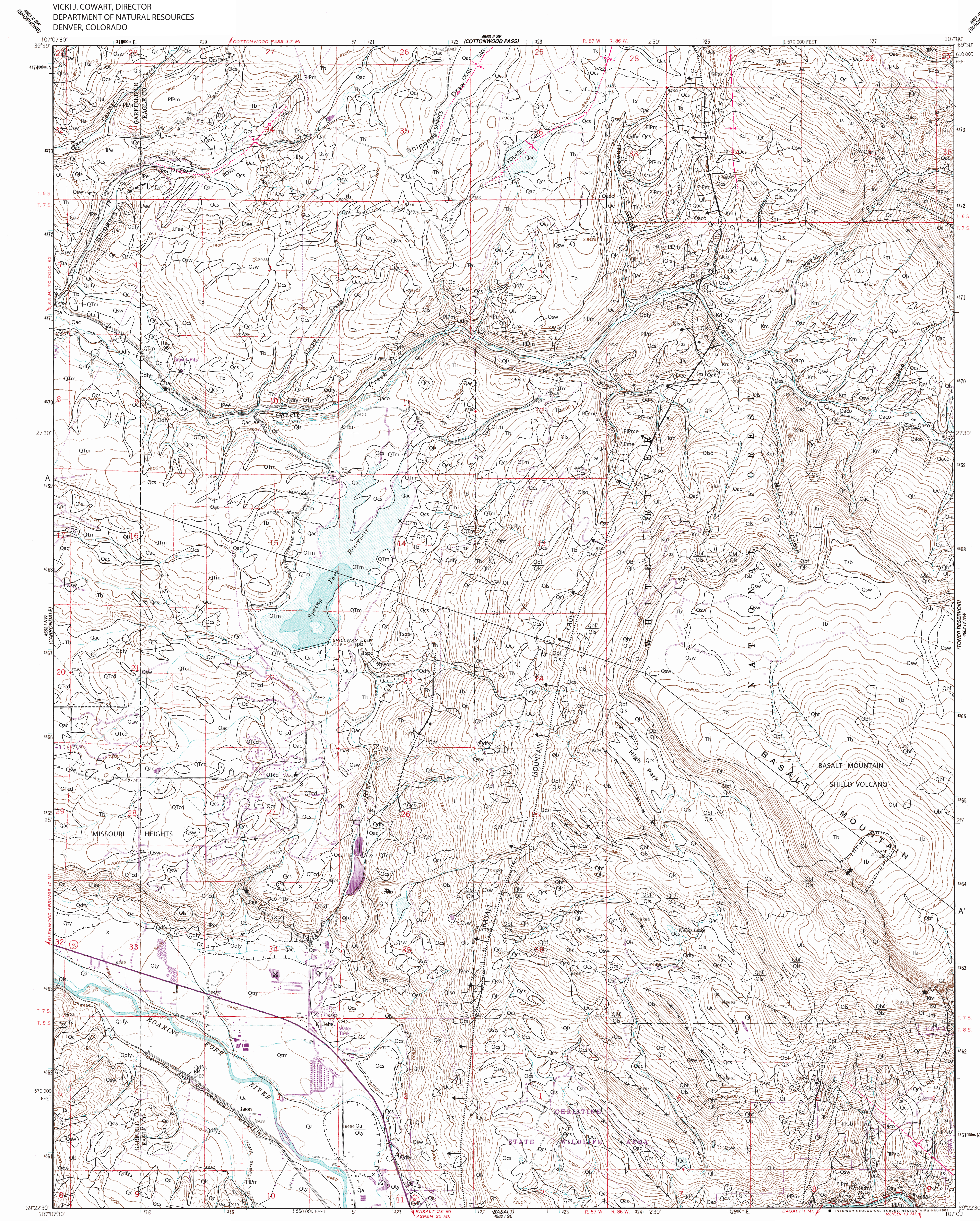
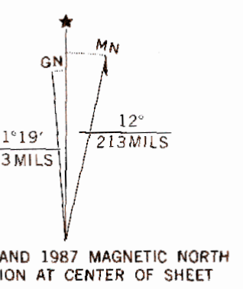
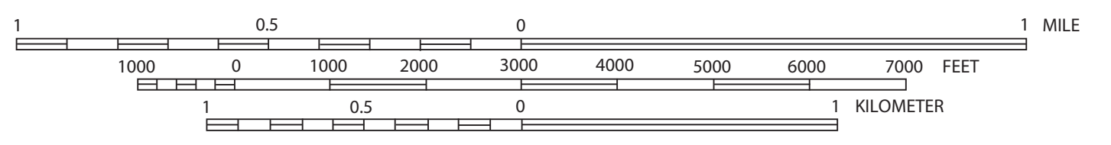
OPEN FILE MAP 98-3
GEOLOGIC MAP OF THE LEON QUADRANGLE
EAGLE AND GARFIELD COUNTIES, COLORADO
Booklet accompanies map

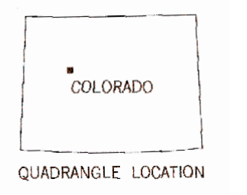


Base from U.S. Geological Survey, 1987
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone



SCALE 1: 24,000





Geology mapped in 1997
Digital map prepared by Cheryl Brchan

CONDENSED DESCRIPTION OF MAP UNITS

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

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 Modern stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. May locally include clayey deposits in some subsidence troughs. 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 basins

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 15–52 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 55–100 ft above modern streams

Qtt Oldest terrace alluvium (middle and early? Pleistocene)—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts moderately to highly weathered. Includes a single, small remnant of a terrace that is about 380–400 ft above the Frying Pan River in the southeast corner of the quadrangle

QTg High-level gravel (early Pleistocene and/or late Tertiary) — Chiefly clast-supported, sandy, silty, cobble and pebble gravel occurring on a subtle ridge line about 1 mile east of El Jebel and about 1,300–1,350 ft above the Roaring Fork River. Clasts are moderately to very highly weathered

QTm Sediments of Missouri Heights (early Quaternary and/or late Tertiary)—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights area in alluvial and colluvial environments. May include pediment deposits derived from and deposited on the sediments of Missouri Heights in area between Spring Park Reservoir and Cattle Creek. 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). Typically is less deformed than underlying rocks. Occurs about 1,000–1,650 ft above the Roaring Fork River

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

Qlsr Recent landslide deposits (latest Holocene)—Includes a recently active landslide near the northeast corner of the map with very fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified rock debris, 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 slope and finer grained in distal areas

Qt Talus (Holocene and late Pleistocene)—Angular, cobbly and bouldery rubble derived from outcrops of basalt, trachyandesite, sandstone, or basalt-rich landslide deposits

Qbf Boulder-field deposits (Holocene and late Pleistocene) —Angular boulders and cobbles of basalt with little or no matrix on moderate to steep slopes. Commonly has an undulatory surface suggestive of flowage as a rock glacier or related to periglacial processes

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

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 and late Pleistocene?)—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. Numeric subscripts indicate relative ages of younger debris fan deposits in the southwest corner of the quadrangle. Deposits labeled Qdfy$_1$ are younger than and derived from deposits labeled Qdfy$_2$

Qac Alluvium and colluvium, undivided (Holocene)— Moderately well-sorted to well-sorted, stratified, interbedded sand, silt, 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. May locally include lacustrine deposits in large subsidence troughs

Qaco Older alluvium and colluvium, undivided (Pleistocene)—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes ranging from about 10–60 ft above the floor of tributary valleys

Qcso Older colluvium and sheetwash deposits, undivided (Pleistocene)—Deposits texturally and depositionally similar to colluvium and sheetwash (Qcs) that underlie surfaces 20–160 ft above adjacent stream beds

Qdfo Older debris flow-deposits (Pleistocene)—Remnant of an inactive debris fan on a ridge line about 80–160 ft above the adjacent stream bed near the southeast corner of the quadrangle. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

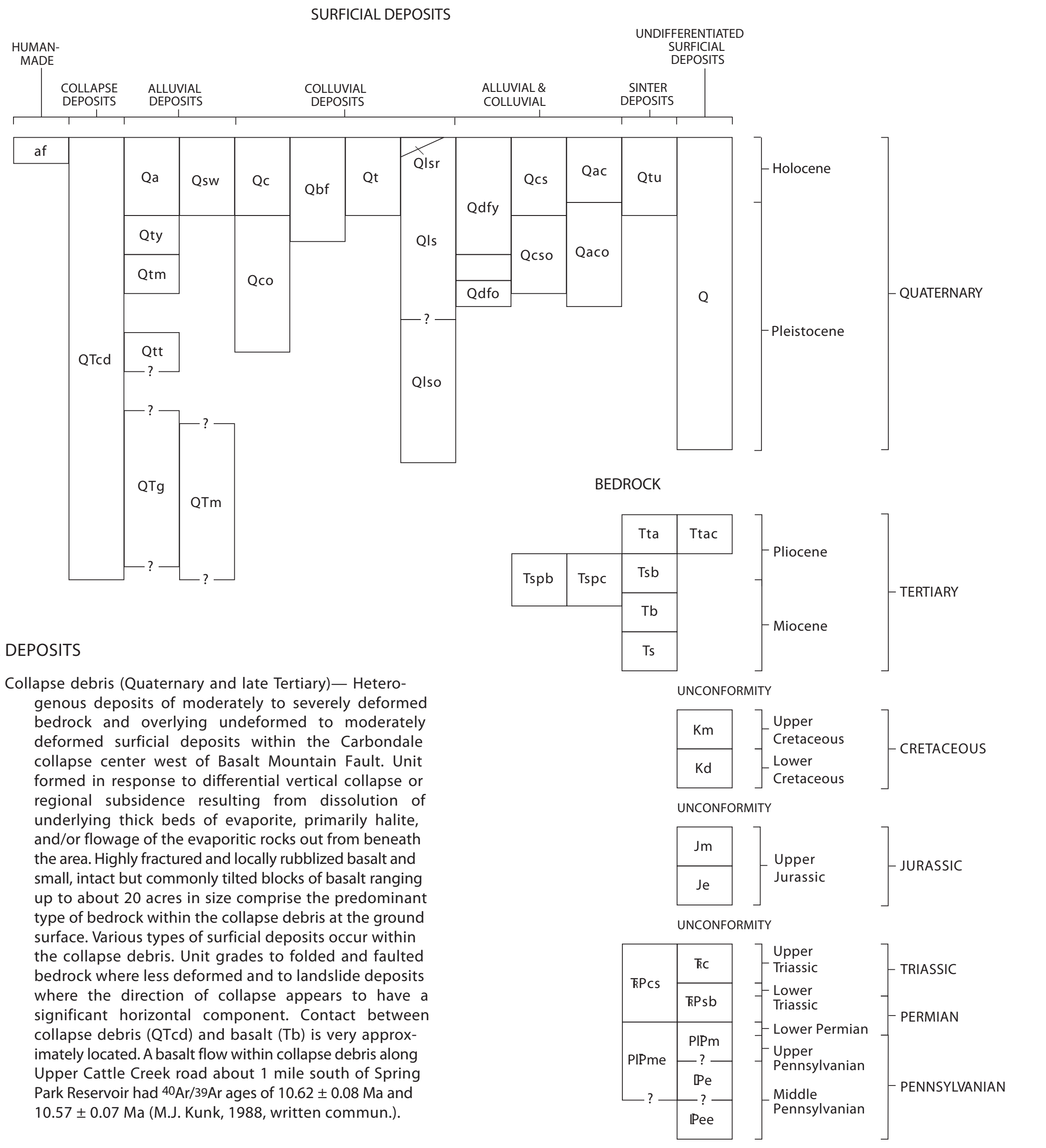
SINTER DEPOSITS—Chemical sediment deposited by a mineral spring

Qtu Tufa (Holocene and late Pleistocene?)—Low-density, porous, calcium carbonate deposits precipitated from a mineral spring along the Basalt Mountain Fault immediately north of Cattle Creek

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

CORRELATION OF MAP UNITS



COLLAPSE DEPOSITS

QTcd Collapse debris (Quaternary and late Tertiary)— Heterogenous deposits of moderately to severely deformed bedrock and overlying undeformed to moderately deformed surficial deposits within the Carbondale collapse center west of Basalt Mountain Fault. Unit 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 commonly 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. 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 the direction of collapse appears to have a significant horizontal component. Contact between collapse debris (QTcd) and basalt (Tb) is very approximately located. A basalt flow within collapse debris along Upper Cattle Creek road about 1 mile south of Spring Park Reservoir had ^{40}Ar/^{39}Ar ages of 10.62 ± 0.08 Ma and 10.57 ± 0.07 Ma (M.J. Kunk, 1988, written commun.).

BEDROCK

Tta Trachyandesite (Pliocene)—Multiple flows of basaltic trachyandesite and trachyandesite perhaps erupted from more than one eruptive center. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts. Groundmass similar to that of Miocene basalt (Tb). ^{40}Ar/^{39}Ar dating of trachyandesite exposed in a roadcut near Cattle Creek and south of the cinder quarries between Shippes Draw and Sleepy Creek yielded a plateau age of 3.094 ± 0.022 Ma (M.J. Kunk, 1998, written commun.)

Ttac Cinder deposits of McNulty quarry (Pliocene)—Dark-gray to black, scoriaceous, cinder deposit exposed in the McNulty cinder quarry. Petrographically this deposit is a xenocrystic olivine basalt; geochemically it is basaltic trachyandesite. Generally lightweight, unconsolidated to weakly consolidated, and very vesicular, but locally is dense, hard, and only slightly to moderately vesicular

Tsb Sediments of Basalt Mountain (Pliocene or Miocene)—Chiefly medium-red-brown, weakly indurated, pebble and cobble gravel in a sandy or silty matrix. Locally bouldery. Deposited over basalt flows on northern edge of Basalt Mountain shield volcano by ancestral Cattle Creek

Tspb Basalt of Spring Park (Pliocene or Miocene)—Medium-gray basaltic flows from an eruptive center about one-half mile east of the dam for Spring Park Reservoir. Petrographically the unit is xenocrystic olivine basalt, while geochemically it is a basaltic trachyandesite. Groundmass predominantly plagioclase and pyroxene. Contains sparse phenocrysts of mainly olivine and rare plagioclase. Locally contains abundant xenocrysts of quartz, sanidine, and plagioclase

Tspc Cinder deposits of Spring Park (Pliocene or Miocene)—Red and red-brown scoriaceous, unconsolidated cinder deposits associated with an eroded eruptive center about one-half mile east of the dam for Spring Park Reservoir in the Griffith cinder quarry. Mostly lightweight and highly vesicular, but locally only slightly to moderately vesicular. Petrographically the rock is olivine basalt with locally abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically these rocks are basaltic trachyandesite

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. Several samples of basalt from Leon quadrangle have been dated using ^{40}Ar/^{39}Ar methods (M.J. Kunk, 1998, written commun.). The lowermost flow in the steep cliff face at the southern edge of Basalt Mountain shield volcano had a plateau age of 10.49 ± 0.07 Ma. The third flow above the base of this cliff gave a plateau age of 10.18 ± 0.06 Ma. The ^{40}Ar/^{39}Ar age for the lower of the two thick, ponded basalt flows within the possible crater at the top of Basalt Mountain shield volcano was 9.83 ± 0.07 Ma, while the upper flow yielded an age of 9.72 ± 0.06 Ma. ^{40}Ar/^{39}Ar dating of the next to lowest basalt flow in a series of flows exposed in a roadcut along Upper Cattle Creek road about 1 mile northwest of El Jebel yielded a plateau age of 10.84 ± 0.06 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. Locally slightly to moderately indurated. Appears to underlie basalt dated at less than 14 Ma in hills south of Catherine in the Carbondale quadrangle (Kirkham and Widmann, 1997). Streufert and others (1998) report that correlative deposits in Basalt quadrangle overlie an ash-flow tuff dated at 36.3 Ma by Marvin and Dodson (1979)

Km Mancos Shale (Upper Cretaceous)—Light- to dark-gray, carbonaceous, silty to sandy shale and thin bentonite beds, gray limestone, and light- to medium-gray, grayish-yellow-weathering, clayey sandstone. Includes the Fort Hays Limestone Member, a thick-bedded, coarse-grained, gray limestone

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. May include Burro Canyon Formation in southern part of quadrangle

Jm Morrison Formation (Upper Jurassic)—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to tan sandstone, and gray limestone. A thick-bedded, coarse-grained, oolitic, tan- and white-weathering, medium-dark-gray limestone at the base of the formation overlies the Entrada Sandstone

Je Entrada Sandstone (Upper Jurassic)—Light-gray, tan, and white, medium- to very fine-grained, well-sorted sandstone with large-scale crossbedding. Weakly to moderately indurated

TRc Chinle Formation (Upper Triassic)—Thin, even-bedded, and structureless beds of dark-reddish-brown, orangish-red, and purplish-red, calcareous siltstone and mudstone and scattered thin lenses of light-purplish-red and gray limestone and limestone-pebble conglomerate. Locally includes a thin, basal conglomeratic sandstone

TRPsb State Bridge Formation (Lower Triassic and Permian)—Reddish-orange, grayish-red, and pale-reddish-pink silty sandstone, clayey siltstone, arkosic sandstone, and conglomeratic sandstone. Includes lenses of sandy dolomite and limestone of the South Canyon Creek Dolomite Member that are up to 18 inches thick and occur about 200 ft above the base of the formation. Sandstone beds are well sorted, equigranular, and have rounded to subrounded sand grains with a high degree of sphericity

TRPcs Chinle and State Bridge Formations, undivided (Triassic and Permian)

PIPm Maroon Formation (Lower Permian? and Upper Pennsylvanian)—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone

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

PIPme Maroon and Eagle Valley Formations, undivided (Lower Permian and Upper and Middle? Pennsylvanian)

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 ductily deformed

MAP SYMBOLS

Contact—Dashed where approximately located; queried where very uncertain

Diapiric contact—Contact between evaporitic formations and overlying formations where the evaporitic rocks are intrusive or piercing into the overlying formations. Teeth are on the intrusive side of the contact

Qbf/Qls Fractional formation—Indicates a thin veneer of the deposit shown in the numerator overlies the deposit shown in the denominator

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

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

Boundary of regional collapse area—Coincides with the Basalt Mountain Fault, which forms the eastern boundary of the Carbondale collapse area described by Kirkham and Widmann (1997). Style of deformation along the collapse boundary in Leon quadrangle is predominantly down-to-the-west tilting, locally accompanied by minor faulting. To the north in Cottonwood Pass quadrangle, the northeastern boundary of the Carbondale collapse area is marked by monoclinal folding of late Tertiary basalts (Streufert and others, 1997b)

Synclinal sag—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

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”
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 were measured on top of apparent surface

55 Inclined beds

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

65 Strike and dip of foliation in extrusive flow rocks—Includes measurements on flows within collapse debris (QTcd). Angle of dip shown in degrees

Linear ridge within landslide on west side of Basalt Mountain

Linear swale along the Basalt Mountain Fault—Separates two different styles of landsliding which are controlled by the underlying bedrock. Mancos Shale underlies the landslide on the east side of the fault, whereas the Eagle Valley Evaporite underlies the landslide on the west side of the fault

Approximate boundary of a subsidence trough developed in surficial deposits—Resultant from collapse into voids created by dissolution or flowage of underlying evaporitic rocks. Queried where very approximate

Approximate boundary of a lava-filled crater at the crest of Basalt Mountain—Exposed part of crater has been filled with two thick, ponded lava flows. The lower flow averages about 200–250 ft thick and the upper flow averages about 40–50 ft thick

Adit

Gravel pit

Cinder quarry

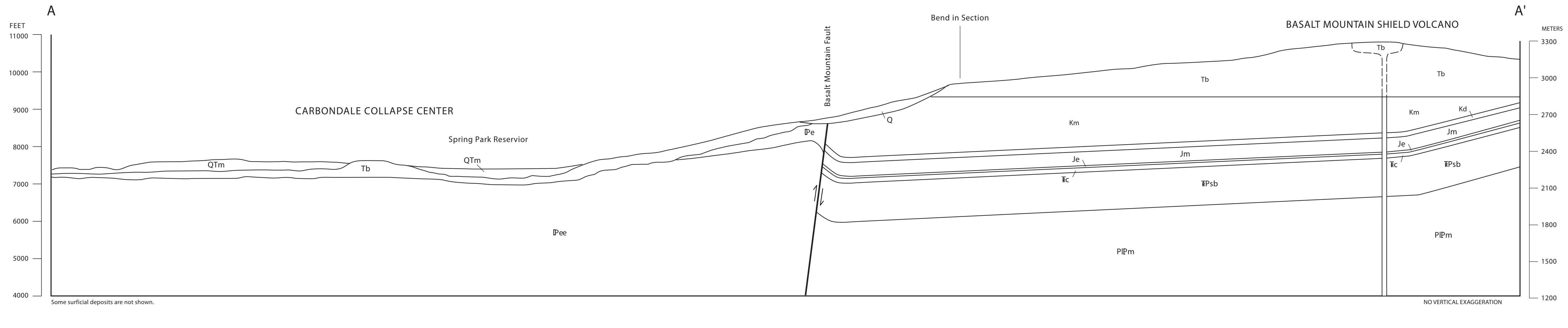
★ Locality of rock sample dated using ^{40}Ar/^{39}Ar method

A —— A' Alignment of cross section

ACKNOWLEDGEMENTS

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey STATEMAP program of the National Cooperative Geologic Mapping Act of 1992, Agreement No. 1434-97-AG-01811. Jeff Hynes and Jim Cappa reviewed the map and full text. Nancy Bauch reviewed the part of the text that describes salt loads. We appreciate the discussions and/or field reviews with Bruce Bryant, Mick Kunk, Jon White, Jim Cappa, Ralph Shroba, Dick Moore, Wayne Shelton, Ralph Mock, and Bill Perry. Tony Svatos pointed out the existence of gravel deposits along the north edge of the Basalt Mountain shield volcano, provided a log of a test pit into these deposits, and initiated arrangements to allow us to park a field trailer on U.S. Forest Service Land. Louis Meyer graciously provided a copy of a geotechnical report for a property within the quadrangle.

Most whole-rock geochemical analyses were performed by Jim Budahn, Dan Unruh, and Dave Siems. A few geochemical analyses were contracted to Chemex Labs, Inc. Mick Kunk guided our sampling effort of rocks to be dated and was responsible for the ^{40}Ar/^{39}Ar dating. Bob Thompson provided chemical analyses and locations for a number of volcanic rock samples he collected in previous years. Photogrammetric models were set by James Messerich on a Kern PG-2 plotter. Jane Ciener served as the technical editor for this map. We appreciate the many helpful landowners who gave permission to enter their property and contributed valuable information.



GEOLOGIC MAP OF THE LEON QUADRANGLE, EAGLE AND GARFIELD COUNTIES, COLORADO

By Robert M. Kirkham, Beth L. Widmann, and Randall K. Streufert
1998

reformatted final 12/29/00