OPEN-FILE REPORT 99-7

Geologic Map of the Mount Sopris Quadrangle, Garfield and Pitkin Counties, Colorado

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

By Randall K. Streufert

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This mapping project was funded by the Colorado Geological Survey
and the U.S. Geological Survey STATEMAP program
of the National Cooperative Geologic Mapping Act of 1992,
Award No. 98HQAG2081.

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GEOLOGIC SETTING

During the past six years the Colorado Geological Survey (CGS) has mapped the geology of nine 7.5-minute quadrangles along the Colorado River from north of Dotsero to Glenwood Springs, up the Roaring Fork valley to Basalt, and the area between these two valleys (Fig. 1). Mount Sopris is the tenth quadrangle in this contiguous block and extends mapping up the Crystal River to Avalanche Creek.

Every map prepared to date has offered new data and interpretations, and the Mount Sopris quadrangle is no exception. Mapping in this quadrangle has contributed to further understanding of Neogene salt-related deformation and geomorphology in an area of active salt tectonism. This study also contains new data on the intrusive history of the Middle Tertiary Mount Sopris stock. In addition, the quadrangle contains Holocene and late

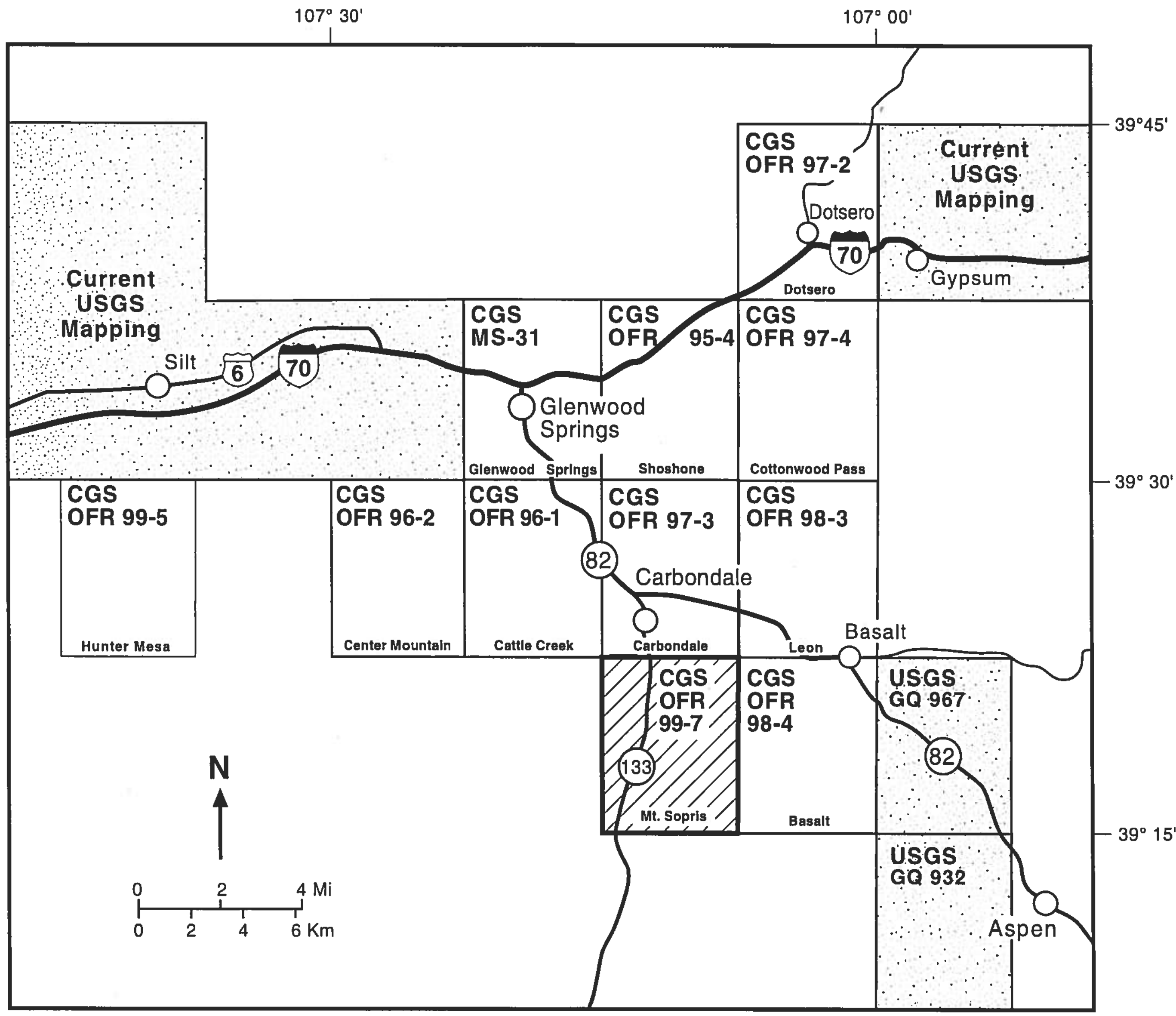

Figure 1. Status of geologic mapping of 7.5-minute quadrangles in the vicinity of Glenwood Springs.

Pleistocene glacial, periglacial, and rock-glacier deposits that are of interest, which are herein described and discussed.

The Mount Sopris quadrangle covers an area of the Crystal River valley extending south of the town of Carbondale to the mouth of Avalanche Creek. The quadrangle contains most of the Mount Sopris stock, a granodiorite pluton which lies in the southern portion of the quadrangle. The twin summits of Mount Sopris are both at an identical elevation of 12,953 ft; the modern Crystal River at the northern boundary of the quadrangle is at an elevation of 6,180 ft. Vertical relief on the north and northwest sides of Mount Sopris approaches 6,400 ft in less than 3 miles of map distance. This dramatic exposure is interpreted to result, in part, from Neogene deformation in the lower Crystal River valley that involves widespread collapse due to salt dissolution.

STRUCTURAL GEOLOGY

The Mount Sopris quadrangle is located at the northwest end of the Elk Mountains. The Mount Sopris stock is the northwesternmost of a series of mid-Tertiary plutons and associated intrusive bodies in the Elk Mountains. The quadrangle is located north of the Elk Range thrust fault and includes a portion of the Grand Hogback Monocline (Fig. 2). Both of these features are related to Laramide compressional tectonics. The quadrangle also includes the Elk Mountain Anticline, an asymmetric fold which is possibly related to Laramide compressional tectonics, the emplacement of Mount Sopris in the Oligocene, or both. This structure has also been modified by salt tectonism. The west side of the Mount Sopris stock is 1.5 miles east of nearly vertical rocks of the Grand Hogback Monocline. In this narrow area, Pennsylvanian and Permian redbeds and evaporitic sequences are tightly folded across the Elk Mountain Anticline. Beds on the east limb of this structure dip to the east and northeast and are locally folded into a syncline adjacent to the Mount Sopris stock. The core of the Elk Mountain Anticline is very well exposed in Perham Creek in the NE¼ sec. 20, T. 9 S., R. 88 W. In this area highly deformed beds of the Eagle Valley Formation are characterized by thrusting and fault-bend-fold development within beds in the formation (intraformational deformation). This deformation may be related to diapiric movement of evaporite beneath the exposed core of the anticline in this area.

Structure relating to the intrusion of the Mount Sopris stock on its northwest and north sides has been largely modified by post-intrusion deformation related to the formation of the Carbondale collapse area during the Neogene. The Mount Sopris stock has a concordant contact with bounding sediments on the east and south sides.

NEOGENE DEFORMATION

One of the most interesting findings to come out of CGS mapping has been the documentation of pervasive Neogene deformation in the Roaring Fork River valley and its tributaries. This deformation is related to salt tectonism and salt dissolution and is associated with some unusual structural and geomorphic elements. Regional evaporite-related deformation was first documented and described in the Carbondale quadrangle (Kirkham and Widmann, 1997). Neogene deformation occurs in a prominent regional depression that coincides for the most part with an area where Pennsylvanian evaporitic rocks lie at, near, or affect the ground surface (Fig. 2). This topographic depression is as much as 4,000 ft lower than the surrounding terrain and has been interpreted by Kirkham and Widmann (1997) as a large collapse block resulting from dissolution and flowage of evaporitic bedrock from beneath the area. Structural features bounding this regional depression have been described in the Cotton-wood Pass quadrangle (Streufert and others, 1997b), Leon quadrangle (Kirkham and others, 1998), Basalt quadrangle (Streufert and others, 1998), and the Cattle Creek quadrangle (Kirkham and others, 1996b). Geologic mapping in the Mount

Sopris quadrangle defines the perimeter of the Carbondale collapse area on its south and southwest sides. This structural feature crosses into the Mount Sopris quadrangle from the east, traverses northwestward along normal faults in and north of the Potato Bill Creek drainage, and proceeds to the northwest underneath thick surficial deposits (Fig. 2). The area containing Tertiary sediments (Ts) placed against Mesozoic rocks by normal faulting north and northeast of Potato Bill Creek is perhaps the best exposure of the southern margin of the collapse area in the quadrangle. In most places the collapse area contains thick surficial deposits that cover bedrock and conceal the structure of the collapse margin. Bedrock within the collapse area is highly faulted, forms discontinuous and erratic outcrops, and is frequently discordant with the Mount Sopris stock. Bedrock within the collapse area has been vertically lowered as much as 2,000 ft, largely in response to dissolution and/or flowage of underlying evaporitic rocks. There are no bedrock exposures between the

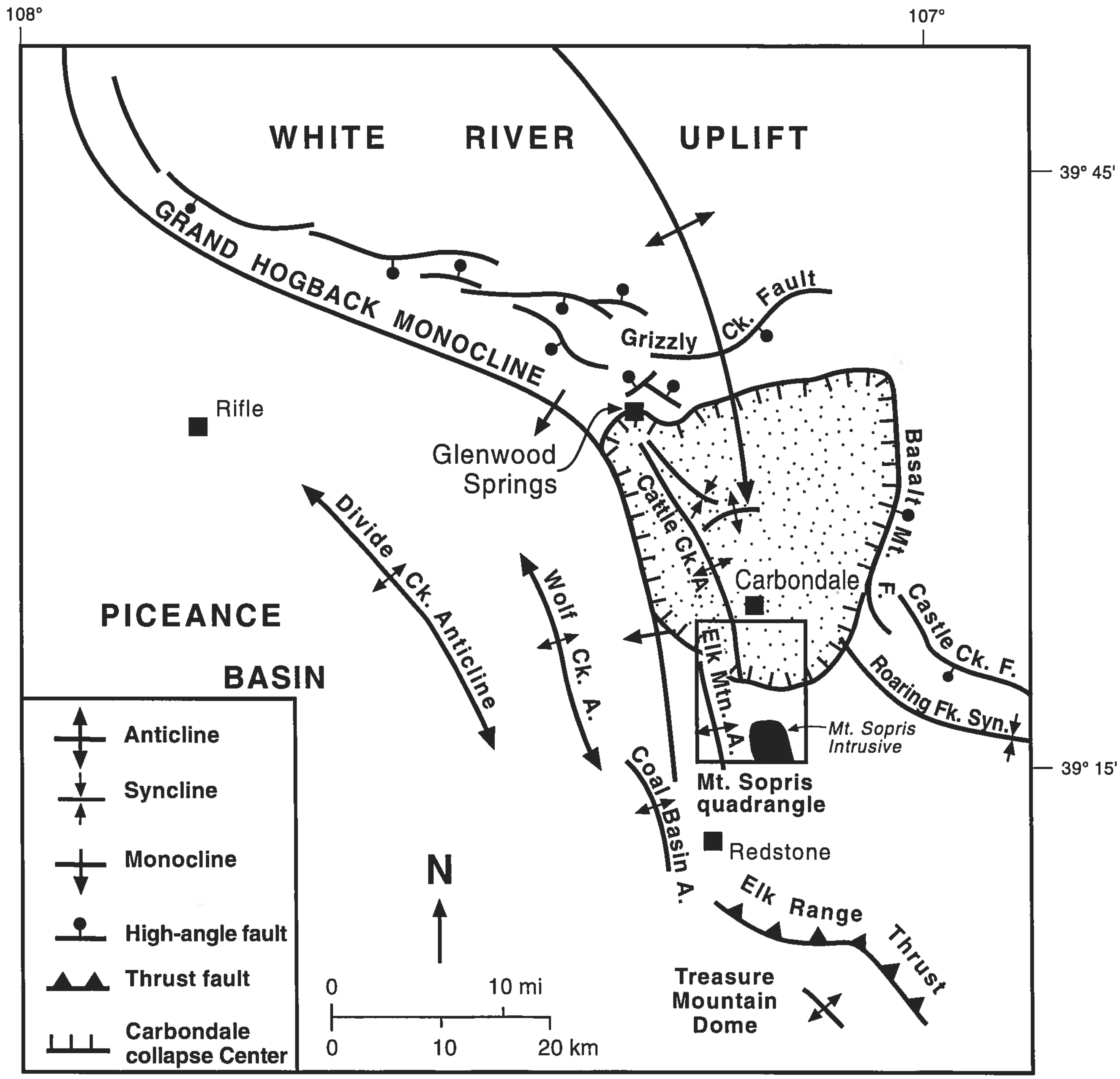

Figure 2. Regional tectonic map (modified from Kirkham and Widman, 1997). Stipple pattern indicates area of collapse related to dissolution and/or flowage of evaporitic rocks.

ridge of Mesozoic rocks north of Potato Bill Creek (NE¼ sec. 34, T. 8 S., R. 88 W.) and the north boundary of the quadrangle, except for exposures of Eagle Valley Evaporite (Pee) in the northwest corner of the quadrangle. These exposures of evaporite are most likely of diapiric origin and probably are related to the Cattle Creek anticline described to the north in the Carbondale quadrangle (Kirkham and Widmann, 1997).

The effects of Neogene salt-related collapse may extend south beyond the true collapse perimeter near Potato Bill Creek, possibly up to the northern margin of the Mount Sopris stock. A large northeast-trending normal fault located between Nettle and Potato Bill Creeks is downthrown to the southeast toward the Mount Sopris stock. This structure, and the complete lack of bedrock exposure on the north-northeast side of the Mount Sopris stock, may be related to deformation peripheral to Neogene collapse; however, this area is extensively covered by Quaternary glacial deposits. Vertical displacement of bedrock inside of and peripheral to the south margin of the Carbondale collapse area may account for some of the large exposure of the Mount Sopris stock.

The Carbondale collapse area contains unusually thick Quaternary and Tertiary alluvial deposits, including thick, bedded, fluvial gravel (Ts) that may be as old as late Tertiary (Miocene). High-level gravel (QTg), and oldest terrace deposits (Qtt), in the northwest corner of the quadrangle west of the Crystal River, are collectively upwards of 800 ft thick. The thicknesses of these deposits may have been affected by collapse related to dissolution and/or movement of evaporitic bedrock. Deposits of pebble- to cobble-sized, locally bouldery, clast-supported, unsorted to well-bedded, fluvial gravel (Ts) occur in the northeast part of quadrangle. The deposits are very weakly indurated to unconsolidated and form a topographic high. This unusually thick occurrence of stream sediment now stands in positive relief due to a reversal of topography. These fluvial deposits have been exposed in the steep slopes at The Crown in the N½ sec. 17, T. 8 S., R. 87 W. In this area these moderately well- to well-bedded deposits dip northeast at 3 degrees. Tertiary sediments (Ts) are estimated to be 1,500+ ft thick; however, the base of the deposit is not exposed. Tertiary sedimentary deposits (Ts) in the Carbondale quadrangle are overlain by Miocene basalt (sec. 31 and 32, T. 7 S., R. 87 W.) that was age dated at younger than 14 Ma (Kirkham and Widmann, 1997). A flow of basalt interbedded with Tertiary sedimentary deposits (Ts) at the west end of Light Ridge in the Basalt quadrangle has been $^{40}Ar/^{39}Ar$ dated at 13.64 ±0.05 Ma (M. Kunk, written commun., 1999). In addition Tertiary sedimentary deposits (Ts) are underlain by 34.22 ±0.17 Ma ash-flow tuff in the Basalt quadrangle (Streufert and others, 1998). These fluvial gravels may have been deposited in a large and steadily subsiding topographic depression that formed in response to dissolution or flowage of evaporitic bedrock. The intrusion of the Mount Sopris stock may have played a part in this process by accelerating dissolution through the heating of ground water. Clast lithologies in this deposit suggest that both the Crystal and Roaring Fork Rivers flowed into the collapse area. Kirkham and Widmann (1997) described a modern analog where Holocene fluvial sediments were deposited in a subsidence trough in the Roaring Fork River valley immediately to the north in the Carbondale quadrangle.

The vertical magnitude of Neogene collapse in this portion of the Carbondale collapse area is in part constrained to a minimum of 2,100 ft by the exposed thickness of Tertiary sediments (Ts). Much of the exposure on the north and northwest sides of present day Mount Sopris is thought to result from dissolution-driven collapse near, and possibly against, the north and northwest flanks of the stock.

ECONOMIC GEOLOGY

The Pennsylvanian Eagle Valley Evaporite (**Pee**) has been metamorphosed to alabaster north of Avalanche Creek in the S½ NW¼ sec. 28, T. 9 S., R. 88 W. The alabaster bed, together with beds of marble and hornfels in the overlying Pennsylvanian Eagle Valley Formation (**Pe**), comprise the mineable reserves of Avalanche Creek Marble and Alabaster Company, Carbondale, Colo. (R. Congden, personal commun., 1998). The Avalanche Creek Mine works a thick bed of massive, locally selenite-veined, alabaster, mostly for statuary blocks. The company also produces tile in its cutting plant in Carbondale, Colo. In addition, beds of marble and quartzite stratigraphically above the alabaster beds are an identified resource at the mine (R. Congden, personal commun., 1998). These contact metamorphosed beds are part of a wedge of upper Paleozoic rock that is cradled between the Mount Sopris stock and the Bulldog stock, a satellite granitoid body of similar composition to the south.

An area of weakly developed lead-zinc-silver mineralization (Bulldog district) is localized along the contact of the Mount Sopris pluton with Pennsylvanian clastic rocks on the southeast side of Mount Sopris in the Redstone quadrangle. Schwarz and Park (1930) described galena with stromeyerite, argentite, covellite, and bornite from the Bulldog Mine. Foland (1967), Pilkington (1954), and Pillmore (1954) have studied the petrology and petrography of Mount Sopris and all mention this metal occurrence. These vein deposits are small, occur only on the southeast side of the Mount Sopris pluton, and are localized at the intrusive contact. Similar veins were not observed during this study near the much less altered contacts in the Mount Sopris quadrangle. Many of the thick gravel deposits in the north half of the quadrangle are a source of sand and gravel. These thick gravel deposits are probably the most valuable mineral resource in the quadrangle.

EXPANDED DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 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 are 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, stratigraphy, and the relative degree of clast weathering and soil development. Correlation of some terraces and interpretations of their ages are hindered by deformation related to underlying evaporitic bedrock and surficial deposits, altering their relative heights above modern streams.

HUMAN-MADE DEPOSITS—

af — **Artificial fill (latest Holocene)**—Composed mostly of unsorted silt, sand, and rock fragments deposited during construction projects. Maximum thickness is 40 ft. Artificial fill may be subject to settlement when loaded if not adequately compacted.

ALLUVIAL DEPOSITS—Composed mostly of silt, sand, and gravel deposited in stream channels, flood plains, glacial outwash terraces and sheetwash areas along the Crystal River and its tributaries.

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Includes modern stream channel deposits of the Crystal River, adjacent flood-plain deposits, and low terrace alluvium that is as much as 10 ft above modern stream level. Mostly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel in a sandy silt 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. Deposits in the Crystal River valley contain clasts of Tertiary hypabyssal rocks and Paleozoic and Mesozoic sedimentary rocks. Unit may locally include organic-rich deposits. It may interfinger with younger debris-flow deposits (Qdfy) where the distal ends of fans extend into modern river channels. Maximum thickness is difficult to estimate owing to active sinkhole development in the area caused by dissolution and flowage of evaporitic bedrock below the Crystal River valley. Unit is commonly 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 valleys of ephemeral and intermittent streams, on gentle slopes, or in basinal areas. Sheetwash deposits typically consist of pebbly, silty sand and sandy and clayey silt. Maximum thickness is about 25 ft. Area is subject to future sheetwash deposition. Unit is susceptible to hydrocompaction, settlement, and piping where fine grained and low in density.

Qty — **Younger terrace alluvium (late Pleistocene)**—Chiefly stream alluvium underlying terraces in the Crystal River valley that range from 10 to 45 ft above modern stream level. Unit is mostly poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand and silt matrix, but unit may include fine-grained overbank deposits. Clasts are mainly subrounded to rounded and are comprised chiefly of several types of middle Tertiary and younger hypabyssal rocks and Paleozoic and Mesozoic rocks, some of which are metamorphosed. These clasts are representative of rock types found in the drainage basin of the Crystal River. Clasts are generally unweathered or only slightly weathered. Unit correlates with younger terrace alluvium (Qty) of Kirkham and Widmann (1997) and may correlate with terrace T7 of Piety (1981), with terrace A of Bryant (1979), or with terrace gravel "a" (Qga) of Freeman (1972). Unit is probably in part equivalent to outwash of Pinedale glaciation, which Richmond (1986) estimated to be about 12 to 35 ka. Thickness averages 30 to 40 ft, although thicknesses may be greater in areas affected by salt-related subsidence. Unit is a good source of sand and gravel.

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Composed of stream alluvium underlying terraces 80 to 120 ft above the Crystal River. These terraces are frequently deformed by diapirism related to upwelling of evaporitic rocks. Intermediate terrace alluvium (Qtm) at the mouth of Avalanche Creek directly overlies evaporitic bedrock and is most likely deformed by diapiric movement of evaporite. A terrace on the east side of the Crystal River, south of the boundary between Garfield and Pitkin Counties, has been deformed and its surface now dips a few degrees to the east and away from the river. The unit consists of poorly sorted, clast-supported, ocassionally bouldery, pebble and cobble gravel in a sand and silt matrix. Fine-grained overbank deposits may be locally present. Clasts are mainly subrounded to rounded and are comprised chiefly of several types of middle Tertiary and younger hypabyssal rocks and Paleozoic and Mesozoic rocks, some of which are metamorphosed. These clasts are representative of rock types found in the drainage basin of the Crystal River. Clasts generally are only slightly weathered at shallow depths. Thickness averages 80 ft. Thickness of unit may have been affected by salt-related subsidence. Unit correlates with intermediate terrace alluvium (Qtm) of Kirkham and Widmann (1997) and may correlate with terrace T6 of Piety (1981), with terrace B of Bryant (1979), or with terrace gravel "b" (Qbg) of Freeman (1972). Unit is a good source of sand and gravel.

Qto **Older terrace alluvium (late and middle? Pleistocene)**—Includes deposits of stream alluvium underlying terraces with upper surfaces from 120 to 200 ft above the Crystal River and Prince Creek. These terraces may have been locally deformed by evaporitic diapirism or subsidence and collapse related to dissolution. Unit is generally a clast-supported cobble or pebble gravel in a sand and silt matrix, but may range to a matrix-supported gravelly sand or silt. Locally it may contain fine-grained overbank deposits. The unit consists of poorly sorted, clast-supported, occasionally bouldery, pebble and cobble gravel in a sand and silt matrix. Clasts are mainly subrounded to rounded and are comprised chiefly of several types of middle Tertiary and younger hypabyssal rocks and Paleozoic and Mesozoic rocks, some of which are metamorphosed. These clasts are representative of rock types found in the drainage basin of the Crystal River. Clasts are slightly to moderately weathered at shallow depths. Thickness of most deposits ranges from 30 to 80 ft; however, extensive deposits of older terrace alluvium (Qto) at the mouth of Prince Creek, in sec. 11 to 14, T. 8 S., R. 88 W., may be up to 100 ft in thickness. The thickness of these terraces may be due in part to the accumulation of gravels in an actively subsiding evaporitic dissolution feature which formed at the confluence of the Crystal River and Prince Creek. In some places the edges of the older terraces (Qto) closest to the valley center dip several degrees away from the Crystal River making correlations between terraces based solely on the height above the river tenuous. Sinkholes are common in the unit. A sinkhole that is filled with slope wash and collapse debris is well exposed in a roadcut on the Prince Creek Road in the NW¼ SE¼ NW¼ sec. 11, T. 8 S., R. 88 W. Unit is the same as older terrace alluvium (Qto) of Kirkham and Widmann (1997). Unit correlates with older terrace alluvium (Qto) mapped on the Basalt quadrangle (Streufert and others, 1998), and it may correlate with terrace C of Bryant (1979), or with terrace gravel "c" (Qgc) of Freeman (1972). Unit may be a source of sand and gravel.

Qtt **Oldest terrace alluvium (middle and early? Pleistocene)**—Consists of stream alluvium in terraces that are from 400 to 850 ft above the Crystal River. Unit underlies an extensive terrace in parts of secs. 9, 16, and 21 of T. 8 S., R. 88 W. on the west side of the Crystal River, and two terrace remnants in secs. 12 and 13 of T. 8 S., R. 88 W on the east side of the Crystal River. Unit also occurs in a small terrace remnant in the SW¼ SW¼ sec. 10, T. 8 S., R. 88 W., and underlies a small terrace south of the mouth of Thompson Creek. The large terrace west of the Crystal River extends from the mouth of Thompson Creek north into the Carbondale quadrangle (Kirkham and Widmann, 1997). These authors describe a subsidence trough developed in these deposits that contains the Lava Creek B volcanic ash, which indicates these terrace gravels are older than 620 ka. This subsidence trough extends into the Mount Sopris quadrangle in the E½ sec. 9, T. 8 S., R. 88 W., but no ash is visible. The terrace gravels underlying this extensive surface thicken southward and are 500 ft thick north of the mouth of Thompson Creek. The thickness of these terrace gravels may in part be due to subsidence related to dissolution of the underlying evaporitic bedrock. Unit is poorly sorted to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. Unit may locally contain lenses and beds of sandy silt and silty sand. Clasts are moderately to strongly weathered even at moderate depths. Clast lithologies are predominantly Tertiary hypabyssal rocks, including material from the Mount Sopris pluton and from various other Tertiary plutons, laccoliths, and stocks in the Elk and West Elk Mountains, with minor Paleozoic and Mesozoic sedimentary clasts, most of which are metamorphosed.

QTg

High-level gravel (early Pleistocene and/or late Tertiary)—Occurs as a single deposit dissected by two drainages into three large high-level terrace remnants, and on hills and ridges in the northwest corner of the quadrangle in secs. 8, 16, 17, 20, and 21, T. 8 S., R. 88 W. Original surfaces preserved on the high-level terrace remnants are around 1000 to 1100 ft above the modern Crystal River. These deposits are deeply dissected in places as much as 200 ft by tributary streams of the Crystal and Roaring Fork Rivers. 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 subrounded to well rounded and are predominantly middle Tertiary hypabyssal rocks, with lesser amounts of quartzite, basalt, white quartz, chert, red sandstone, and hornfels, all most likely eroded from the Elk and West Elk Mountains. Clasts are moderately to very highly weathered. These deposits are 200 to 280 ft thick at their east edge in sec. 16 and 21, T. 8 S., R. 88 W., where they are adjacent to oldest terrace alluvium (Qtt). They may be thicker at or near the west boundary of the quadrangle. Unit is the same as and continuous with high-level gravel (QTg) mapped in the Carbondale quadrangle by Kirkham and Widmann (1997).

Terrace Alluvium of Thompson Creek

Qgt_1

Younger terrace alluvium of Thompson Creek (late Pleistocene)—Chiefly stream alluvium underlying terraces from about 80 to 160 ft above Thompson Creek. Unit consists mostly of poorly sorted, clast-supported, bouldery, pebble and cobble gravel with a sand and silty sand matrix. Fine-grained overbank deposits are locally present. Clasts are well rounded to sub-angular and are comprised predominantly of basalt and Mesozoic sedimentary rocks. In places these deposits consist of over 50 percent rounded to well rounded, cobble- and boulder-sized clasts of vesicular basalt. These clasts likely were derived from basalt-rich surficial deposits formerly present in the upper reaches of Thompson Creek. The original source of the basalt clasts was probably a Miocene basalt-capped plateau that was once located west of the quadrangle in the vicinity of the Grand Hogback Monocline, but which has now been completely removed by erosion. Clasts are slightly to moderately weathered. Maximum thickness is about 50 ft. Unit may correlate in part with older terrace alluvium (Qto) mapped along the Crystal River and its tributaries but is in part somewhat older. It is a source of sand and gravel.

Qgt_2

Older terrace alluvium of Thompson Creek (late and middle? Pleistocene)—Composed of stream alluvium underlying terraces from 320 to 400 ft above Thompson Creek. Similar in texture, sorting, lithology, and genesis to younger terrace alluvium of Thompson Creek (Qgt_1), except clasts are moderately weathered. Maximum thickness is about 40 ft. Near the mouth of Thompson Creek the unit was deposited in a cut into middle Pleistocene oldest terrace alluvium (Qtt), indicating these deposits are somewhat younger. Unit may be of similar age to the gravel of Nettle Creek (Qgn) and other oldest debris-flow deposits (Qdfo) in the quadrangle. Unit is a potential source of sand and gravel.

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

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, except in those colluvial deposits which are derived from fluvial gravel deposits, in which case clasts are rounded to subrounded. Commonly is unsorted or poorly sorted with weak or no stratification. Clast lithology is variable and dependent upon types of bedrock or surficial deposits occurring on 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), colluvium and sheetwash (Qcs), younger debris-flow deposits (Qdfy), and sheetwash deposits (Qsw) along some tributary drainages and hillslopes. Maximum thickness is 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.

Qt

Talus (Holocene and late Pleistocene)—Angular, cobbly, and bouldery rubble derived from outcrops of granodiorite of Mount Sopris (Tgs) and metamorphosed sediments of the Eagle Valley Formation (Pe) that was transported downslope principally by gravity as rockfalls, rockslides, and rock topples. Unit commonly lacks matrix material. Talus deposition is active and widespread on the north and northwest sides of Mount Sopris, especially in the steep glacial cirques. Talus is gradational into and frequently in-corporated with younger rock glaciers (Qrg_1) and is occasionally incorporated into landslides (Qls). Talus deposits may also accumulate at the toe of younger rock glaciers, such as those in the N½ sec. 14, T. 9 S., R. 88 W. Thickness of unit generally increases downslope from source areas and attains a general thickness of about 50 ft. Thicknesses of talus deposits in the cirques of Mount Sopris may be somewhat greater in the low-relief areas adjacent to transverse ridges of younger rock glaciers. Talus deposits locally contain periglacial features that may be transitional into younger rock glaciers (Qrg_1). Areas mapped as talus are subject to rockfall, rockslide, and rock-topple hazards. Talus in transitional areas with younger rock glaciers (Qrg_1) may be subject to severe frost heave effects. Unit is a source of riprap. Unit is usually difficult to excavate.

Qls

Landslide deposits (Holocene and Pleistocene)—Highly variable deposits consisting of unsorted, unstratified rock debris, gravel, sand, silt, and clay. 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, earthflows, and extensive slope-failure complexes. Landslides are common and of considerable areal extent in the northeast portion of the quadrangle in areas where relatively thick and mostly unconsolidated deposits of glacial till (Qti), and Tertiary sedimentary deposits (Ts), underlie the ground surface. Some of the isolated hills mapped as Tertiary sediments (Ts) in this area may be eroded remnants of landslide deposits. Landslide deposits also occur on the south face of Mount Sopris where they have been derived from older colluvium (Qco), talus (Qt), and felsenmeer (Qf). Maximum thickness is about 200 ft, but usually it is less than 100 ft thick. 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 drainage divides, ridge lines, and dissected hillslopes as erosional remnants of formerly more extensive deposits that were transported by gravity and aided by sheetwash. Unit occurs in a north-south-trending zone below the steep exposed west and northwest margins of the Mount Sopris stock. In this area the Crystal River valley has a vertical relief of over 6,300 ft in about 2.6 miles, including steep slopes (30 to 45 degrees) of exposed granodiorite that often have over 4,000 ft of relief from base to top. Unit consists predominantly of material derived from the Pennsylvanian Eagle Valley Formation (Pe), with lesser amounts of granodiorite of Mount Sopris (Tgs). Genesis, texture and bedding are somewhat similiar to colluvium (Qc), although these deposits most likely include significant rock-topple events and are very clast-rich. Unit locally contains relatively large blocks of intact rock, some of which are upwards of 12 ft in length. These deposits are interpreted as resulting from large-scale shedding of metamorphosed clastic rocks from the steep-walled margin of the Mount Sopris pluton, possibly in response to subsidence and/or collapse related to dissolution of evaporitic bedrock. Maximum thickness may exceed 100 ft. Generally is not subject to significant future colluvial deposition, except where adjacent to eroding hillslopes. Unit could be prone to landsliding and difficult to excavate in areas where large blocks are present.

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 may be 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 (Qa) adjacent to stream channels. Clast lithology is diverse as debris-flow deposits involve most named bedrock units and surficial deposits. Younger debris-fan deposits derived from redbeds and evaporitic clastic sequences of the Pennsylvanian Maroon (PPm) and Eagle Valley Formations (Pe) occur at most tributary mouths along the Crystal River in the southern half of the quadrangle. Younger debris fans are developed from thick surficial deposits including Tertiary sediments (Ts), Pleistocene terrace deposits (Qtm, Qto, Qtt), and landslide deposits (Qls) in the northern half of the quadrangle. On the west side of the Crystal River large, coalescing debris fans extend well out from the valley wall and cover large areas of younger terrace alluvium (Qty). These large debris-fan complexes are derived from thick deposits of oldest terrace alluvium (Qtt). Original depositional surfaces of unit are usually preserved, except where they have been disturbed by human activities. Debris-flow bridges were built in numerous drainage gullies along the Sweet Jessup water ditch in secs. 15 and 22, T. 8 S., R 88 W. to carry the frequently occurring debris-flow events over and beyond this irrigation ditch. Maximum thickness of unit is about 75 ft. Area is subject to flooding and to future debris-flow, hyperconcentrated, and alluvial deposition following intense rainstorms. Mudflow and sheetwash processes may prevail on the distal parts of some fans. 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 are corrosive if derived from evaporitic rocks.

Qac

Alluvium and colluvium, undivided (Holocene and late 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 on valley sides. Deposits of alluvium and colluvium probably interfinger. 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 dependent upon type of bedrock and surficial deposits in source areas. Thickness is commonly 5 to 20 ft; maximum thickness 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)—Similiar in texture, lithology, and depositional environment to younger debris-flow deposits (Qdfy). Geomorphic features of original depositional surfaces are commonly recognizable, but the surfaces are 10 ft or more above active debris-flow channels, which have been incised into or are adjacent to them. Maximum thickness is about 60 to 80 ft. 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 deposits are fine-grained and have low density.

Qdfo

Older debris-flow deposits (late and middle? Pleistocene)—Unit occurs in three disconnected remnants of a former large debris fan north of Mount Sopris. Modern Prince and Thomas Creeks have incised 40 to 120 ft into these deposits. Where exposed, the unit is a dark-gray to black, gravelly, sandy, clayey silt with scattered cobbles, occasional boulders of Mount Sopris granodiorite (Tgs), and minor pebble-sized sandstone fragments of Mancos Shale (Km). These large fan remnants are frequently covered with a thin veneer of sheetwash rendering inspection difficult in most places. These deposits are located between glacial till (Qti) of probable Pinedale age to the south and Tertiary sedimentary deposits (Ts) to the north. Unit may in part correlate with the gravel of Nettle Creek (Qgn), which occurs in a somewhat similar geomorphic setting. Clasts are moderately to highly weathered. Thickness exceeds 200 ft in places. Where fine grained and low in density, unit may be prone to piping, settlement, and perhaps hydrocompaction.

Qaco

Older alluvium and colluvium, undivided (late and middle? Pleistocene)—Deposits of alluvium and colluvium ranging from about 10 to 100 ft above and adjacent to perennial, intermittent, and ephemeral streams. Texture, bedding, clast lithology, sorting, and genesis are similiar to alluvium and colluvium (Qac). Unit locally includes debris-flow and sheetwash deposits. Area is not susceptible to alluvial deposition. Area is subject to active colluvial and sheetwash deposition where adjacent to hillslopes. Unit is a potential source of sand and gravel.

Qgn

Gravel of Nettle Creek (middle ? Pleistocene)—Consists of a single deposit south of Nettle Creek. Unit consists of poorly sorted, matrix-supported, occasionally bouldery, pebble and cobble gravel in a sandy, clayey silt, or silty sand matrix. It locally includes lenses of moderately well-sorted, gravelly, sandy, clayey silt that is both matrix- and clast-supported. Clasts are angular to subangular and consist of granodiorite of Mount Sopris (Tgs), with subordinate amounts of Paleozoic and Mesozoic sedimentary rocks. Clasts are moderately to very highly weathered. Unit overlies Pennsylvanian and Permian redbeds of the Maroon Formation (PPm) and is partially overlain at the eastern edge of its exposure by glacial till (Qti) and older rock glacier deposits (Qrg_2). Unit forms a bench-like, gently sloping surface that is covered with up to 4 ft of sheetwash. Nettle Creek is incised as much as 50 ft into this deposit. Maximum thickness of the deposit in the westernmost exposure is about 80 ft. Unit is well exposed along the private road above the Carbondale water-intake and chlorination plant. In this area the deposit is very likely a debris-flow in origin. Unit may be genetically similar to older debris-flow deposits (Qdfo) in the large, dissected debris-fan remnant north of Mount Sopris in upper Thomas and Prince Creek drainages. Unit may be prone to piping, settlement, and perhaps hydrocompaction where fine grained and low in density. Unit is a potential source of sand and gravel.

PERIGLACIAL DEPOSITS—Coarse rock debris and minor sand, silt, and clay deposited in cold environments by the processes of freeze-thaw action, nivation, and solifluction.

Qf **Felsenmeer (Holocene and late Pleistocene)**—Unit extensively mantles bedrock on the upper south slopes of Mount Sopris above 9,000 ft. Consists of angular to subangular boulders, cobbles, and pebbles in a sandy matrix. Clasts are composed of the immediately underlying rock units: the granodiorite of Mount Sopris (Tgs) and quartzite and hornfels of the Pennsylvanian Eagle Valley Formation (Pe). Unit locally is deformed by downhill flowage (solifluction). Deposits are probably similar to concentrations of coarse rock debris occurring on gently sloping surfaces on the summit of the Park Range (Madole, 1991). These deposits were interpreted as felsenmeer, which is chiefly the product of congeliturbation (the mechanical weathering, and differential mass-movement of rock debris by frost action), and, in places, transport by solifluction. Unit may locally include nivation deposits consisting of sediments derived from beneath and around the fluctuating margins of snowbanks, chiefly by frost action, melt-water transport, and solifluction. These deposits may be similar to nivation deposits found on gentle, high-level slopes along the summit of the Park Range that were not reoccupied by small glaciers during latest Pleistocene and Holocene time (Madole, 1991).

ROCK-GLACIER DEPOSITS—Very coarse rock debris and minor sand and silt transported and deposited by active and inactive rock glaciers.

Qrg_1 **Younger rock glaciers (Holocene and late Pleistocene?)**—Deposits most likely consist of two layers of material. The cores of these deposits are most likely mixtures of rock rubble and interstitial fine-grained sediments in a matrix of ice or permafrost. The outer layer consists of clast-supported, matrix-free, angular to subangular, predominantly boulder-sized rock fragments of granodiorite of Mount Sopris (Tgs) and metamorphosed sediments of the Pennsylvanian Eagle Valley Formation (Pe). Younger rock-glaciers occur as lobate, tongue-like deposits emanating from the steep cirques on the north and northwest sides of Mount Sopris. In some cases the cores of these rock glaciers may contain ice that is older than the material transported on the surface (B. Bryant, written commun., 1999). The coarse rock debris and other sediments in younger rock glaciers likely originated as talus and colluvium that was mostly deposited by rockfall and rock-topple events. Unit may locally include sediments derived from landslide and snow avalanche events. In the heads of steep-walled cirques on Mount Sopris, talus grades into younger rock glacier deposits. Younger rock glaciers are currently active and downvalley limits coincide with steep active fronts. Younger rock glaciers have a ropy, lobate surface morphology and have encroached on or overridden older landforms. Talus cones are locally developed along the active fronts. Unit is very sparsely vegetated to unvegetated. The presence of interstitial ice gives active rock glaciers an "inflated" appearance. Unit includes material mapped as both latest Pleistocene (Pinedale) and Holocene (Neoglacial) rock-glacier deposits (Birkeland, 1973; Meierding and Birkeland, 1980).

Absolute ages of Colorado rock glaciers are problematic; however, a few radiocarbon dates used in conjunction with relative dating methods (Birkeland, 1973; Benedict, 1968, 1973; Miller, 1973; Carrara and Andrews, 1973) aid their age classification. Late Pleistocene and early Holocene rock- glacier deposits are recognized throughout the high mountains of Colorado (Meierding and Birkeland, 1980). Relative dating and stratigraphic studies suggest that material in the lower half of the rock glacier in the head of Thomas Creek is Pinedale (late Pleistocene) in age (Birkeland, 1973). This lower portion may also contain rock-glacier deposits of early Holocene age. In contrast, the upper half of this rock glacier, including active source areas in the upper cirque, contains material of suspected Neoglacial age (Birkeland, 1973). All of this material is actively moving down-valley out of these steep cirques. Documented rates of movement of active rock glaciers in Colorado are scarce, but include 3.9 in/yr in the Front Range (White, 1971), 4.9 in/yr in the Sawatch Range (Miller, 1973), and as much as 23.6 in/yr in the Elk Mountains (Bryant, 1971).

Unit is very unstable and is not suitable for permanent structures. Upper reaches of younger rock glaciers are subject to severe rock fall hazards. Excavation of unit may be difficult. Unit may be a source of rip rap.

Qrg$_2$ **Older rock-glacier deposits (Holocene and/or late Pleistocene)**—Consists of angular to subangular boulders and cobbles of granodiorite of Mount Sopris (Tgs) and Pennsylvanian Eagle Valley Formation (IPe) in a matrix of unsorted rock fragments, sand, silt, and clay. Unit is mostly clast-supported but may locally be matrix-supported. Deposits are genetically similar to younger rock glacier deposits (Qrg$_1$) but are inactive. Unit displays a similar morphology to that of younger rock glaciers (Qrg$_1$), except that their profiles appear more subdued. This may be due to the absence of interstitial ice and/or permafrost, which creates a "deflated" appearance. Older rock-glacier deposits are frequently covered with mature coniferous vegetation where there is a matrix. They underlie and generally extend outward past the current terminus of younger rock glacier deposits (Qrg$_1$). Unit appears to overlie glacial till (Qti) in many places; however, this contact is very poorly exposed. The older rock-glacier deposit in the S½ sec. 7, T. 9 S., R. 87 W. overlies glacial till (Qti) that is of suspected Pinedale age. It is overlain by the terminus of a younger rock glacier (Qrg$_1$), which is of proposed Pinedale age on the basis of relative-dating and stratigraphic criteria (Birkeland, 1973). This suggests that the older, now inactive, rock-glacier deposit (Qrg$_2$) in this area represents a separate and distinct episode of rock-glacier formation subsequent to the Pinedale glaciation. Alternatively, the formation of rock glaciers may have been continuous since the end of Pinedale glaciation and that the older (Qrg$_2$) and younger (Qrg$_1$) rock-glacier deposits in this locality are gradational. Unit is relatively stable but may be prone to landsliding. Unit may be a source of sand and gravel.

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

Qti **Till, undivided (late and late middle? Pleistocene)**—Heterogeneous deposits of gravel, sand, silt, and clay deposited by or adjacent to ice as ground, lateral, and end moraines on the north and northeast sides of Mount Sopris. Deposits are dominantly poorly sorted, unstratified or poorly stratified, matrix-supported, bouldery, pebble and cobble gravel with a matrix of silty sand. Clasts are typically angular to subrounded pieces of granodiorite of Mount Sopris (Tgs), with subordinate amounts of Paleozoic sedimentary rocks. The large apron of till that extends from the southeast corner of the quadrangle to Thomas Lakes is characterized by very hummocky knob and kettle topography. On the surface of these deposits boulders of Mount Sopris granodiorite (Tgs) are numerous and are unweathered to slightly weathered. Morphology and degree of weathering of clasts suggests that these deposits are of Pinedale age. They were most likely deposited as disintegration moraine (ablation till) as the Pinedale glacier on the north-northeast side of Mount Sopris eroded in place (R. Madole, oral commun., 1998). The very hummocky landforms on these deposits make them difficult to differentiate from landslide deposits, particularly since till is prone to landsliding. Deposits of glacial till in Sec. 11, SE ¼ sec. 10, and E½ sec. 15, T. 9 S., R. 88 W., were deposited as lateral moraines. In places these deposits are steep sided, and have sharp moraine crests. In other places the moraine crests and slope profile is more subdued, or less well developed. Clasts are unweathered to moderately weathered. In these areas these deposits may include both Bull Lake and Pinedale age glacial tills. Maximum thickness is estimated at 250 ft. Unit is very prone to landsliding. Unit is a potential source of sand and gravel.

BEDROCK—

Ts **Sedimentary deposits (Miocene?)**—Very weakly indurated to unconsolidated deposits of interbedded fluvial gravel, sand, and silt. Includes pebble, cobble, and locally bouldery, clast-supported, unsorted to well- bedded, sandy gravel. Clasts are subrounded to well rounded and are composed of various rock types depending on location. Near Mount Sopris the deposits contain high percentages of clasts of middle Tertiary hypabyssal rock, whereas deposits located closer to the Roaring Fork River valley are rich in Proterozoic plutonic clasts. This suggests that the Crystal River, Roaring Fork River, and ancestral Thomas and Prince Creeks all contributed sediment to this unit. All deposits contain minor amounts of basalt clasts. Unit occurs in northeast portion of quadrangle where deposits form a topographic high. These fluvial deposits may be as much as 1,500 ft in thickness. They apparently were deposited in a large and steadily subsiding topographic depression that probably was related to dissolution or flowage of evaporitic bedrock. This unusually thick deposit of stream sediment now underlies topographically elevated ground and is an example of inverse topography. This deposit and the subsidence feature in which it formed are part of the Carbondale collapse center described by Kirkham and Widmann (1997). These authors describe a possible recent analog of thick fluvial deposits in a subsidence basin in the Roaring Fork river valley immediately to the north in the Carbondale quadrangle. Tertiary sediments (Ts) in the Mount Sopris quadrangle are continuous with deposits mapped to the east in the Basalt quadrangle (Streufert and others, 1998) that overlie, and hence are younger than, ash-flow tuff (Taf) that has been dated by $^{40}Ar/^{39}Ar$ methods at 34.22 ±0.17 Ma (M. Kunk, written commun., 1998). A basalt flow that is interbedded with these sediments in the Basalt quadrangle has been $^{40}Ar/^{39}Ar$ dated at 13.64 ±0.05 Ma (M. Kunk written commun., 1999). Unit is a source of sand and gravel.

Tgs

Granodiorite of Mount Sopris (Oligocene)—Main body of Mount Sopris stock is predominantly granodiorite but composition may range locally from monzodiorite to tonalite. Accessory minerals in the stock are biotite, magnetite, zircon, apatite, and sphene. The granitoid body (Bulldog stock) located beneath and south of Avalanche Creek, is mineralogically similar but has been affected by argillic, and possibly localized propylitic alteration. Texturally the Mount Sopris stock lacks distinct flow foliation, ranges from equigranular to prophyritic, and is medium to fine grained.

The granodiorite of Mount Sopris contains subhedral to anhedral phenocrysts of plagioclase and quartz in a fine-grained to cryptocrystalline, hypidiomorphic groundmass of plagiocalse, quartz, and minor K-feldspar. Plagioclase phenocrysts are both continuously and discontinuously zoned. Some plagioclase phenocrysts have a poikilitic texture enclosing quartz crystals, and locally contain embayments of fine-grained and/or microcrystalline groundmass. The lower and middle exposed portions of the Mount Sopris stock range from porphyritic to equigranular, and contain medium-grained, euhedral to anhedral phenocrysts of plagioclase, quartz, and biotite in a fine-grained groundmass of plagioclase, quartz, and subordinate K-feldspar. On the east ridge, and on both the east and west summits, the granodiorite of Mount Sopris is porphyritic, fine-grained, and contains phenocrysts of zoned plagioclase and quartz in a cryptocrystalline groundmass, and locally contains spherulites. The spherulites are composed of fine-grained crystals of plagioclase and quartz in a microcrystalline groundmass.

The Bulldog stock, located along the south edge of the quadrangle and to the south of Avalanche Creek, is equigranular and contains euhedral to subhedral crystals of zoned plagioclase and quartz with accessory biotite. These rocks have been subjected to a fairly pervasive argillic alteration characterized by replacement of feldspar phenocrysts by clay minerals and alteration of biotite to chlorite. A thin section prepared from sample MSR-25 contains interstitial carbonate and possibly pyrite indicating that propylitic alteration may have occurred locally. Pillmore (1954) and Pilkington (1954) suggest that the Bulldog stock, and other granitoids peripheral to the main body of the Mount Sopris intrusive, may represent the first of two episodes of emplacement. Early consolidation in the Mount Sopris magma chamber may have produced a tonalitic border zone that was later intruded and cut by the main, further- differentiated, granodioritic body of Mount Sopris. In the NE¼ sec. 28, T. 9 S., R. 88 W. sediments of Eagle Valley and Maroon Formations have been deflected to the northwest by the intrusion of the Bulldog stock, and later partially cut by the intrusion of the main Mount Sopris stock. This suggests that the Bulldog stock is most likely older than the main body of the Mount Sopris stock. The Pennsylvanian/Permian sediments that are cradled in the contact between the two intrusives are metamorphosed to alabaster, hornfels, and marble.

The Mount Sopris stock was intruded to a high crustal level into a thick section of Paleozoic and Mesozoic sedimentary rocks. On its east and southeast sides it has concordantly upwarped and metamorphosed sediments of the late Paleozoic Eagle Valley and Maroon Formations. On the east ridge of Mount Sopris a sequence of hornfels-grade contact metamorphic rocks is well-exposed in a large roof pendant. These rocks are locally brecciated (intrusion breccia). The contact metamorphic aureole on Mount Sopris diminishes rapidly outward from the stock and is probably at a maximum 300 ft thick. Mineralogy within the aureole is typical of that found in medium- to high-grade (hornfels facies, pyroxene hornfels subfacies) zones located near the inner edge of contact metamorphism caused by the intrusion of batholiths into clayey carbonate sequences. The mineralogy, texture of metamorphic rocks, and the narrow width of the zone of contact metamorphism indicate a relatively dry intrusive event without appreciable exchange of volatile elements between the stock and intruded country rock. The thin zone of contact metamorphism is probably also a function of the relatively shallow depth of emplacement and rapid cooling of the Mount Sopris magma chamber (B. Bryant, written commun., 1999). The stock is discordant on its west side where it was intruded into complexly folded redbeds of the Pennsylvanian/Permian Maroon Formation that were most likely previously deformed by development of the Laramide Grand Hogback Monocline. Structure associated with the Mount Sopris stock on its north side may have been modified by Neogene collapse associated with formation of the Carbondale collapse area.

Previous studies of the Mount Sopris stock indicate a K/Ar age of 34.2 $\pm$0.8 Ma on biotite and a fission-track date of 34.3 $\pm$ 4.1 Ma on zircon (Cunningham and others, 1994). A sample from this study (Sample MSR-24) submitted for $^{40}Ar/^{39}Ar$ dating to the New Mexico Geochronological Research Laboratory (NMGRL) yielded a date of 34.74 $\pm$0.19 Ma. This integrated age on biotite probably records the time of cooling of the granodiorite through 350°C. A plateau age of 31.14 $\pm$0.22 Ma on feldspar was obtained from the same sample (MSR-24), but radiogenic yields do not rise above 66 percent and average percent. Poor radiogenic yields from K-feldspar are probably due to alteration and preclude calculations of cooling rates.

Km

Mancos Shale (Upper Cretaceous)— Predominantly medium- to dark-gray, carbonaceous, silty to sandy shale with minor bentonite beds, dark-gray limestone, and medium-gray, grayish-yellow-weathering, clayey sandstone. May include the Fort Hays Limestone Member (unit Kmf of Freeman, 1972), a dark-gray, thickly bedded limestone which occurs about 300 ft above the base, and upper and lower sandstone members (units Kms & Kmsl of Freeman, 1972) mapped in the Woody Creek quadrangle to the east. The main body of the Mancos Shale is medium- to dark-gray, marine shale. Isolated outcrops of the unit occur north and northeast of Mount Sopris but are mostly covered by surficial deposits. Unit is highly faulted and broken and probably has been displaced vertically or tilted north into the Carbondale collapse center. Slopes underlain by Mancos Shale are frequently mantled with landslides. Total thickness of the Mancos Shale in the Woody Creek quadrangle to the east is 5,200 ft (Freeman, 1972). The Mancos Shale is very prone to landsliding. Unit is susceptible to shrink-swell problems where it contains expansive clay.

Kdb

Dakota Sandstone and Burro Canyon Formation, undivided (Lower Cretaceous)— Dakota Sandstone consists of light-gray to tan, medium- to coarse-grained, moderately well-sorted quartz sandstone and conglomeratic sandstone in well-cemented, thick beds. Dakota Sandstone also contains beds of shale, carbonaceous shale, and coal. The underlying Burro Canyon Formation consists of greenish-gray claystone and yellowish-gray, medium-grained sandstone with lenses of green and red chert, and quartz pebbles. Sandstones of unit are very well indurated and generally form prominent outcrops. Freeman (1972) reported thicknesses for the Dakota Sandstone and Burro Canyon Formation as 200 ft and 225 ft, respectively, in the Woody Creek quadrangle to the east. Thickness of the combined unit in Basalt quadrangle is 200 to 250 ft (Streufert and others, 1998). The best exposure of the unit is on the ridge north of Potato Bill Creek in secs. 34 and 35, T. 8 S., R. 88 W. The Dakota Sandstone is conformable with the overlying Mancos Shale (Km). Unit may present rockfall hazard when exposed in steep cliffs or embankments.

Jm

Morrison Formation (Upper Jurassic)—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to pale-yellowish-gray sandstone, and gray limestone. Sandstones are common in the lower half of the unit and may be equivalent to the Salt Wash Member in nearby areas. Thickness is variable but averages about 300 to 350 ft. The best exposure of the unit is on the ridge north of Potato Bill Creek in secs. 34 and 35, T. 8 S., R. 88 W. Contact with overlying Dakota Sandstone and Burro Canyon Formation (Kdb) is sharp and unconformable. Shale and claystone beds in the unit are prone to landsliding.

Je

Entrada Sandstone (Upper Jurassic)—Tan to white, medium- to fine-grained, well-sorted, poorly indurated, crossbedded, sandstone. Sand grains are mostly rounded to subrounded quartz grains. Thickness is about 40 to 60 ft. Exposure is generally poor due to the weakly cemented nature of the unit. The Entrada Sandstone is well exposed on the ridge north of Potato Bill Creek in secs. 34 and 35, T. 8 S., R. 88 W. Contact with overlying Morrison Formation is sharp and conformable.

Jme

Morrison Formation and Entrada Sandstone, undivided (Upper Jurassic)—Includes Morrison Formation and Entrada Sandstone where poor exposures preclude mapping of units separately. Shale and claystone portions of Morrison Formation may be prone to landsliding.

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. All rock types contain detrital mica. Sandstones are coarse to fine grained, moderately to poorly sorted, and contain sand grains that are generally angular to subangular. Unit crops out extensively in the western portion of the quadrangle, both in the Crystal River valley and on ridges above Assignation and Camp Foster Creeks. Upper portion of unit is well exposed on the ridge north of Potato Bill Creek in secs. 34 and 35, T. 8 S., R. 88 W. The Triassic Chinle Formation and the Permian/Triassic State Bridge Formations are not identified in this exposure. Upper contact is sharp and unconformable. Thickness of the unit in adjacent quadrangles to the north is 3,000 to 5,000 ft (Kirkham and others, 1997). Formation thickness in this quadrangle is difficult to assess because of structural complexities and limited exposure. Formation is prone to rockfall where exposed in steep cliffs. Unit is very prone to debris-flow activity.

IPe

Eagle Valley Formation (Middle Pennsylvanian)—Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, brownish-tan, fine- to coarse-grained, gypsiferous sandstone, gypsum, and carbonate rocks. Immediately adjacent to the Mount Sopris pluton these rocks have been contact metamorphosed to hornfels, quartzite, alabaster, and marble. Unit represents a stratigraphic interval in which the redbeds 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. Unit ranges from 500 to 3,000 ft thick to the north in the Carbondale quadrangle (Kirkham and Widmann, 1997). The Eagle Valley Formation is less than 500 ft thick in the Basalt quadrangle (Streufert and others, 1998). Thickness of unit in the Mount Sopris quadrangle is variable but probably averages about 1,000 ft. 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 redbed sequence of the Maroon Formation.

In the Crystal River Valley the Eagle Valley Formation is frequently deformed by diapirism and flowage of evaporite. This is caused both by movement of intraformational evaporite and by diapirism from underlying beds of the Eagle Valley Evaporite. Unit is highly deformed in the core of the Elk Mountain Anticline on the south side of Perham Creek in the N½ SW¼ NE¼ sec. 20, T. 9 S., R. 88 W. This anticline may have been modified by salt tectonism after its formation.

Unit caps the east slopes of Mount Sopris in the southeast corner of the quadrangle. In this area sediments of the Eagle Valley Formation were concordantly deformed and contact metamorphosed by the intrusion of the Granodiorite of Mount Sopris (Tgs). This thin wedge of metamorphosed sediments caps the east summit of the peak where all but the basal 40 ft of the formation have been removed by erosion. These sediments form a south-southeast dipping surface on the southeast and south sides of Mount Sopris. The contact zone between the Eagle Valley Formation (Pe) and the granodiorite of Mount Sopris (Tgs) is well exposed on the east ridge of Mount Sopris in the NW¼ sec. 19, T. 9 S., R. 87 W. In this 1-mile-long exposure, the contact varies from sharp, with massive granodiorite immediately overlain by hornfels, quartzite, and marble, to a 10-ft-wide zone of brecciation in which granodiorite and contact metamorphosed rocks are complexly intermixed. Argillaceous beds in the Eagle Valley Formation have been metamorphosed to green to greenish-gray and white, banded and laminated to massive, diopside hornfels, all with a granoblastic texture. The diopside hornfels beds were probably dolomitic shale, siltstone, and fine-grained sandstone originally. Limestone beds in the contact metamorphic aureole have been altered to reddish-brown, dull-green, and white, massive, coarse- to medium-grained marble. Sandstone beds have been metamorphosed to granular, coarse-grained quartzites that locally contain blebs of magnetite. Brecciated zones are mineralogically similar to unbrecciated zones. A roof pendant of Eagle Valley Formation occurring 1,700 ft north of the west summit of Mount Sopris is a remnant of a magnetite skarn deposit formed in the zone of contact metamorphism (C. Pillmore, personal commun., 1998). The presence of this remnant magnetite skarn deposit, and magnetite-bearing quartzites, indicates that the intrusion of the granodiorite of Mount Sopris (Tgs) may have locally involved the exchange of volatile elements between the stock and the surrounding country rock.

Near the mouth of Avalanche Creek, beds of quartzite, marble, and alabaster, occurring in wedge of contact-metamorphosed Eagle Valley Formation (Pe), and Eagle Valley Evaporite (Pee) are included in the mineable reserves of the Avalanche Creek Mine (see Economic Geology section).

Unit may be susceptible to subsidence and sinkholes. Surficial deposits derived from it are prone to collapse, compaction, piping, and corrosion problems.

Pee

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 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.

Gypsum beds are exposed on the west side of the Crystal River, across from the mouth of Avalanche Creek, in the exposed core of the Elk Mountain Anticline. In this area thinly bedded clastic sediments of the overlying Eagle Valley Formation (Pe) are intensely deformed in the exposed section located in the SE¼ sec. 20, T. 9 S., R. 88 W. This intense deformation occurs near exposures of the Eagle Valley Evaporite. Diaprism and/or flowage of evaporite may have modified this asymmetric anticline after its formation. Beds of white to gray, mottled, locally brecciated and selenite-veined, very fine-grained alabaster occur in a zone of contact metamorphism just north of Avalanche Creek.

The base of the formation is not exposed in the quadrangle. To the north the thickness of the Eagle Valley Evaporite is reported to range from about 1,200 ft to perhaps 9,000 ft where it is tectonically thickened along the Grand Hogback (Mallory, 1971). A minimum thickness of 2,700 ft is reported by Kirkham and Widmann (1997) near Catherine, north of the quadrangle. Contact with overlying Eagle Valley Formation is both conformable and intertonguing and is defined as the base of the lowest red bed. The Eagle Valley Evaporite may contain cavernous voids caused by near-surface dissolution of halite and gypsum. The unit is prone to development of sinkholes into which overlying deposits may subside or be piped. Surficial deposits derived from unit may be subject to compaction, settlement, sinkhole, and corrosion problems. Gypsum and halite may be an exploitable resource within the formation.

Table 1: Whole-rock analysis of rocks from the Mount Sopris quadrangle [Samples analyzed by Chemex Labs Inc., Sparks, NV. Values given in percent.]

Sample #	*SiO_2*	*$Al2O_3$*	*CaO*	*Cr_2O_3*	*Fe_2O_3*	*K_2O*	*MgO*	*MnO*	*Na_2O*	*P_2O_5*	*TiO_2*	*LOI*	*TOTAL*
MSR-1	68.64	15.80	1.61	<0.01	1.44	0.17	1.20	0.03	8.77	0.26	0.56	1.20	99.96
MSR-17	65.55	15.48	3.05	<0.01	3.32	3.50	1.22	0.05	4.85	0.23	0.55	0.85	98.65
MSR-18	65.08	15.64	2.94	<0.01	4.13	4.41	1.12	0.04	3.71	0.24	0.53	0.70	98.54
MSR-24	65.34	15.30	3.26	<0.01	4.24	3.65	1.29	0.05	3.99	0.24	0.55	1.08	98.99
MSR-25	63.02	15.76	3.71	<0.01	4.42	3.22	1.26	0.06	4.01	0.24	0.50	2.66	98.86
MSR-27	65.33	15.58	4.02	<0.01	0.74	0.44	0.16	0.03	8.07	0.27	0.54	3.39	98.57

Trace element analysis of rocks from the Mount Sopris quadrangle
[Samples analyzed by Chemex Labs Inc., Sparks, NV. Values given in parts per million.]

Sample #	Ba	Cs	Hf	La	Nb	Rb	Sr	Ta	Y	Zr
MSR-1	138	<1	6	54	13	5	143	<1	24	208
MSR-17	1365	<1	4	48	12	45	611	<1	26	184
MSR-18	1445	<1	5	38	12	79	600	<1	26	212
MSR-24	1215	<1	5	60	12	78	564	<1	25	200
MSR-25	1370	<1	4	43	7	57	664	<1	24	171
MSR-27	173	<1	5	41	11	19	170	<1	20	168

Sample Descriptions:
Mount Sopris Quadrangle

MSR-1 Mount Sopris granodiorite (Tgs), fine-grained, porphyritic, from east summit of Mount Sopris, elevation 12,953 ft..

MSR-17 Mount Sopris granodiorite (Tgs), fine-grained, porphyritic, from upper east flank of Mount Sopris at contact with Pennsylvanian Eagle Valley Formation (Pe), elevation 11,920 ft.

MSR-18 Mount Sopris granodiorite (Tgs), medium-grained, porphyritic, from lower exposures on southwest side of Mount Sopris, elevation 8,800 ft.

MSR-24 Mount Sopris granodiorite (Tgs), medium-grained, porphyritic, from lower exposures on the west-north west side of Mount Sopris, elevation 9,200 ft.

MSR-25 Bulldog stock (Tgs), medium-grained, equigranular, propylitically altered, from the northernmost part of a satellite lobe of Mount Sopris that occurs near south boundary line of quadrangle, elevation 8,000 ft.

MSR-27 Mount Sopris granodiorite (Tgs), fine-grained, porphyritic, from east summit of Mount Sopris, elevation 12,953 ft..

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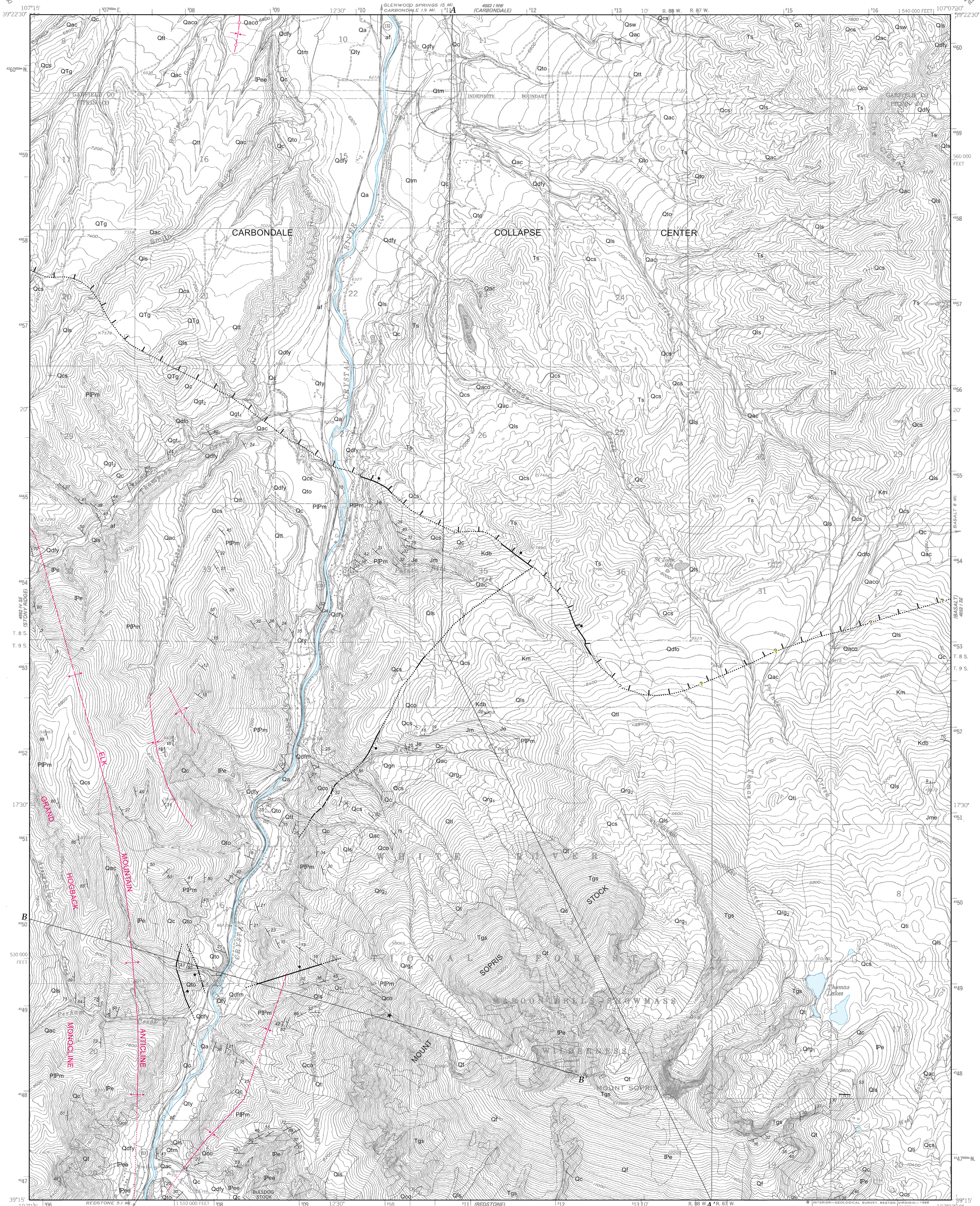
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE MAP 99-7
GEOLOGIC MAP OF THE MOUNT SOPRIS
QUADRANGLE, GARFIELD AND PITKIN 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 1998
Digital map prepared by Cheryl Brchan

CONDENSED DESCRIPTION OF MAP UNITS

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

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 (Holocene and late Pleistocene)**—Mostly poorly sorted, clast supported gravel in a sandy or silty matrix. Includes terraces up to about 10 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. Underlies terraces about 10-45 ft above the Crystal River. May include fine-grained overbank deposits

Qtm — **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces about 80 to 120 ft above the Crystal River

Qto — **Older terrace alluvium (late and middle? Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts slightly to moderately weathered. Underlies terraces about 120 to 200 ft above the Crystal River and Prince Creek

Qtt — **Oldest terrace alluvium (middle and early? Pleistocene)**—Consists of poorly sorted to moderately well-sorted, clast-supported, slightly bouldery, cobble and pebble gravel with a sand matrix. May contain lenses and beds of sandy silt and silty sand. Clasts are moderately to strongly weathered. Underlies terraces from 400 to 850 ft above the Crystal River

QTg — **High-level gravel (early Pleistocene and/or late Tertiary)**—Consists of clast supported, sandy and silty pebble and cobble gravel, and gravelly sandy silt that locally is moderately well cemented with carbonate. Unit underlies three large high-level terrace remnants with preserved surfaces that are 1,000 to 1,100 ft above the Crystal and Roaring Fork rivers. Clasts are moderately to very highly weathered

Terrace Alluvium of Thompson Creek

Qgt_1 — **Younger terrace alluvium of Thompson Creek (late Pleistocene)**—Chiefly poorly sorted, clast-supported, bouldery, pebble and cobble gravel in a sand and silty sand matrix. Clasts are predominantly vesicular basalt and sedimentary rocks. Unit underlies terraces that are 80 to 160 ft above Thompson Creek

Qgt_2 — **Older terrace alluvium of Thompson Creek (late and middle? Pleistocene)**—Similar in texture, sorting, lithology, and genesis to younger terrace alluvium of Thompson Creek (Qgt_1), except clasts are moderately to highly weathered. Unit underlies terraces that are 320 to 400 ft above Thompson Creek

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

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 a colluvial slope and finer grained in distal areas

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of granodiorite of Mount Sopris (Tgs) and metamorphosed sediments of the Eagle Valley Formation (IPe)

Qls — **Landslide deposits (Holocene and Pleistocene)**—Highly variable deposits consisting of unsorted, unstratified rock debris, gravel, sand, silt, and clay that was deposited as rotational and translational landslides, complex slump-earthflows, and extensive slope-failure complexes. Range in age from recently active landslides to long-inactive landslides

Qco — **Older colluvium (Pleistocene)**—Found on drainage divides, ridge lines, and dissected hillslopes in a north-south-trending zone below the steep exposed west and northwest margins of the Mount Sopris pluton. Locally contains large blocks and rock-topple deposits. Generally not subject to future deposition except where adjacent to eroding hillslopes

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

Qdfy — **Younger debris-flow deposits (Holocene)**—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. 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 late Pleistocene)**—Ranges from poorly sorted to well-sorted, stratified, interbedded, pebbly sand, sandy silt, and sandy gravel to unsorted and unstratified to poorly stratified, clayey, silty sand, bouldery sand, and sandy silt

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 contact between the two types of deposits are very gradational and difficult to locate

Qdfm — **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similiar 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 10 ft or more above active debris-flow channels

Qdfo — **Older debris-flow deposits (late and middle? Pleistocene)**—Occurs in three remnants of a large debris fan north of Mount Sopris near the heads of Prince and Thomas Creeks. Deposits are dark-gray to black, gravelly, sandy, clayey silt with scattered cobbles, and occasional boulders of Mount Sopris granodiorite (Tgs). Unit may correlate with the gravel of Nettle Creek (Qgn)

Qaco — **Older alluvium and colluvium, undivided (late and middle? Pleistocene)**—Deposits of alluvium and colluvium ranging from about 10 to 100 ft above and adjacent to perennial, intermittent, and ephemeral streams. Texture, bedding, clast lithology, sorting, and genesis are similiar to alluvium and colluvium (Qac). Unit locally includes debris-flow and sheetwash deposits

Qgn — **Gravel of Nettle Creek (middle? Pleistocene)**—Consists of a single deposit occurring south of Nettle Creek. Unit consists of poorly sorted, matrix-supported, occasionally bouldery, pebble and cobble gravel in a sandy, clayey silt, or silty sand matrix. Locally includes lenses of moderately well-sorted, matrix- to clast-supported, gravelly, sandy, clayey silt. Unit is probably of debris-flow origin

PERIGLACIAL DEPOSITS—Coarse rock debris and sediments deposited in cold environments by the processes of freeze-thaw action, nivation, and solifluction

Qf — **Felsenmeer (Holocene and late Pleistocene)**—Consists of angular to subangular boulders, cobbles, and pebbles in a sandy matrix that mantles the upper south slopes of Mount Sopris above 9,000 ft. Clasts are granodiorite of Mount Sopris (Tgs) and quartzite and hornfels of the Pennsylvanian Eagle Valley Formation (IPe)

ROCK-GLACIER DEPOSITS—Very coarse rock debris and sediments originating as talus and colluvium that were transported and deposited by rock glaciers

Qrg_1 — **Younger rock glaciers (Holocene and late Pleistocene?)**—Angular to subangular, predominantly boulder-sized rock fragments of granodiorite of Mount Sopris (Tgs) and metamorphosed sediments of the Pennsylvanian Eagle Valley Formation (IPe) mantling ice-cored, lobate, tongue-like, rock-glaciers emanating from steep cirques on the north and northwest sides of Mount Sopris. Covering mantle is clast-supported and matrix-free. Cores are a mixture of rock rubble and interstitial fine-grained sediments in a matrix of ice or permafrost. Younger rock glaciers are currently active

Qrg_2 — **Older rock glacier deposits (Holocene and/or late Pleistocene)**—Consists of angular to subrounded, boulders and cobbles of Mount Sopris granodiorite (Tgs) and Pennsylvanian Eagle Valley Formation (IPe) in a matrix of unsorted rock fragments, sand, silt, and clay. Unit is mostly clast-supported but may contain areas that are matrix-supported. Deposits are genetically similar to younger rock glacier deposits (Qrg_1) but are inactive

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by or adjacent to ice in moraines

Qti — **Till, undivided (late and late middle? Pleistocene)**—Heterogeneous deposits of gravel, sand, silt, and clay deposited by or adjacent to ice as ground, lateral, and end moraine on the north and northeast sides of Mount Sopris. Dominantly poorly sorted, unstratified or poorly stratified, matrix-supported, bouldery, pebble and cobble gravel with a matrix of silty sand. Clasts are typically angular to subrounded pieces of granodiorite of Mount Sopris (Tgs), with lesser amounts of Paleozoic sedimentary rocks. May include moraines of Pinedale and Bull Lake ages

UNDIFFERENTIATED SURFICIAL DEPOSITS

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

BEDROCK

Ts — **Sedimentary deposits (Miocene?)**—Very weakly indurated to unconsolidated deposits of pebble- to cobble-sized, locally bouldery, clast-supported, unsorted to well-bedded fluvial sediments. Matrix is silty sand. Deposit apparently accumulated in a large subsidence basin

Tgs — **Granodiorite of Mount Sopris (Oligocene)**—The Mount Sopris stock is predominantly granodiorite; however, the unit locally contains tonalite and quartz monzodiorite phases. The Bulldog stock, located beneath and south of Avalanche Creek, is mineralogically similar but has been affected by argillic alteration. An $^{40}Ar/^{39}Ar$ integrated date on biotite of 34.74 ± 0.19 Ma indicates the age of cooling of the Mount Sopris stock through 350°C (Esser and McIntosh, 1999)

Km — **Mancos Shale (Upper Cretaceous)**—Predominantly medium- to dark-gray, carbonaceous, silty to sandy shale with minor bentonite beds, dark-gray limestone, and medium-gray, grayish-yellow-weathering, clayey sandstone. May includes the Fort Hays Limestone Member, a dark-gray, thickly bedded limestone which occurs about 300 ft above the base

Kdb — **Dakota Sandstone and Burro Canyon Formation, undivided (Lower Cretaceous)**—Dakota Sandstone consists of light-gray to tan, medium- to coarse-grained, moderately well-sorted quartz sandstone and conglomeratic sandstone in well-cemented, thick beds. Dakota Sandstone also contains shale, carbonaceous shale, and coal beds. Burro Canyon Formation consists of greenish-gray claystone and yellowish-gray, medium-grained sandstone with lenses of green and red chert, and quartz pebbles

Jm — **Morrison Formation (Upper Jurassic)**—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to pale-yellowish-gray sandstone, and gray limestone. Sandstones are common in the lower half of unit and may be equivalent to the Salt Wash Member in nearby areas

Je — **Entrada Sandstone (Upper Jurassic)**—Tan to white, medium- to fine-grained, well-sorted, poorly indurated, cross-bedded, sandstone. Sand grains are mostly rounded to subrounded quartz

Jme — **Morrison Formation and Entrada Sandstone undivided (Upper Jurassic)**—Includes Morrison Formation (Jm) and Entrada Sandstone (Je) where contact between two units is not mappable

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. All rock types contain detrital mica. Sandstones are coarse to fine grained, moderately to poorly sorted. Sand grains are generally angular to subangular

IPe — **Eagle Valley Formation (Middle Pennsylvanian)**—Interbedded reddish-brown, gray, reddish-gray, and tan siltstone, brownish-tan, fine- to coarse-grained, gypsiferous sandstone, gypsum, and carbonate rocks. Immediately adjacent to the Mount Sopris pluton these rocks have been contact metamorphosed to hornfels, quartzite, alabaster, and marble

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 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. Includes metamorphosed beds of alabaster

MAP SYMBOLS

Contact—Dashed where approximately located; queried where uncertain

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

Anticline—Showing trace of axial surface; dashed where approximately located; dotted where concealed

Syncline—Showing trace of axial surface; dashed where approximately located; dotted where concealed

Asymmetric Syncline—Showing trace of axial surface; shorter arrow indicates steeper limb; dashed where approximately located; dotted where concealed

Synclinal sag—Showing trace of axial surface of minor synclinal depression or swale related to dissolution and/or flowage of underlying evaporitic bedrock; dashed where approximately located

Limit of Carbondale collapse center—Showing perimeter of large regional topographic depression related to dissolution and flowage of evaporitic bedrock; dotted where concealed; querried where uncertain

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

Alignment of cross sections

Sackung feature—Deep-seated rock creep producing a ridgetop trench

Locality of rock sample—Age dated by $^{40}Ar/^{39}Ar$ method

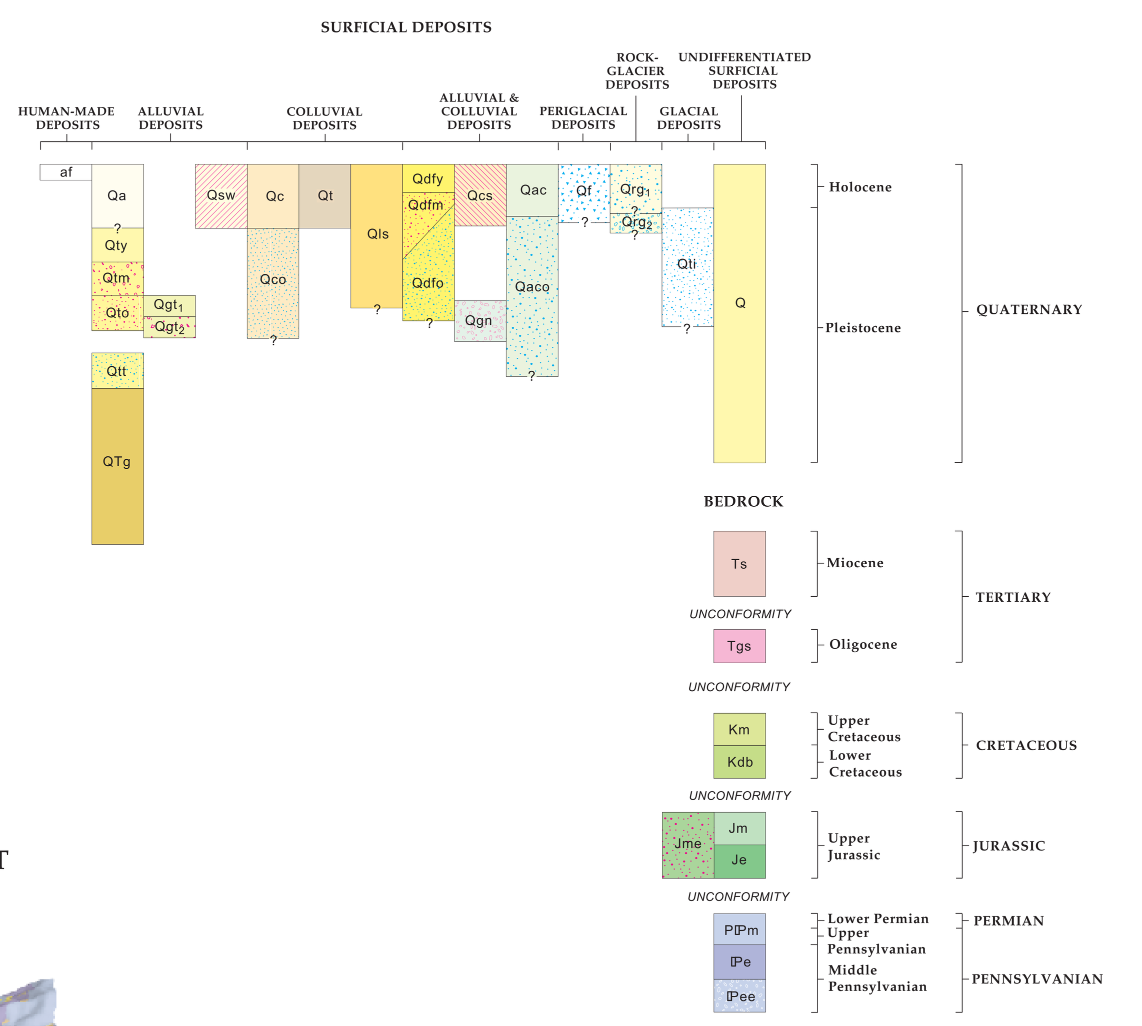
Mine portal

ACKNOWLEDGMENTS

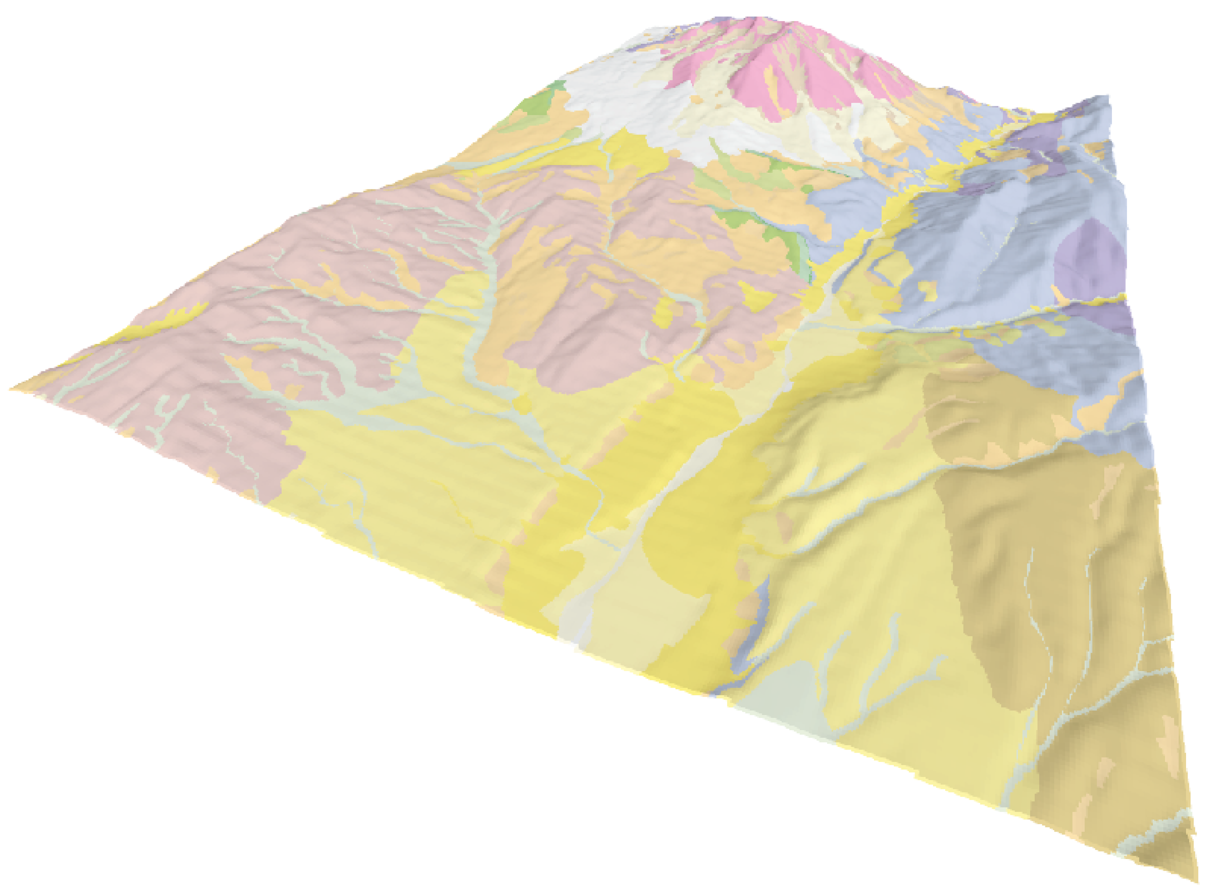
This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey STATEMAP program of the National Cooperative Geologic Mapping Act of 1992, Award No. 98HQAG2081.

This map was reviewed by Bruce Bryant, Jim Cappa, Robert Kirkham, and Peter Birkeland. The following geologists provided helpful suggestions throughout the course of the study: Bruce Bryant, Bob Kirkham, Rich Madole, Jim Cappa, Bob Scott, Chuck Pillmore, Peter Birkeland, Karl Kellogg, Paul Carrara, Bill Perry, Florian Muldonado, Chris Carroll, Jon White, and Wendy Meyer. Sandin E. Phillipson provided a copy of an unpublished report (1998) on Mt. Sopris including collection, analysis, and interpretation of samples from the Mount Sopris stock. Whole-rock and trace-element analyses were performed by Chemex Labs, Inc., Sparks, Nevada. Jane Ciener was the map and text editor. Photogrammetric models were set by Jim Messerich on a Kelsh PG-2 Plotter. Matt Morgan created the shaded relief map with geology overlay and the cross section profile from the USGS 1:24000 scale DEM. I appreciate the many helpful landowners who gave permission to enter their properties.

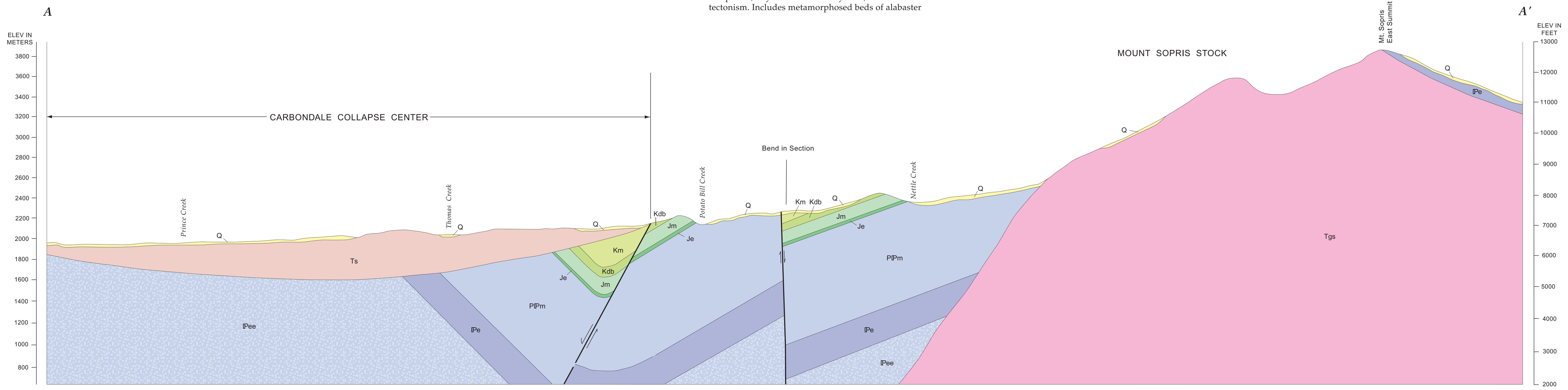
CORRELATION OF MAP UNITS

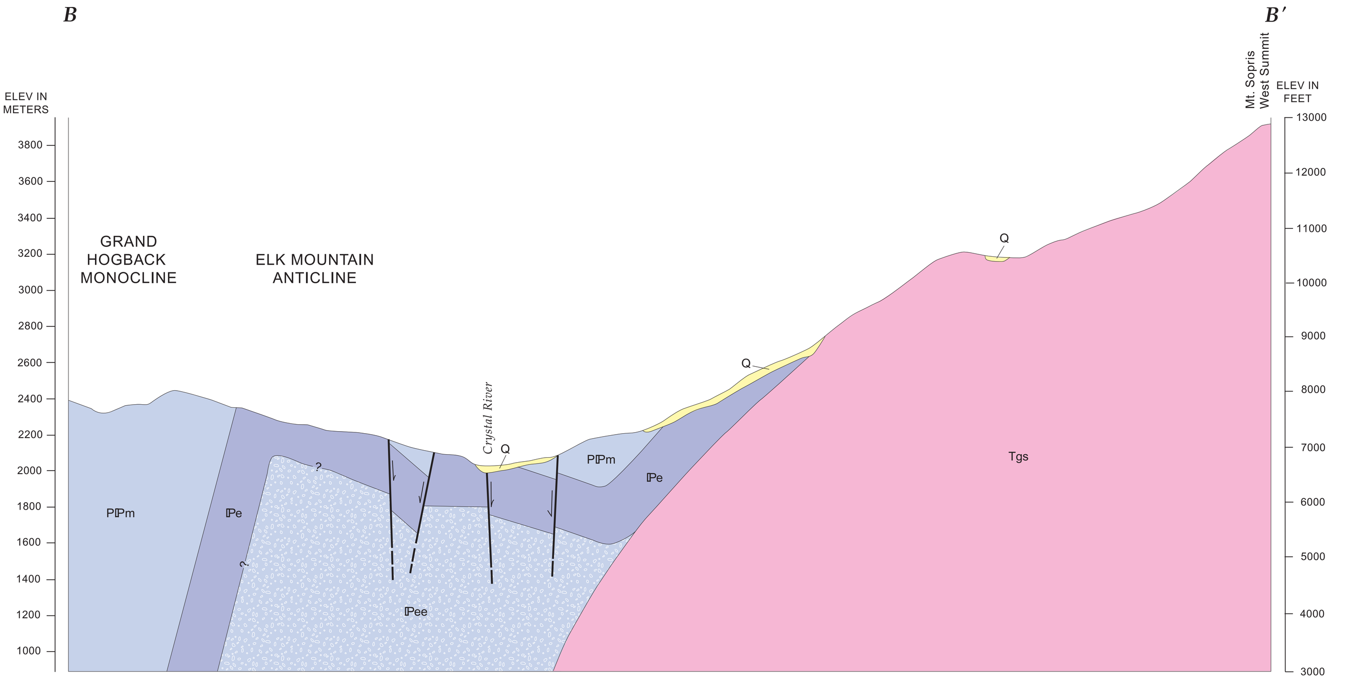


SHADED-RELIEF MAP OF THE MOUNT SOPRIS QUADRANGLE WITH GEOLOGY OVERLAY, OBLIQUE VIEW LOOKING SOUTHEAST



State of Colorado, Bill Owens, Governor
Department of Natural Resources, Greg E. Walcher, Director
Colorado Geological Survey, Vicki Cowart, State Geologist
Denver, Colorado





GEOLOGIC MAP OF THE MOUNT SOPRIS QUADRANGLE, GARFIELD AND PITKIN COUNTIES, COLORADO

By Randall K. Streufert

1999