OPEN-FILE REPORT 06-4

Geologic Map of the Gunnison Quadrangle, Gunnison County, Colorado

Bill Owens, Governor,
State of Colorado

COLORADO
DEPARTMENT OF NATURAL RESOURCES

Russell George, Executive Director,
Department of Natural Resources

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Colorado Geological Survey

by
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Colorado Geological Survey
Department of Natural Resources
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Description of Map Units, Structural Geology, Mineral Resources, Water Resources, and Geologic Hazards

by

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 06-4, *Geologic Map of the Gunnison Quadrangle, Gunnison County, Colorado* is to describe the geologic setting, mineral and water resources, and geologic hazards of this 7.5-minute quadrangle located in western Colorado. Field work for this project was conducted during the summer of 2005 by consulting geologists James C. Coogan and Allen Stork, and field assistants Alex Csar and Raelene Wentz.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program, which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 05HQAG0064, and the Colorado Geological Survey (CGS) using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the severance tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist and Division Director
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INTRODUCTION

The Gunnison 7.5’ quadrangle is centered on the town of Gunnison, near the junctions of the Gunnison River, Ohio Creek, and Tomichi Creek in central Gunnison County, Colorado. The quadrangle lies on the southeastern margin of the Piceance basin between the Elk, West Elk and San Juan Mountains (fig. 1). The geology of the Gunnison 7.5’ quadrangle is generally known through unpublished field studies by Western State College and regional-scale mapping by Tweto and others (1976) and Ellis and others (1987). The adjacent Big Mesa (Hedlund, 1974), Iris NW (Hedlund and Olson, 1974), Iris (Olson 1976b) and Almont (Coogan and others, 2005) quadrangles have been mapped at 1:24,000 scale. More detailed studies of petrology and geochemistry or the Precambrian rocks of the Gunnison quadrangle have been conducted by Vance (1984) and Tobin (1982). A more detailed study of the structure of the Precambrian rocks has been conducted by Lafrance and John (2001)

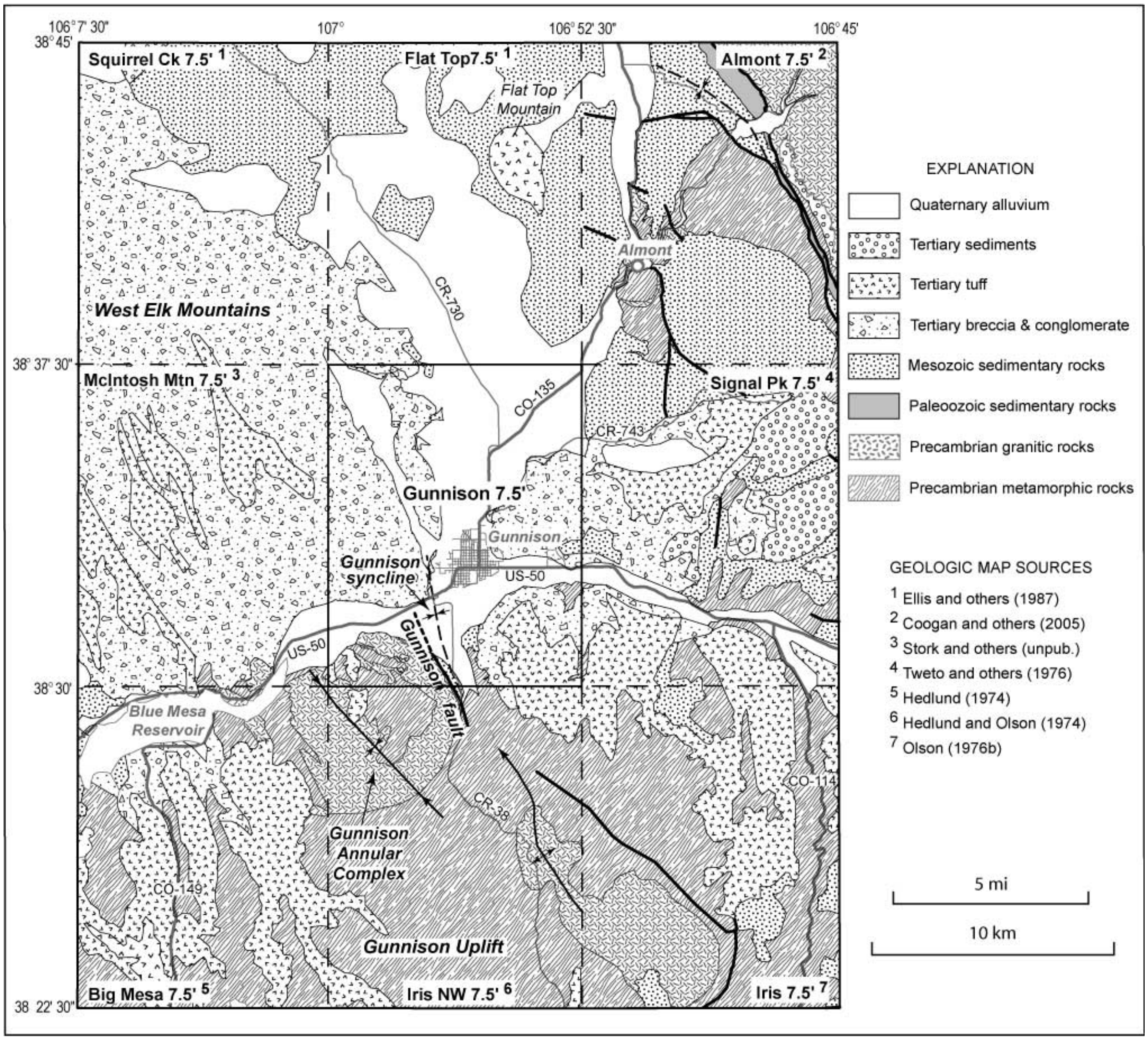

Figure 1. Generalized bedrock geologic map and topographic index map for the area surrounding the Gunnison 7.5’ quadrangle. Modified from Tweto (1979).

Geologic time divisions used in this report are shown in figure 2. The oldest rocks exposed in the Gunnison quadrangle are Precambrian metamorphic and igneous rocks located in the southern part of the quadrangle. Paleoproterozoic metamorphic rocks include biotite quartz schist and amphibolite. Paleoproterozoic igneous rocks include quartz diorite and the tonalite of South Beaver Creek within the Gunnison Annular Complex (fig. 1). Paleozoic rocks are absent in the Gunnison quadrangle as the result of erosion of Cambrian through Middle Pennsylvanian strata and nondeposition of Middle Pennsylvanian through Middle Jurassic strata during and after Middle Pennsylvanian through Permian Ancestral Rockies uplift of the area. Mesozoic sedimentary rocks directly overlie Precambrian rocks in the quadrangle. From oldest to youngest, these sedimentary rocks include the Upper Jurassic Junction Creek Sandstone, the Upper Jurassic Brushy Basin Member of the Morrison Formation, the Lower Cretaceous Burro Canyon Formation, the Upper Cretaceous Dakota Sandstone, and the Upper Cretaceous Mancos Shale. Uppermost Cretaceous and lowermost Tertiary rocks were eroded and/or never deposited because of uplift of the Gunnison area during the Laramide Orogeny. Therefore, the Precambrian metamorphic and igneous rocks and Mesozoic sedimentary rocks are unconformably overlain by an Oligocene volcanic and sedimentary sequence that includes from oldest to youngest: the debris flows of the West Elk Breccia and interbedded non-volcanic gravels; the bedded tuffs of West Elk Creek; the Blue Mesa Tuff; the Sapinero Mesa Tuff; the Fish Canyon Tuff; the Carpenter Ridge Tuff; gravel deposits that intertongue with the Blue Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge

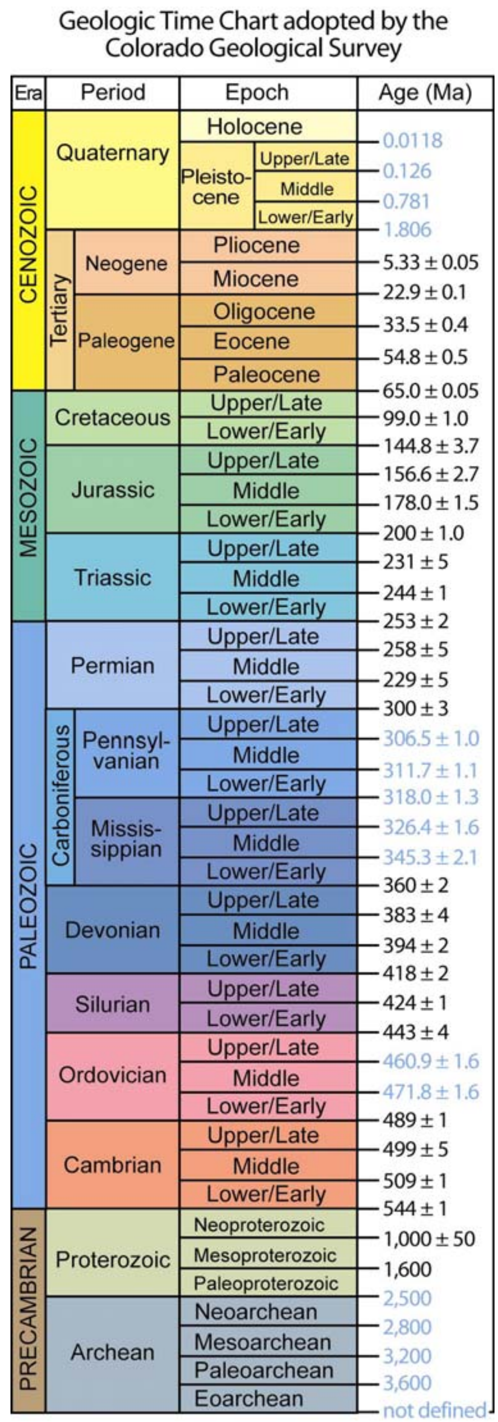

Figure 2. Geologic time chart used for this report. Numerical ages shown in black are from the Geological Survey of Canada (Okulitch, 2002); ages shown in blue are from the International Commission on Stratigraphy, (2005).

Tuffs; and gravel, breccia and sand deposits that locally lie between the bedded tuffs of East Elk Creek and the Fish Canyon Tuff, between the Sapinero Mesa and Fish Canyon Tuffs, and between the Fish Canyon and Carpenter Ridge Tuffs. Surficial deposits include gravel deposits of uncertain lower Pleistocene to Pliocene age, as well as Quaternary mass-wasting, alluvial, and human-made deposits.

ACKNOWLEDGEMENTS

Field and office discussions with Bruce Bartleson, Don Graham, and John Stamm helped to improve the map. Our field assistants had major responsibility for sections of the map and greatly improved the quality of our mapping. Alex Csar worked on the ash flow stratigraphy exposed on Tenderfoot Mountain, both for this project and as part of a Bartleson-Prather Research Scholarship from Western State College. Raelene Wentz worked on the West Elk Breccia throughout the quadrangle.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill and disturbed surfaces (latest Holocene)** -- Unsorted sand, silt, gravel, or rock fragments, that may contain construction material deposited as spoils from quarrying operations, as flood-control and airport construction, or as landfills.

ALLUVIAL DEPOSITS

Qa **Stream and flood-plain alluvium (Holocene)** -- Sand, silt, clay, and gravel in channels and flood plains; composition depends on source area; 0 to 40 m (0 to 130 ft.) thick.

Qt_0 **Stream terrace alluvium (Holocene to upper Pleistocene)** -- Sand, silt, clay, and gravel in a terrace above the modern flood-plains; terrace 0-3 m (0-10 ft.) above **Qa** with the height of the terrace diminishing downstream.

Qt_1 **Stream terrace alluvium (upper Pleistocene)** -- Sand, silt, clay, and gravel in terraces above flood plains; terrace 0-6 m (0-20 ft.) above the **Qt_0** terrace with the height of the terrace diminishing downstream. This terrace correlates with the **Qt_1** terrace mapped on the adjacent Almont quadrangle (Coogan and others, 2005). Two charcoal samples taken from the Wilson Pit gravel quarry (Section 4 T. 50 N. R. 1 E.) have yielded C^{14} ages of 47.7 ± 1.2 Ka before present and 49.1 ± 1.5 Ka before present (WSC unpublished data) for sediments preserved in the **Qt_1** terrace. Depth of the samples is hard to determine because of the quarrying operation; however, the first sample was from the base of the reddish B horizon (?) 10 cm below the disturbed surface. The second sample was taken 15 m west of the first sample, 1.5 m below the base of the B horizon.

Qt_2 **Stream terrace alluvium (middle? Pleistocene)** -- Sand, silt, clay, and gravel in terraces above flood plains.; terrace 0-6 m (0-20 ft.) above the **Qt_1** terrace. This terrace is exposed in two areas that are tentatively correlated by height above the current flood plain. In the Antelope Creek drainage this unit consists of a mix of terrace and fan gravels that produce a conspicuous bench perched on bedrock above the modern alluvium.

Qf **Alluvial-fan deposits (Holocene to upper Pleistocene)** -- Mostly poorly stratified and poorly sorted sand, silt, and gravel deposited mainly by a combination of debris flow and alluvial processes at the mouths of drainages; generally less than 20 m (65 ft.) thick. Holocene alluvial-fan deposits are not incised and are graded to modern flood plains.

Qfo **Alluvial-fan deposits (upper and middle? Pleistocene)** -- Mostly poorly stratified and poorly sorted sand, silt, and gravel deposited mainly by a combination of debris flow and alluvial processes at the mouths of drainages; generally less than 12 m (40 ft.) thick. Pleistocene alluvial-fan deposits are incised and are graded to Pleistocene alluvial terraces.

Qdf **Debris-fan deposits (Holocene and upper Pleistocene)** -- Mostly poorly stratified and poorly sorted sand and gravel that is commonly angular; deposited mainly by rockfall and sheetwash at the base of steep slopes; generally less than 12 m (40 ft.) thick.

MASS-WASTING DEPOSITS

Qc **Colluvium (Holocene and upper Pleistocene) --** Poorly stratified sand, silt, and gravel that caps hilltops and gentle to moderate slopes; deposited by a variety of processes, including slopewash and soil creep; composition depends on local bedrock; generally less than 6 m (20 ft.) thick. Colluvium on slopes southwest of Tenderfoot Mountain (Section 13 T. 49 N. R. 1 W.) is deeply incised by Holocene drainages and may be upper Pleistocene in age.

Qce **Eolian colluvium (Holocene) --** Poorly stratified sand and silt that accumulate in drainages on the lee side of ridges; initially deposited by eolian processes and modified by variety of processes, including slopewash and soil creep, with minor fluvial reworking; 0 to 6 m (0 to 20 ft.) thick.

Qls **Mass-movement deposits, undivided (Holocene to upper Pleistocene)** -- Includes slides, slumps, and flows, as well as colluvium and talus mapped on and adjacent to steep slopes where several mass-movement processes contribute to the deposit; composition varies from poorly sorted clay to boulder-sized material depending on local source terrain; generally characterized by hummocky topography, head and internal scarps, and chaotic bedding in displaced bedrock; morphology is subdued with age; thicknesses are highly variable from 0 to 12 m (0 to 40 ft.) thick.

Qlso **Mass-movement deposits (Pleistocene?)**—Older slides, slumps, and flows whose surface has been reworked by fluvial and eolian process but still exhibit hummocky internal morphology; originate in clay-rich bedrock of the Cretaceous Mancos Shale and Jurassic Brushy Basin Member of the Morrison Formation; these deposits have been cut into by the Holocene flood plain; up to 20 m (65 ft.) thick.

Qef **Earthflow deposits (Holocene? to Pleistocene?)** – Large-scale earthflows exhibiting internal flow or hummocky morphology; originate in clay-rich bedrock of the Cretaceous Mancos Shale and downslope from unconsolidated Quaternary deposits; up to 6 m (20 ft.) thick.

ALLUVIAL AND MASS-WASTING DEPOSITS

Qac **Alluvium and colluvium (Holocene and upper Pleistocene)** -- Includes stream and fan alluvium and colluvium; Holocene deposits are not incised and are graded to modern flood plains, whereas upper Pleistocene deposits are incised and are graded to upper Pleistocene alluvial terraces; generally less than 6 m (20 ft.) thick.

QUATERNARY OR TERTIARY DEPOSITS

QTg **Gravel deposits (lower Pleistocene? to Pliocene?) –** Sub-rounded to rounded unconsolidated deposits of sand, gravel and boulders (up to 25 cm) size; boulders and cobbles include Precambrian granites and metamorphic rocks, Paleozoic and Mesozoic sandstones, and Tertiary volcanics; forms a conspicuous channel to the west of Antelope Creek that is 60 to 105 m (200 to 350 ft.) above the current flood plain; 0-25 m (0-80 ft.) thick.

TERTIARY SEDIMENTS AND VOLCANIC DEPOSITS

Tgb **Gravel, breccia, and sand deposits (Oligocene) --** This unit is composed of sub-angular to sub-rounded unconsolidated gravels and breccias with interbedded coarse sands. Deposits contain sediment from sand to boulder (up to 15 cm) size. Boulders and cobbles include Tertiary volcanics, Precambrian tonalite and granodiorite, and metamorphic rocks such as amphibolite, biotite quarzite, and biotite-quartz gneiss. These clasts are consistent with a provenance in the Gunnison Gold Belt to the south. These deposits occupy channels at several stratigraphic horizons: between the bedded tuffs of East Elk Creek and the Fish Canyon Tuff (0-40 m; 0-130 ft thick), between the Sapinero Mesa and Fish Canyon Tuffs (0-25m; 0-80 ft. thick), and between the Fish Canyon and Carpenter Ridge Tuffs (0-60m; 0-200 ft. thick). Gravels not capped by Oligocene tuffs may be younger (Miocene to Pliocene) if deposited in channels that were later eroded though all the tuffs.

Tg **Gravel deposits (Oligocene) –** This unit is composed of sub-rounded to rounded unconsolidated river gravels. Gravel deposits contain sediment from sand to boulder (up to 50 cm) size. Boulders and cobbles include Precambrian granites and metamorphic rocks, Paleozoic and Mesozoic sandstones, and Tertiary volcanics. Extensive gravel deposits continue to the south and east (Olson, 1976a,b). These clasts are consistent with a provenance to the east and were deposited in Oligocene drainages that had headwaters near the current position of the Continental Divide (Gregory and Chase, 1994). These gravels mark various positions of paleo-Tomichi Creek as it was disrupted by Oligocene volcanism. These gravels overlie the West Elk Breccia and intertongue with the Blue Mesa, Sapinero Mesa, Fish Canyon, and Carpenter Ridge Tuffs. The deposits are 0-75m (0-250 ft.) thick.

Tc **Carpenter Ridge Tuff (Oligocene) –** The Carpenter Ridge Tuff is a red-brown densely to partly welded rhyolitic ash flow tuff containing 2-5% phenocrysts of plagioclase, sanidine, and biotite. The partly welded tuff has conspicuous pumice fragments (up to 4 cm). Lipman (2000) recommends an age of 27.35 MA for this tuff; modified to 27.55 Ma based on a new Ar/Ar calibration that dates the Fish Canyon Tuff at 28.04 Ma (Lipman, personal communication 2006). The Carpenter Ridge Tuff has a maximum preserved thickness of 50 m (160 ft).

Tf **Fish Canyon Tuff (Oligocene) –** The Fish Canyon Tuff is a light-gray nonwelded to dark-gray-brown densely welded dacitic ash flow tuff. The tuff contains 35-40% phenocrysts of plagioclase, sanidine, biotite and hornblende, with lesser amounts of quartz and titanite. The base of the tuff contains abundant angular lithic fragments (~1 to 5 cm) of locally derived Precambrian schists, quartzites, and amphibolites. As the tuff weathers, these lithic fragments produce a distinctive colluvial lag deposit at the base of the tuff. Lipman (2000) recommends an age of 27.6 Ma for this unit; modified to 28.04 Ma based on a new Ar/Ar calibration (Lipman, personal communication 2006). . The Fish Canyon Tuff has a maximum preserved thickness of 85 m (280 ft).

Ts **Sapinero Mesa Tuff (Oligocene) –** The Sapinero Mesa Tuff is a gray nonwelded to red-brown densely welded rhyolitic ash flow tuff containing 2-5% phenocrysts of plagioclase, sanidine, and biotite. In the scattered outcrops, welding decreases from west to east with red-brown densely welded devitrified tuff preserved in the far southwest, dark-gray partially welded tuff beneath Tenderfoot Mountain, and nonwelded pumiceous ash interbedded with gravels to the east of Tenderfoot Mountain. The partially welded tuffs have conspicuous 1-2 cm light-gray pumice fragments. Bove and others (2001) report an average sanidine Ar/Ar age of 28.19 ± .06 Ma. The Sapinero Mesa Tuff has a maximum preserved thickness of 15 m (50 ft).

Tb **Blue Mesa Tuff (Oligocene) –** The Blue Mesa Tuff is a dark-gray to red-brown densely welded rhyolitic ash flow tuff containing <5% phenocrysts of plagioclase, sanidine, and biotite. This unit is only found in the far southwest corner of the map area as a black vitrophyre with conspicuous 2-3 cm pumice fiamme. Red-brown densely welded devitrified tuff is locally found above the vitrophyre. Bove and others (2001) report a sanidine Ar/Ar age of 28.40 ± .07 Ma. The Blue Mesa Tuff has a maximum preserved thickness of 9 m (30 ft).

Te **Bedded tuffs of East Elk Creek (Oligocene) --** This unit contains interbedded tuff, tuffaceous sandstone, and siltstone. The unit is white to light-green-brown. Individual ash beds contain abundant white angular pumice lapilli (up to 5 mm), and smaller pumice fragments are common in the tuffaceous sandstones. This unit is typically covered by colluvium from stratigraphically higher gravels and welded tuffs in the Gunnison quadrangle. However, the unit is well exposed in several prominent white cliffs up to 40 m (130 ft.) high on the north side of Blue Mesa Reservoir, where the unit was mapped as a tuffaceous conglomeratic facies of the West Elk Breccia by Hedlund and Olson (1973). The unit is younger than a biotite-bearing pumice clast from the unit that was dated at 30.7 ± .4 Ma (Stork and Panter, unpublished data). This unit is 0-55 m (0-180 ft.) thick.

Tw **West Elk Breccia (Oligocene) –** The West elk Breccia is predominantly a brownish-gray volcanic breccia and tuff breccia with minor interbedded tuff, tuffaceous sandstones and conglomerate. Breccia beds are pooly sorted, matrix supported, with large scale stratification, and probably were emplaced as volcanic mud and debris flows. The clasts in the breccia include andesite, dacite, and rhyolite up to 2 m in diameter. Reworked clasts of older West Elk Breccia are up to 4 m in diameter. Some debris-flow units in the West Elk Breccia contain reworked paleo-Gunnison and Tomichi stream gravels and therefore have clasts of Precambrian granite and metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks in an ashy matrix. West Elk volcanism had been dated to 30.5 ± .8 Ma by Coven and others (1999). This unit thickens markedly across the quadrangle from zero in the northeast to at least 180 m (600 ft.) on the western edge of the quadrangle. Gaskill and others (1981) report a maximum thickness for the volcaniclastic facies of the West Elk Breccia of approximately 550 m (1800 ft.) in adjacent quadrangles.

Twg **Gravel of the West Elk Breccia (Oligocene) –** Well-rounded, unconsolidated river gravels are found within the West Elk Breccia as discontinuous lenses. Gravel deposits contain clasts from sand to boulder (up to 1.5 m) size. Boulders include Precambrian granites and metamorphic rocks, Paleozoic and Mesozoic sandstones, and Tertiary volcanics. Individual lenses of gravel are up to 30 m (100 ft.) thick.

MESOZOIC SEDIMENTARY ROCKS

Km **Mancos Shale (Upper Cretaceous) –** Mancos Shale exposures in the Gunnison quadrangle consist of dark-gray to gray fissile shale and mudrock with rare, thin, tan sandstone and tan calcareous sandstone. The Mancos Shale underlies extensive areas of surficial Quaternary mass-movement and alluvial deposits in the northern half of the quadrangle. The widely separated distribution of small Mancos Shale outcrops in the Gunnison quadrangle precludes mapping of the individual members of the formation that were identified by Coogan and others (2005) in the Almont 7.5' quadrangle to the northeast (fig.1). In general, small outcrop areas east of the Gunnison River correlate to the lower member, and outcrops west of the Gunnison River correlate to the upper shale map unit of Coogan and others (2005). The intervening Mancos Shale map units in the Almont quadrangle include the calcareous shale of the Smoky Hill Member, the lower shale of the Smoky Hill Member, the Fort Hays Limestone Member, the unnamed shale member and the Juana Lopez Member, the Codell Sandstone Member, and the lower shale (Coogan and others, 2005). These units are either not exposed or are not distinguishable in the limited and small outcrops of the Gunnison quadrangle.

Kd **Dakota Sandstone (Upper Cretaceous) --** The Dakota Sandstone is dominated by yellow-brown to gray sandstone with interbedded conglomerate and mudstone. Sandstone is quartz arenite with a minor component of chert grains. Chert and quartz pebble conglomerate marks the base, but conglomerate locally is absent where there are no scours. Three distinct parts are recognized in the map area. The lower third consists of resistant interbedded fine- to coarse-grained sandstone and pebble conglomerate that fills channel scours up to 3 m (10 ft) deep into underlying strata. This part is dominated by trough and low-angle cross-stratification with minor horizontal stratification. The middle part of the Dakota consists of a recessive zone of thinly bedded, brown and gray, carbonaceous, laminated, fine- to medium-grained sandstone, siltstone, and thin, silty coal horizons. Black carbonaceous clots and plant-stem impressions are abundant. The upper third of the Dakota consists of a resistant yellow-brown to gray sandstone that is overlain by medium-bedded bioturbated siltstone and interbedded gray to black silty shale. The Dakota Sandstone records a marine transgression. The basal third was deposited in braided streams. The middle part represents a swampy shoreline environment and the uppermost Dakota was deposited in a sandy, tide-influenced shallow marine environment. There is no complete exposure of the Dakota Sandstone in the Gunnison quadrangle. However, the Dakota Sandstone is 20 m (65 ft) thick in the Gunnison River Canyon immediately northeast of the map area (Coogan and others, 2005). Thickness of the Dakota varies with the depth of basal scours into underlying strata, and most variations are attributed to the lower fluvial part of the formation. The Dakota has a sharp unconformable contact on the Lower Cretaceous Burro Canyon Formation. The upper contact with the overlying Upper Cretaceous Mancos Shale is gradational and records a continued sea level rise into a deep marine environment.

Kbc **Burro Canyon Formation (Lower Cretaceous) –** The Burro Canyon Formation consists of basal cliff-forming conglomeratic sandstone that is interbedded with thin intervals of slope-forming varicolored claystone and mudstone in the upper part of the formation. The basal conglomeratic sandstone ranges from 0 to 12 m (0 - 40 ft) thick and consists of crossbedded chert pebble conglomerate that grades upwards into coarse- to fine-grained sandstone. The maximum thickness of the Burro Canyon Formation is estimated as 14 m (45 ft), however the thickness varies greatly because the Burro Canyon Formation scours deeply into the underlying Brushy Basin Member of the Morrison Formation. The formation is unconformably overlain by the Upper Cretaceous Dakota Sandstone.

Jmb **Brushy Basin Member of the Morrison Formation (Upper Jurassic) –**The Brushy Basin Member is a heterogeneous assemblage of lithologies and consists of irregular alternations of green siliceous claystone, red silty shale, gray limestone, and sparse lenses of sandstone and conglomeratic sandstone. Beds of all lithologies are less than 1.5 m (5 ft) thick. Green claystone is the dominant rock type and mostly is structureless, although laminations are locally evident. Laminated red silty shale increases in abundance toward the base of the member. Gray limestone is micritic and contains evidence of plant rootlets. Clasts in conglomeratic sandstone lenses are composed predominantly of intraclasts of limestone, green claystone, and red shale. The Brushy Basin Member is the product of a broad low-relief fluvial flood plain. Claystone and shale are flood-plain deposits. Lenticular sandstone and conglomerate bodies were deposited in the low energy river channels that cut across the flood plain. Limestone was deposited in shallow ponds that formed in depressions on the plain, between the river channels. North of U.S. Highway 50 where the base of the unit is not exposed, the maximum exposed thickness of the Brushy Basin Member is ~ 50 m (170 ft) near the east edge of the Gunnison quadrangle. The Brushy Basin Member reaches up to 70 m (230 ft) thick in the Almont quadrangle to the northeast (Coogan and others, 2005), but this thickness may include up to 19 m (63 ft) of the overlying Burro Canyon Formation, which is largely indistinguishable from the Brushy Basin in that area. The Brushy Basin forms sagebrush-covered slopes and mostly is concealed beneath a thick mantle of colluvium. Where it cannot be recognized by stratigraphic position, it typically is identified by chips of green and red shale in small drainages and gullies. Its recognition is further complicated by its tendency to collapse into landslides, slumps, and debris flows. The base of the Brushy Basin Member is not exposed in the quadrangle. Northeast of the quadrangle, the Brushy Basin Member rests conformably on the Salt Wash Member of the Morrison Formation, which is up to 6 m (20 ft) thick in the Almont quadrangle (Coogan and others, 2005). However, the fluvial channel facies of the Salt Wash Member is absent where the Brushy Basin rests conformably on the Jurassic Junction Creek Sandstone in exposures one half mile south of the center Gunnison quadrangle along County Road 38.

Jj **Junction Creek Sandstone (Upper Jurassic) --** The Junction Creek Sandstone consists of well-sorted, fine- to medium-grained, yellow-white quartz sandstone. It is mostly crossbedded on a large scale with single sets up to 15 feet thick. The basal 3 to 5 m (10 - 16 ft) of the formation locally consists of medium-grained horizontal and wavy-bedded sandstone with abundant quartz granules and pebbles; symmetrical ripples of aqueous origin occur rarely on bedding surfaces. The bulk of the formation was deposited in an eolian dune setting. Basal strata were deposited on a long-lived erosion surface in a marginal shallow marine setting. The top of the Junction Creek is not exposed in the quadrangle and the base is poorly exposed and typically covered by an apron of disaggregated sand grains. The formation nonconformably overlies Precambrian igneous and metamorphic rocks. The Junction Creek Sandstone has a maximum exposed thickness of ~15 m (50 ft) in the south-central part of the quadrangle, with a complete thickness of 27 to 38 m (90 - 125 ft) in the Almont quadrangle to the northeast (Coogan and others, 2005). The Junction Creek Sandstone is correlative with the Bluff Sandstone in southeast Utah on the basis of intertonguing of both of these units with the lower Morrison Formation (O'Sullivan, 1980, 1998, Coogan and others, 2005).

PROTEROZOIC IGNEOUS AND METAMORPHIC ROCKS

Xsb **Tonalite of South Beaver Creek (Paleoproterozoic) –** This unit contains light-gray to pink hornblende biotite tonalite, biotite trondhjemite and biotite granite with tonalite as the dominant rock type. The tonalite/trondhjemite has 50-60% plagioclase (An_{25-30}), 20-30% quartz, 5-10% biotite, and less than 5% hornblende and microcline. The granite has

40% plagioclase (An_{25}), 35% quartz, 30% microcline, and 3% biotite. Accessory minerals include magnetite, titanite, zircon, and apatite. The granite is cut by late-stage quartz-microcline pegmatite dikes and by prophyritic tonalite dikes as described by Vance (1984). Bickford and others (1989) report a conventional $^{207}Pb/^{208}Pb$ age on zircon of 1,721 ± 7 Ma from a sample at the Aberdeen Quarry on the adjacent Iris NW quadrangle. Hill and Bickford (2001) report a SHRIMP $^{207}Pb/^{208}Pb$ age of 1,700 Ma for homogeneous zircons and overgrowth rims from the same sample. These zircons have an inherited component with zircon cores as old as 2521 ± 14 Ma. Detailed petrography and geochemistry of these rocks is presented by Vance (1984) and Tobin (1982). These rocks are equivalent to the granite of South Beaver Creek of Hedlund (1974) and Hedlund and Olson (1974).

Xqd **Quartz diorite (Paleoproterozoic) –** This unit is a gray coarse-grained hornblende quartz diorite. The rock consists of 50-60% plagioclase (An_{30-45}), 20-30% hornblende, less than 10% quartz, and less that 5% biotite and magnetite. Accessory minerals include titanite, zircon, and apatite. Bickford and others (1989) report a conventional $^{207}Pb/^{208}Pb$ age on zircon of 1,730 ± 6 Ma from a quartz diorite body in the adjacent Iris NW quadrangle. Detailed petrography and geochemistry of the quartz diorite is presented by Vance (1984) and Tobin (1982).

Xs **Biotite quartz schist (Paleoproterozoic)** - This unit is predominantly a dark-gray fine-grained biotite quartz schist but also contains dark-gray biotite quartz gneiss, dark-gray biotite quartzite, and light-gray to pink feldspathic quartzite. Migmatitic gneiss with ptygmaitcally folded quartz-rich leucosomes are common near the margins of the tonalite of South Beaver Creek. The biotite-bearing units are dominated by granoblastic quartz, microcline, and plagioclase (albite-oligoclase) with variable amounts (5-50%) of aligned biotite to produce the foliation. Accessory minerals include muscovite, epidote, blue-green hornblende, titanite, and apatite. The feldspathic quartzites contain granoblastic quartz, microcline, and plagioclase (albite-oligoclase) and rare garnet metacrysts that are limited to a few isolated outcrops in the southwest corner of the quadrangle. These rocks are equivalent to the quartz-biotite schist of Hedlund (1974), Hedlund and Olson (1974), and Olson (1976b), and the biotite schist of Tobin (1982).

Xa **Amphibolite (Paleoproterozoic) –** This unit is a black to greenish-black fine- to medium-grained amphibolite. The amphibolite is weakly foliated in most places but grades into gneissic structures locally. The amphibolite consists of 35-70% green amphibole, 25-50% plagioclase (andesine An_{30-45}), and smaller amounts of quartz (<5%), chlorite, epidote, biotite, titanite, and apatite. Amphibolites are often cut by quartz or epidote veins. These rocks are equivalent to the amphibolite and hornblende schist of Hedlund (1974), Hedlund and Olson (1974), and Olson (1976b), the amphibolite of Tobin (1982), and the amphibolite and fine-grained hornblende diorite of Vance (1984).

STRUCTURAL GEOLOGY

The Gunnison quadrangle contains a record of three phases of mountain building in Colorado that include the assembly of Precambrian basement terranes, the Pennsylvanian through Permian Ancestral Rockies uplift; and the early Tertiary Laramide Orogeny. Precambrian metamorphic and igneous rocks in the southwestern part of the quadrangle lie along the northern margin of the Gunnison annular complex, a doubly plunging synform that records polyphase deformation and intrusion that occurred between 1730 and 1700 million years ago during the early assembly of North America (Lafrance and John, 2001; Bickford and others, 1989). The quadrangle is located on what was the eastern flank of the ancestral Uncompahgre uplift active in Pennsylvanian and Permian time (Kluth and Coney, 1981). The Ancestral Rockies history is evident only in the nonconformity between the Jurassic Junction Creek Sandstone and Precambrian basement rocks, where the regional Paleozoic section was eroded from the Gunnison area during and after Ancestral Rockies uplift. The early Tertiary Laramide Orogeny is principally represented by the general gentle northward and westward dip of Mesozoic strata across the quadrangle. A discrete zone of Laramide reverse faulting and folding is exposed along the Gunnison fault and the Gunnison syncline in the southwestern part of the quadrangle. A second area of possible Laramide folding is located in the northwestern part of the quadrangle where a zone of east-dipping Mancos Shale interrupts the otherwise uniformly gentle westward dip in this area. This folding may result from slip on an underlying Laramide fault at the level of the Precambrian basement, or it could indicate the presence of a post-Laramide intrusion at depth.

PRECAMBRIAN STRUCTURE

Gunnison Annular Complex

The Proterozoic metasedimentary and intrusive complex mapped along the southwestern border of the Gunnison quadrangle forms the north limb of a northwest-trending, doubly plunging synform that is termed the Gunnison annular complex by Lafrance and John (2001) (fig. 1). The Gunnison annular complex developed by polyphase deformation and intrusion. The biotite quartz schist and gneiss and amphibolite map units are part of the metasedimentary and metavolcanic Cochetopa succession that was deposited in a continental-arc margin setting (Knoper and Condie, 1988). These metamorphic rocks display relict bedding in areas south of the Gunnison quadrangle, as well as an early bedding-parallel foliation (S_1 of Lafrance and John, 2001). Lafrance and John (2001) documented multiple subsequent intrusion and deformation events, beginning with intrusion of quartz diorite sills along bedding and foliation in the center of the complex. The quartz diorite was subsequently synformally folded about a northwest trend to form the competent core to the annular complex. A final protracted deformation stage included further foliation development, intrusion, and right-lateral shear. Further folding along the northwest trend imparted a strong late foliation (S_3 of Lafrance and John, 2001) that wrapped concentrically around the quartz diorite core. This S_3 foliation is dominant on the north margin of the complex in the Gunnison quadrangle where it masks the earlier S_1 foliation, and it corresponds to the foliation mapped for this report. The tonalite of South Beaver Creek was then injected along foliation and intrusion-induced fractures to form the outer ring intrusions. Finally, Lafrance and John (2001) document northwest-oriented right-lateral shear that deformed the outer ring intrusions.

LARAMIDE STRUCTURE

The Eocene Laramide orogeny is represented in the Gunnison quadrangle by both general tilt domains as well as discrete structures. The northward dip of Mesozoic strata in the southern part of the quadrangle is the result of tilting on the north flank of the Gunnison uplift (fig. 1), a Precambrian-cored Laramide uplift that continues westward to the Black Canyon of the Gunnison River. The general westward dip of Mesozoic strata in the northern two-thirds of the quadrangle is associated with tilting on the west flank of the Laramide Sawatch uplift, which is expressed locally by Precambrian rocks exposed in the eastern Almont quadrangle (fig. 1). Discrete Laramide structures include the Gunnison fault and Gunnison syncline. In addition, an area of folding of the upper Mancos Shale is poorly exposed in the northwest part of the quadrangle along cross section A-A'. This folding may result from slip on an underlying Laramide fault at the level of the Precambrian basement, or it could indicate the presence of a post-Laramide intrusion at depth.

Gunnison Fault

The Gunnison fault is exposed in the southwestern part of the quadrangle in the area of the Hartman Rocks recreation area (fig. 1; cross section B-B"). The fault trace lies along the prominent topographic change from the gentle slope of the Hartman Rocks base area to the ridge of Precambrian rocks west of the base area. The Gunnison fault is a high-angle reverse fault that strikes northwest and dips 70^o to 80^o to the southwest, placing early Proterozoic amphibolite and quartz biotite schist and gneiss of the hanging wall over the Jurassic Brushy Basin Member of the Morrison Formation in the footwall. The fault has a minimum vertical throw of ~ 90 m (300 ft) between the estimated elevation of the Precambrian surface beneath the Brushy Basin outcrops of the footwall and the highest elevation of Precambrian rocks in the hanging wall. The southwest-to-northeast transport of the hanging wall is evident from local westward overturned dips in footwall strata. The northward limit of the Gunnison thrust is obscured by overlying Quaternary sediments and the Oligocene West Elk Breccia. However, it probably extends north-northwestward at least as far as the northernmost extent of the genetically related Gunnison syncline ~ 2.4 km (1.5 mi) north of U.S. Highway 50 immediately west of the Gunnison River.

Gunnison Syncline

The Gunnison syncline is a northwest-trending, asymmetric syncline with a gentle east limb and a steep west limb that is locally overturned to ~60^o west dip immediately adjacent to the Gunnison fault (fig. 1; cross section B-B). The overturned west limb is the result of footwall drag across the Gunnison fault, and the asymmetry of the syncline documents the southwest-to-northeast transport of the hanging wall. The syncline extends north-northwestward from the south edge of the quadrangle in the Hartman Rocks area, beneath the alluvium of the Gunnison River and Tomichi Creek valleys, to where it is defined by outcrops along and north of U.S. Highway 50. The inferred axial trace of the syncline is mapped ~ 2.4 km (1.5 mi) north of U.S. Highway 50 in an area of isolated Mesozoic outcrops immediately west of the Gunnison River before it is covered by overlying Quaternary sediments and the Oligocene West Elk Breccia. Despite the extensive cover and generally poor quality of Mesozoic outcrops along the syncline, the mapped bedding attitudes in the Junction Creek through Dakota Formations adequately define a shallow northwest plunge for the synclinal axis. Stereonet analysis of the average dip of seventeen outcrops from the Hartman Rocks area and the area north of U.S. Highway 50 define a plunge of 3^{o} toward 330^{o} for the axis of Gunnison syncline (fig. 3).

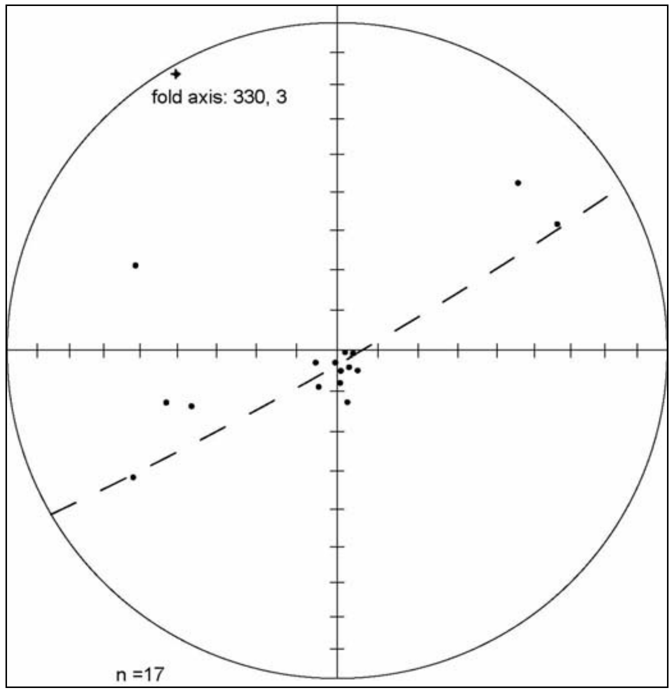

Figure 3. Equal area, lower hemisphere stereonet plot of poles to bedding for average bedding attitudes from seventeen outcrops along Gunnison syncline in the Hartman Rocks area and the area north of U.S. Highway 50. The calculated fold axis plunges 3^{o} toward 330^{o}.

Folds within the Mancos Shale

An area of possible Laramide folding is located in the northwestern part of the quadrangle where a zone of east dip in the upper Mancos Shale interrupts the otherwise uniformly gentle west dip of Mesozoic strata that characterizes the north half of the Gunnison quadrangle. The east-dipping Mancos outcrops are located in the southeast corner of sections 10 and the southwest corner of section 11 of Township 50 N, Range 1 W. These exposures lie ~1.6 km (1 mi) east of more steeply west-dipping Mancos outcrops located in the northwest corner of section 15 of the same township. The opposing dip directions of these two outcrop areas defines a localized arching of upper Mancos strata along cross section A-A’ that is not evident north and south of the key outcrop area. The north-south extent of this folding is unknown because the Mancos in adjacent areas is overlain by the West Elk Breccia or is only exposed beneath landslide deposits where highly weathered outcrops do not display bedding. It is therefore uncertain whether the folded upper Mancos is a localized dome or a linear anticline with a more extensive north-south extent. Folding of the upper Mancos in this area could be associated with slip on a linear Laramide reverse fault at the deeper Precambrian basement level. It is equally plausible that this localized folding lies above a post-Laramide domal intrusion above the basement that would be similar to many of the smaller Oligocene intrusions mapped to the north and west of the Gunnison quadrangle by Ellis and others (1987).

MINERAL RESOURCES

Economic Minerals

There has been no significant economic mineral production within the Gunnison quadrangle. Areas to the south, within the Gunnison Gold Belt, have produced base and precious metals from both stratiform and vein deposits within the Precambrian (Streufert, 1999). Within most of the quadrangle potential Precambrian host rocks are deeply buried by overlying Mesozoic sediments and unfaulted Tertiary volcaniclastic rocks. Uranium prospects are present in the Morrison Formation along the Gunnison Fault but no significant mineralization was found.

Quartz diorite (**Xqd**) is extensively quarried both in the Gunnison quadrangle and in adjacent quadrangles. The quartz diorite is deeply weathered and breaks easily into angular grus used locally for fill and road base.

Significant sand and gravel resources are available from the alluvial deposits (**Qa** and **Qt**$_{\mathbf{0,1,2}}$) and potentially from the unconsolidated Tertiary gravels (**Tg**) that crop out in the southeast part of the quadrangle. Dimension stone and moss rock for local use have been quarried on a small scale throughout the area from outcrops of Mesozoic sandstones and some of the welded tuffs.

Oil and Gas

The Gunnison quadrangle lies at the far southern edge of the Piceance Basin petroleum province and contains a sedimentary sequence that is associated with oil and gas accumulations elsewhere in the state and region (Spencer and Wilson, 1988). The Dakota and Junction Creek Sandstones locally exhibit porosity characteristic of petroleum reservoirs. The Mancos Shale is a known petroleum source rock and low-porosity Mancos sandstone reservoirs produce oil and gas in the northern Piceance Basin (Spencer and Wilson, 1988). However, the deep erosion level in the Gunnison area precludes large-scale oil and gas accumulation in the quadrangle. All potential reservoirs are in communication with surface waters or shallow alluvial groundwater and are essentially flushed of hydrocarbons.

Water Resources

Shallow alluvium in the Gunnison, Tomichi, and Ohio Creek valleys forms the principal aquifer in the Gunnison quadrangle. These gravels provide domestic water for the town of Gunnison through a group of shallow wells drilled into the **Qt**$_{\mathbf{0}}$ terrace. The Dakota and Junction Creek Sandstones are potential confined aquifers in the region, particularly to the north and west where these units plunge into the Piceance basin. However the small local recharge areas and the discontinuous nature of outcrops on the erosion surface between the Precambrian and overlying volcanic rocks make the extent of the resource difficult to assess. Thick sections of impermeable rocks such as the Mancos Shale, West Elk Breccia, and other Tertiary volcaniclastic units make reliable groundwater development problematic in much of the area.

GEOLOGIC HAZARDS

Slopes underlain by the tuffs of East Elk Creek, poorly welded portions of the Fish Canyon Tuff, the Mancos Shale, and the Brushy Basin Member of the Morrison Formation have the potential for mass movement. Past movement in these units is evident throughout the map area. Rockfall hazards exist on extremely steep slopes beneath densely welded Carpenter Ridge Tuff and in a variety of units being undercut by the Gunnison River or Tomichi Creek including the Precambrian exposures near Hartman Rocks, the West Elk Breccia exposed in the Palisades west of Gunnsion, and the West Elk Breccia exposed at the base of Tenderfoot Mountain. Geologic hazard areas have been identified and mapped in detail for Gunnison County by Soule (1976).

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