

OPEN-FILE REPORT 06-10

**Geologic Map of the Maysville Quadrangle,
Chaffee County, Colorado**

**Description of Map Units, Structural Geology,
Mineral and Water Resources, and Geologic Hazards**

by

James R. Shannon¹ and James P. McCalpin²

¹ Colorado School of Mines, Golden, CO

² GEO-HAZ Consulting, Crestone, CO

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geologic Mapping Program under STATEMAP Agreement No. 05HQAG0064.



Bill Owens, Governor, State of Colorado
Vince Matthews, State Geologist and Division Director, Colorado Geological Survey
Denver, Colorado
2006

FOREWORD

The Colorado Geological Survey is pleased to present Open File Report 06-10, *Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado*. Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle. Field work for this project was conducted during the summer of 2005.

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 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

TABLE OF CONTENTS

Introduction.....	7
Location and Access.....	7
Geologic and Tectonic Setting.....	12
Previous Studies.....	30
Methods.....	34
Acknowledgments.....	37
Description of Map Units.....	38
Surficial Deposits.....	38
Human-Made Deposits.....	38
Glacial Deposits.....	38
Periglacial Deposits.....	43
Alluvial Deposits.....	46
Colluvial Deposits.....	54
Alluvial-Colluvial Deposits.....	56
Tertiary Rocks and Deposits.....	59
Tertiary Igneous Rocks.....	73
Paleozoic Sedimentary Rocks.....	108
Proterozoic Rocks.....	113
Structural Geology.....	150
Discussion.....	168
Geologic Hazards.....	173
Economic Geology.....	180
Water Resources.....	195
References.....	198
Appendix.....	CD-ROM

LIST OF FIGURES

Figure 1. Shaded relief map showing the location (red) of the Maysville 7.5-minute quadrangle, Chaffee County, Colorado.....	8
Figure 2. Overview of Maysville quadrangle showing main physiographic features and tectonic elements.....	9
Figure 3. Location of Maysville quadrangle in relation to major regional tectonic and geologic elements of western Colorado.....	13
Figure 4. Regional geologic-tectonic setting of the Upper Arkansas Valley graben segment of the Rio Grande rift, central Colorado.....	14
Figure 5. Detailed geologic-structural-tectonic setting of the southern Upper Arkansas Valley graben segment of the Rio Grande rift, central Colorado.....	23
Figure 6. Location of the Maysville 7.5-minute quadrangle and index of previously completed 15-minute and 7.5-minute geologic quadrangle mapping in the region.....	31
Figure 7. Geologic time chart used for this report.....	36

Figure 8. Road-cut exposure of Bull Lake till (Qbt).....	40
Figure 9. Longitudinal topographic profile of Quaternary terraces and moraines of the South Arkansas River.....	48
Figure 10. View west up South Arkansas River valley overlooking west Maysville.....	49
Figure 11. View west up South Arkansas River valley showing Bull Lake outwash older (Qboo) and younger (Qboy) terraces.....	51
Figure 12. View of younger alluvial fan deposits (Qfy) on south side of South Arkansas River.....	58
Figure 13. Road-cut exposure of Dry Union Formation Upper Arkansas graben sequence (Td).....	63
Figure 14. Crude bedding in coarse conglomerate in highest levels of exposure of the Dry Union Formation South Arkansas graben sequence (Td2).....	65
Figure 15. Subcrop of fissile volcanic ash bed (Td2v) in the Dry Union Formation South Arkansas graben sequence.....	67
Figure 16. Photomicrograph of volcanic ash (Td2v) from the Dry Union Formation South Arkansas graben sequence (Td2).....	68
Figure 17. View of eastern volcanic ash bed (Td2v) in the Dry Union Formation South Arkansas graben sequence (Td2).....	69
Figure 18. Close-up view of intensely shattered Paleozoic dolomite (gray) and minor chert (white) from the central Paleozoic landslide sheet (Td2ls) in the Dry Union Formation South Arkansas graben sequence (Td2).....	71
Figure 19. Outcrop of central Paleozoic landslide sheet (Td2ls) in the Dry Union Formation South Arkansas graben sequence.....	72
Figure 20. View of Shavano Lake in Squaw Creek glaciated valley overlooking the southern Upper Arkansas Valley graben.....	77
Figure 21. Slabs of North Fork border (Tnfb, left) and leucogranite (Tnfg, right) stained for alkali feldspar.....	83
Figure 22. Billets and slabs of Tertiary quartz latite hybrid dikes (Tqlp) stained for alkali feldspar showing range of textures and xenocryst contents.....	87
Figure 23. Coarse block talus of Mount Princeton finer-grained quartz monzonite (Tmpf) with irregular flinty-crush rock (Tfcr, dark gray) bands related to the Mount Aetna cauldron ring zone.....	93
Figure 24. Billets of Mount Pomeroy subunit (Tmpp, left) in comparison to Tertiary quartz monzodiorite (Tqm) medium grained (middle) and fine grained (right) dike.....	99
Figure 25. Billets and slabs of Tertiary (?) andesite hybrid dikes (Ta) showing variations in textures.....	105
Figure 26. Bedding laminations in Paleozoic limestone outlier about 6,000 ft west-southwest of Maysville.....	112
Figure 27. Outcrop of Proterozoic foliated granodiorite (Xgdf) exhibiting	

mylonitic, augen textures.....	121
Figure 28. Subcropping contact between Proterozoic granodiorite (Xgd, boulder upper left) and amphibolite gneiss (Xag; dark gray clasts).....	124
Figure 29. Outcrop of epidote calc-silicates overprinting the matrix of Proterozoic amphibolite agglomerate (Xaa).....	128
Figure 30. Outcrop of Proterozoic quartzite (Xq) representing lenses of metachert (?).....	132
Figure 31. Subcropping zone of muscovite-cordierite schist (Xmc) with large porphyroblasts of cordierite (dark brown).....	134
Figure 32. Photomicrograph of muscovite-cordierite schist (Xmc) showing cluster of cordierite porphyroblasts.....	135
Figure 33. Hand sample, billet and slab of muscovite-sillimanite gneiss (Xmsg).....	137
Figure 34. Hands samples of Proterozoic muscovite felsic schist (Xmfs) showing medium- to coarse-grained, quartz-rich variety (left) and fine- to medium-grained muscovite porphyroblastic variety (right).....	140
Figure 35. Outcrop of Proterozoic hornblende intermediate gneiss (Xhig) with localized mylonitic fabrics.....	143
Figure 36. Outcrop of Proterozoic amphibolite agglomerate (Xaa) with mixed mafic and felsic metavolcanic clasts.....	146
Figure 37. Outcrop of Proterozoic lineated amphibolite (Xal).....	148
Figure 38. Steep rift-related fault cutting California leucogranite (Tcm) in upper Squaw Creek.....	162
Figure 39. Summary of Rio Grande rift architecture and location of Tertiary and Quaternary volcanic ash localities.....	170
Figure 40. Photomicrograph of mineralized calc-silicate gneiss (Xcs) from the Bon Ton mine- SW adit.....	194

LIST OF TABLES

Table 1. Whole-rock chemical analyses of select igneous rocks from the Maysville quadrangle, Colorado.....	78
Table 2. Whole-rock chemical comparison of quartz latite porphyry hybrid dike with Mount Aetna ring dikes and average andesibasalt.....	88
Table 3. Whole-rock chemical comparison of Tertiary (?) andesite hybrid dikes with average rhyolite and andesibasalt.....	107
Table 4. Compilation of Miocene-Pliocene and Quaternary volcanic ash localities in the southern part of the Upper Arkansas Valley graben and South Arkansas graben.....	172
Table 5. Summary of landslide deposit areas, by map unit in the Maysville quadrangle.....	173
Table 6. Summary of measured earthquakes within a 6-mi radius of the center of the Maysville quadrangle.....	177

Table 7. Historical (pre-instrumental) earthquakes in or near the Maysville quadrangle, according to Kirkham and Rogers (2000)..... 179

Table 8. Geochemistry of select mineralized rocks from mines and prospects in the Maysville quadrangle, Colorado..... 190

LIST OF PLATES

- Plate 1. Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado
- Plate 2. Map Components (Correlation of Map Units and 3-D Oblique View) to Accompany the Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado
- Plate 3. Map Components (Geologic Cross Sections) to Accompany the Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado

LIST OF APPENDICES

Appendix 1. Maysville quadrangle point-file database with location and structure data 220



INTRODUCTION

LOCATION AND ACCESS

The Maysville 7 ½ minute quadrangle is located in Chaffee County in the mountainous region of central Colorado. It is characterized by dramatically contrasted physiography, including the southwesternmost part of the Upper Arkansas Valley in the eastern half, and the high southern Sawatch Range in the western half (figs. 1 and 2). The small community of Maysville is situated along U.S. Highway 50, which traverses east-west across the southern part of the quadrangle. Highway 50 is the main access across the southern Sawatch Range where it crosses the Continental Divide at Monarch Pass about eight miles west-southwest of Maysville. The closest city with amenities is Poncha Springs, located about six and half miles east-southeast of Maysville. The largest towns that service the southern Upper Arkansas Valley are Salida and Buena Vista, located 10 mi east and 21 mi north-northeast, respectively, of Maysville. U.S. Highway 285 is the other major road in the region and it runs north-south approximately 2.5 mi east of, and parallel to, the eastern quadrangle boundary.

Access is variable across the quadrangle and principally consists of Chaffee County roads and U.S. Forest Service (primary, secondary and low standard) roads. Many of the current Forest Service roads are old and were privately constructed to access mine and prospect areas. Many are abandoned but are still useful for foot access to remote areas. The Denver & Rio Grande Western Railroad reached the Salida area in 1880. A narrow-gage branch line extended west along the South Arkansas River to the major mines in the Monarch and Garfield mining districts (terminated about 3 mi N-NE of Monarch Pass). This branch line has been abandoned, portions of the old grade are still apparent across the southern part of the Maysville quadrangle.

The Colorado Trail is a 469 mi trail between Denver and Durango. A portion of this well-maintained trail extends for about seven miles (roughly N35°E) across the northwest quadrant of the Maysville quadrangle. It provides access to a large portion

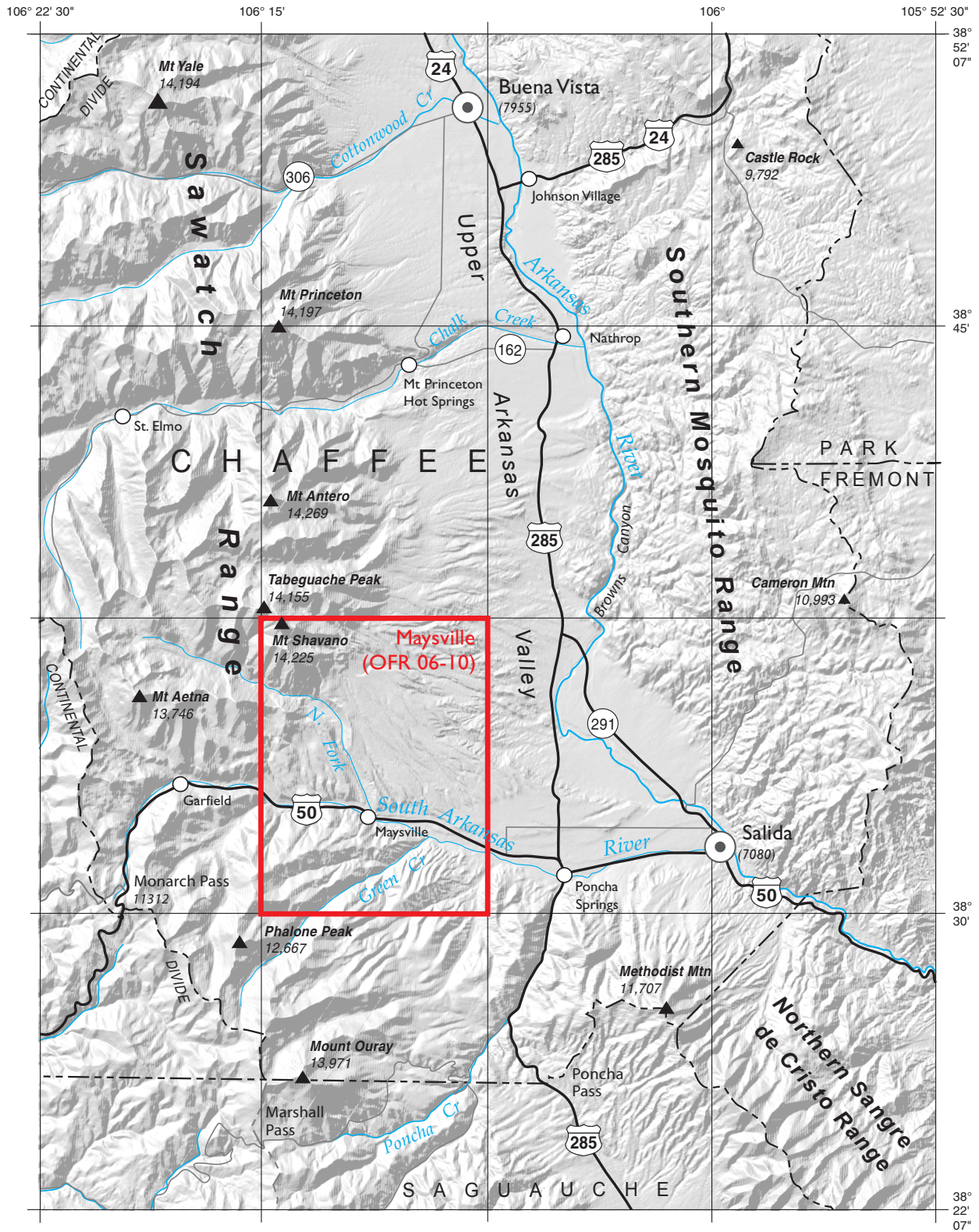


Figure 1. Shaded relief map showing the location (red) of the Maysville 7.5-minute quadrangle, Chaffee County, Colorado.

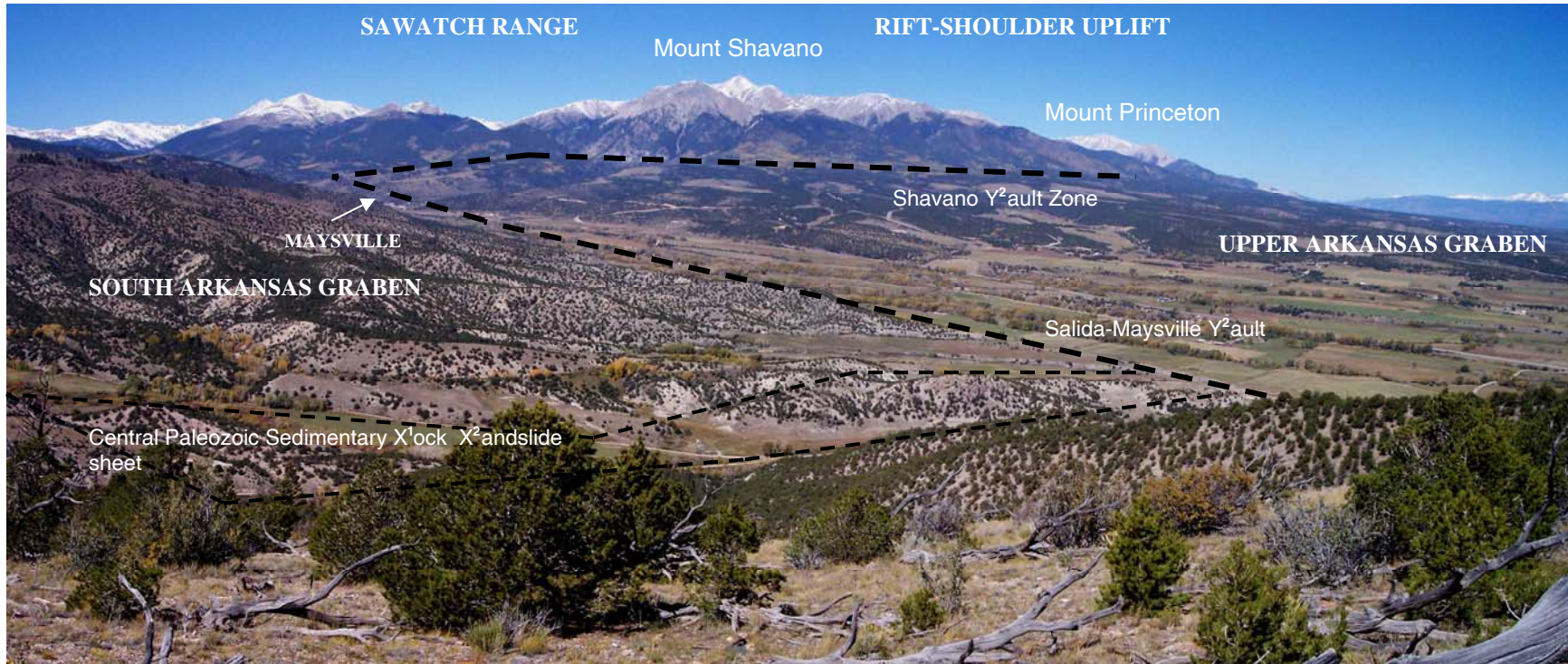


Figure 2. Overview of Maysville quadrangle showing main physiographic features and tectonic elements. View is looking northwest from near the southeast corner of the quadrangle.

of the range front area between the South Arkansas River and Sand Creek. A roughly five sq mi area, including the bulk of Mount Shavano, in the northwest corner of the quadrangle has very difficult access. Peripheral access to this area is provided by Forest Service roads (240, 252 and 255) and the Colorado Trail. The main trail access into this area is the Mount Shavano/Tabeguache Peak Trail, which uses the old trail in the south fork of Squaw Creek. This trail provided access to the mines and prospects on the patented claims on Mount Shavano and is currently maintained by the Forest Service.

The Maysville quadrangle includes several physiographic elements. Along the western part of the Maysville quadrangle is the eastern flank of the Sawatch Range (fig. 1). The northwest corner of the quadrangle consists of the rugged southern and eastern flanks of Mount Shavano. The southwest quadrant includes a series of east-northeast-trending, bold ridges and valleys related to an area of Proterozoic rocks. The northeastern and central part has low elevations and subdued topography related to the southwestern part of the southern terminus of the Upper Arkansas Valley. The northeastern margin of the quadrangle includes an area of low-lying badland topography related to the Dry Union Formation. The central part of the quadrangle is a large, gently southeast sloping area of Quaternary gravels that largely conceal the underlying Dry Union Formation. The southeastern quadrant consists of a distinctive area of grass-covered, northeast-trending sub-ridges formed in an uplifted area of the Dry Union Formation.

The maximum relief in the quadrangle is about 6,480 ft. Altitudes range from a low of 7,750 ft along the South Arkansas River in the southeastern corner to a high of 14,229 ft at the summit of Mount Shavano in the northwest corner. Tabeguache Peak (14,155 ft) occurs about 200 ft N-NW of the northwest corner of the quadrangle. Other prominent landmarks in the region include Pahlone Peak (12,667 ft) and Mount Ouray (13,971 ft), located 1.5 mi S-SW and 5.5 mi S-SE, respectively, of the southwest corner of the quadrangle. The Continental Divide is located about 3 mi SW of the southwest corner of the quadrangle.

The Arkansas River is the principal drainage for the Upper Arkansas Valley and comes as close as about 2.2 mi to the east boundary of the quadrangle (fig. 1). The southern part of the quadrangle is traversed by the South Arkansas River, the main tributary draining the southern Sawatch Range in the Monarch Pass area. The North Fork

of the South Arkansas River (subsequently referred to as the North Fork) is another main tributary that enters the South Arkansas River at Maysville. It drains a large area on the east side of the Continental Divide north of Monarch Pass. Squaw Creek is the main drainage in the north and northeast part of the quadrangle extending from north of Mount Shavano to the Arkansas River, about 2 mi east of the east quadrangle boundary.

A number of major and minor glaciated valleys are present in the western part of the quadrangle (see plate 1). They include the major glaciated drainages of the South Arkansas River, the North Fork, and Fooses Creek. The source areas for these glaciers include large areas on the east side of the Continental Divide. Minor glaciated valleys include Squaw Creek and the South Fork of Squaw Creek. The source areas for the glaciers that came down these drainages are small and almost entirely contained within the quadrangle area. Green Creek in the south part of the quadrangle drains an area of the Continental Divide between Pahlone Peak and Mount Ouray and has a small terminal moraine that extends into the southern boundary of the quadrangle.

The heavily forested east flank of the Sawatch Range covers the western half of the quadrangle. In the north half of the quadrangle, the steep forested slopes on the flank of the Sawatch Range extend across the range front area and continue onto the gently east- and southeast-dipping gravel surfaces. The upper slopes of Mount Shavano, above timberline (about 12,000 ft elevation), principally consist of steep talus slopes with some cliff outcrops. Most of the agricultural activity in the Maysville quadrangle is concentrated in Missouri Park, the low-lying area along and north of the South Arkansas River in the southeast part of the quadrangle.

Overall, bedrock exposure in the Maysville quadrangle is poor and is estimated to be less than five percent of the plane surface area. The steep slopes of the southern Sawatch Range are largely talus covered and have minor outcrop. Larger outcrops are associated with cliff exposures predominantly in the over steepened glaciated valleys of the North Fork, Squaw Creek and the south fork of Squaw Creek. In general, the best outcrops are along the main ridge and spur crests. Poor outcrop in the east part of the quadrangle is related to the predominantly unconsolidated nature of the Dry Union Formation and Quaternary gravels.

A land status summary of the area of the Maysville quadrangle is available on a

1:126,720 scale map of the San Isabel National Forest (U.S. Forest Service, 1998). A general estimated breakdown includes approximately 60 percent San Isabel National Forest land; approximately 20 percent combined Bureau of Land Management and Colorado State lands; and approximately 20 percent private land. Rapid development is occurring on private lands in the northeast quadrant of the quadrangle and along parts of the South Arkansas/Highway 50 corridor. Some of this development has resulted in restricted access to forest lands by the blocking and closure of old access roads.

During the last 40 to 50 years the region has experienced a major transition from the largely resource-based agriculture and mining economies to one of recreation and tourism. In spite of the seasonal nature, whitewater rafting on the Upper Arkansas River has become the premier industry in the region. Growth and development and future water resources are critical issues of the region.

GEOLOGIC AND TECTONIC SETTING

The Maysville quadrangle is located in a geologically diverse and tectonically complex region (figs. 3 and 4) that has experienced multiple deformation and magmatic events from the Proterozoic to recent times. The quadrangle is at or close to the intersection of four major tectonic and tectono-stratigraphic features of regional significance: (1) the Late Paleozoic Central Colorado trough (DeVoto, 1972); (2) the Late Cretaceous to early Tertiary Laramide Sawatch uplift (Tweto, 1975 and 1980c); (3) the Laramide to late Tertiary Colorado mineral belt (Tweto and Sims, 1963; Simmons and Hedge, 1978; Cunningham and others, 1994); and (4) the late Cenozoic Rio Grande rift (Chapin, 1971; Knepper, 1976; Tweto, 1979a; and Chapin and Cather, 1994) (fig.2). In addition, the site is also located in a structurally complex and dynamic zone associated with the transverse-structural zone that separates the Upper Arkansas Valley graben from the San Luis Valley graben (fig 5). The following summary of the tectonic and magmatic history of central Colorado provides a detailed geologic framework in which the geology of the Maysville quadrangle can be related and interpreted. Readers mainly interested

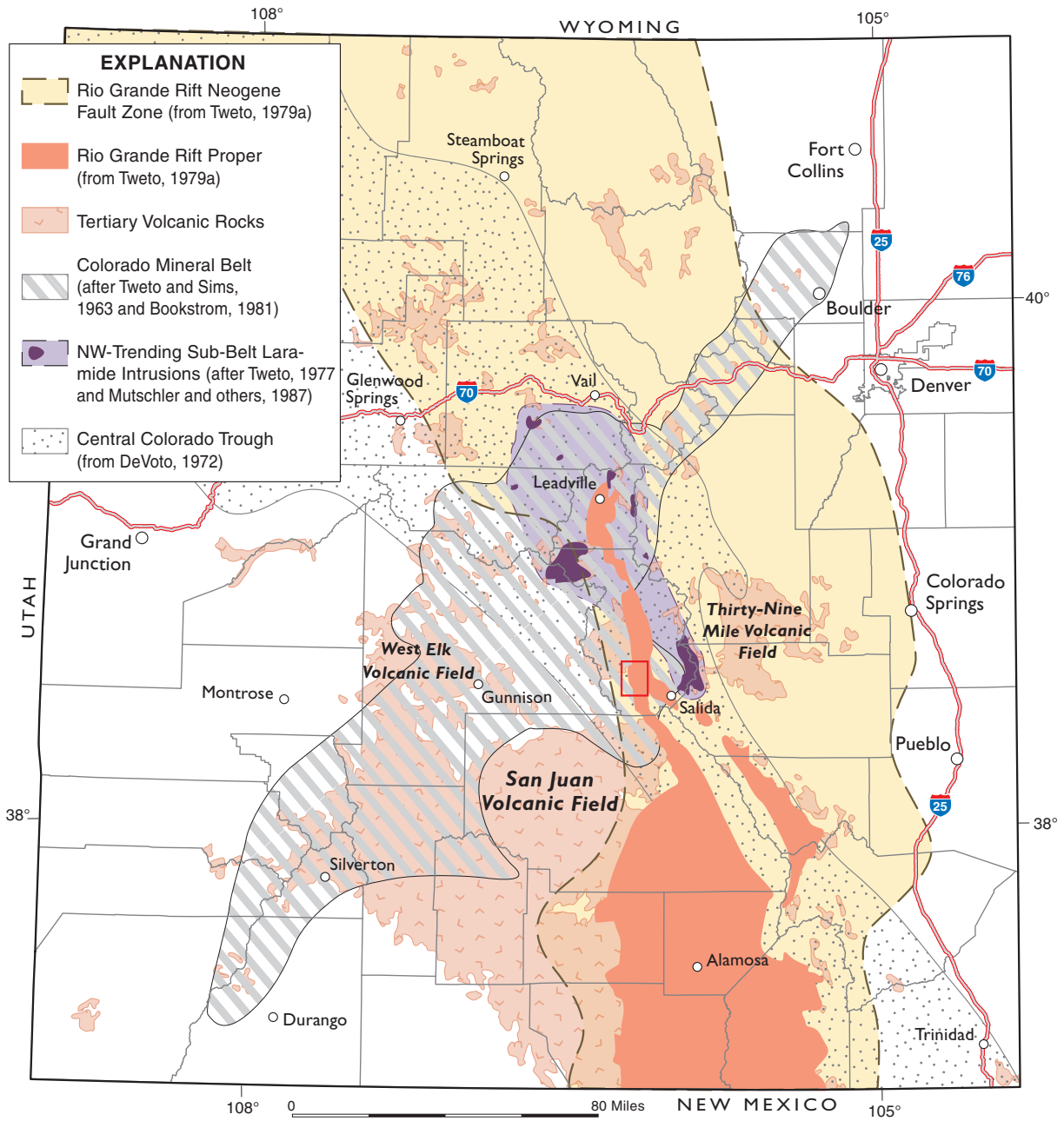


Figure 3. Location of the Maysville quadrangle (red rectangle) in relation to major regional tectonic and geologic elements in western Colorado.

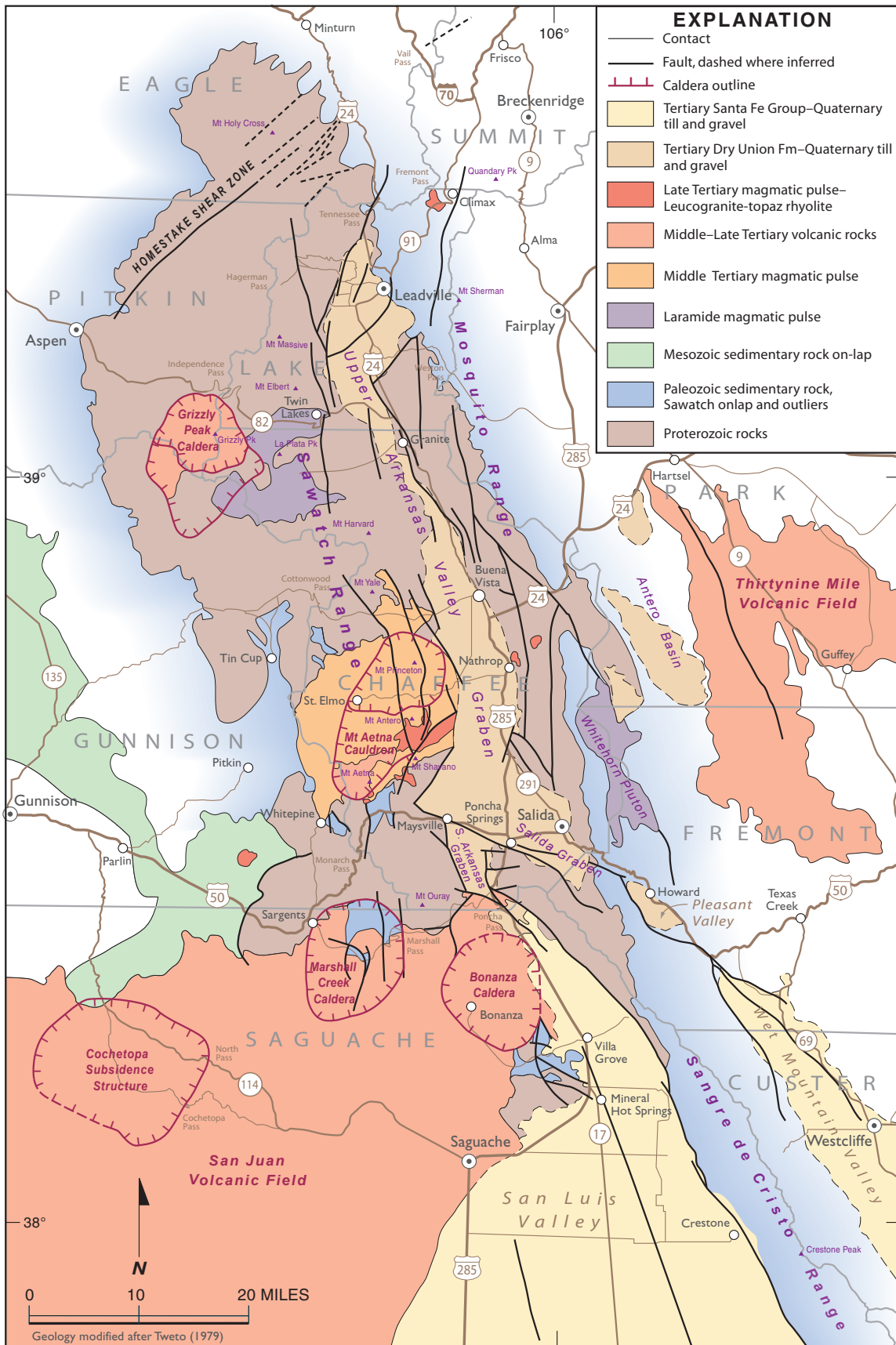


Figure 4. Regional geologic-tectonic setting of the Upper Arkansas Valley graben segment of the Rio Grande rift, central Colorado. Base geology from Tweto (1979b); modified from sources discussed in text.

in descriptions of the geologic units of the Maysville quadrangle may wish to skip to the Description of Map Units section.

The rocks in the Maysville quadrangle range in age from Early Proterozoic to recent and include high-grade metamorphic rocks, a wide variety of intrusive rocks, sedimentary rocks, and unconsolidated surficial deposits. The central Colorado area was subjected to at least three major, separate orogenic events: (1) Early Proterozoic orogeny at about 1.7 Ga (Tweto, 1980a and 1980b; Reed and others, 1987); (2) Mississippian-Pennsylvanian (Ancestral Rocky Mountain) orogeny (DeVoto, 1972; Tweto, 1980a; Kluth and Coney, 1981); and (3) Laramide orogeny (Tweto and Sims, 1963; Tweto, 1975, 1980a and 1980c). During Late Cenozoic time the region experienced complex crustal extension and broad regional epirogenic uplift associated with development of the Rio Grande rift (Knepper, 1976; Eaton, 1979 and Tweto, 1979a and 1980a).

Precambrian rocks in the Maysville quadrangle include a complex sequence of regionally metamorphosed volcanic, sedimentary, and igneous rocks that belong to the 1,800 Ma Proterozoic Layered Gneiss Complex (Tweto, 1980b and 1987). The metamorphism of the gneisses peaked at about 1,740 m.y. ago. The late Early Proterozoic gneisses in the Maysville quadrangle are dominated by felsic and hornblendic gneisses, including abundant amphibolites that were metamorphosed to the upper amphibolite facies. They are part of an east-west trending belt of similar age supracrustal rocks that extends from southwest of Gunnison to east of Salida (Bickford and Boardman, 1984). U-Pb zircon age determinations and petrologic character support that these supracrustal and associated intrusive rocks are part of a 310 mi wide belt of rocks that were accreted to the southern edge of the Archean craton during the Early Proterozoic between 1790 and 1660 Ma (Reed and others, 1987).

Largely on the basis of observations in the Front Range, Tweto (1980b) described at least three periods of Precambrian folding that affected the gneisses. The Proterozoic gneisses were metamorphosed and folded during an early period of deformation followed by a second period of folding (Early Proterozoic orogeny) that was associated with regional intrusions associated with the 1,700 Ma Routt Plutonic Suite (Tweto, 1987). Tweto (1987) summarized the predominantly granodiorite to quartz monzonite intrusions of the late Early Proterozoic Routt Plutonic Suite as generally concordant and foliated,

and they are classified as catazonal and synorogenic.

Four major systems of Proterozoic faults and shear zones (NE-trending, NNW-trending, WNW-trending, and E-trending) are recognized in Colorado (Tweto, 1980a and 1980b). Recurrent movements on many major faults and shear zones occurred during the Proterozoic and at various times during the Phanerozoic (Tweto, 1977 and 1980a). The NE-trending shear zones started forming during the folding and metamorphism of the gneiss complex (Tweto, 1987). However, they were active principally during and following intrusion of the second major Proterozoic magmatic event, 1,400 Ma Berthoud Plutonic Suite, and produced the third generation of folding in the gneissic rocks (Tweto, 1980a). The Berthoud Plutonic Suite consists of quartz monzonite to granite intrusions that are generally discordant and non-foliated to weakly foliated and are classified as mesozonal and anorogenic (Tweto, 1987). Evidence for intrusive activity related to the third major Precambrian igneous event (late Middle Proterozoic), the 1,000 Ma Pikes Peak Batholith (Tweto, 1987), is more restricted to the Front Range and is lacking in the Maysville quadrangle and the surrounding region.

The predominant north-northwest-trending Proterozoic fault system, with indications of both pre-1,700 m.y. and post 1,400 m.y. movements, is responsible for the strong north-northwest geologic and structural grain of the Colorado mountain province (Tweto, 1980a). In his detailed review of the tectonic history of west-central Colorado, Tweto (1977) stressed the long history of recurrent movements on the north-northwest-trending faults. Tweto (1977, p. 13) specifically stated that “the north-northwest trend of faults of the Arkansas Valley graben suggests inheritance from Precambrian faults, though evidence of Precambrian origin of the faults is thus far lacking”.

The third major system of west-northwest-trending Precambrian faults extends across most of southern Colorado (Tweto, 1980b). An east segment crosses the Wet Mountains and the northern Sangre de Cristo Range near Salida and a west segment occurs in the Gunnison River region. The fourth major system of east-trending Precambrian faults is predominantly present in the northern Front Range (as well as the western San Juan Mountain region and the White River Plateau) and parallels major lithic contacts in the basement and a linear fabric on regional gravity and magnetic maps (Tweto, 1980a, 1980b and 1987).

During the Early and Middle Paleozoic, central Colorado was located in an east-west-trending trough or structural low (the Colorado Sag) in the northeast-trending Trans-Continental Arch. The trough area received intermittent shallow marine sedimentation which was periodically interrupted by epirogenic uplift and erosion resulting in numerous unconformities between the various Lower and Middle Paleozoic formations (Tweto, 1980a). Knepper (1974) documented evidence for at least five major episodes of epirogenic uplift and suggested as many as nine may be present. On the basis of his regional geology compilation and tectonic analysis study, Knepper (1974; p.50) stated that no folds or faults of early or middle Paleozoic age have been identified in the region.

The Mississippian-Pennsylvanian (Ancestral Rocky Mountains) orogeny was characterized by development of three major, in part fault-bounded uplifts: the Front Range, Uncompahgre-San Luis, and Apishapa Highlands (Tweto, 1980a). The northwest-trending highlands were separated by a structural trough, the northwest-trending Central Colorado trough which cut diagonally across the west-central part of Colorado (DeVeto, 1972) and includes the area of the Maysville quadrangle (fig. 3). The similar paleo-sedimentation patterns for Upper Cambrian through Permian sedimentary rocks suggest that the late Paleozoic orogenic highlands and the intervening Central Colorado trough were modifications and enhancements of the early and middle Paleozoic epirogenic positive areas and the intervening Colorado Sag. Tweto (1980a) characterized the late Paleozoic highlands as asymmetric, having steep fault-bounded margins on one side and moderate up warping on the other.

A long standing controversy in Colorado geology involves the nature and timing of the Sawatch Uplift and whether or not a positive highland existed intermittently in this area during the early to middle Paleozoic and especially during the late Paleozoic orogeny. Early workers showed the area of the Laramide Sawatch uplift with the various Paleozoic formations lapping the eastern and western margins, thus indicating uncertainty in their paleo-continuity (Litsey, 1958). In contrast, some later workers proposed that an Ancestral Sawatch uplift existed in the present area of the Sawatch Range and that it divided the Central Colorado trough into two depositional sub-basins (DeVeto, 1972). Tweto (1980a) did not support the view of an Ancestral Sawatch uplift and specifically

states that the Sawatch is one of a few major uplifts that lack a pre-Laramide expression (Tweto, 1980a, p.8). On the basis of sedimentological features and stratigraphic relationships of the Belden and Minturn Formations, De Voto (1990), stated “the ancestral Sawatch element, which was moderately uplifted in Late Mississippian time, underwent vigorous tectonic uplift during the Early Pennsylvanian” and “the ancestral Sawatch Uplift was still topographic high undergoing erosion during the Middle Pennsylvanian.”

De Voto (1990) stated that central Colorado was broken into a mosaic of fault blocks during the Late Paleozoic orogeny. The Late Paleozoic faults in central Colorado have a dominant north-northwest to northwest trend and a less common northeast trend. However, no Late Paleozoic faults are shown in the area of the Upper Arkansas Valley graben or in the adjacent southern Sawatch Range and Southern Mosquito Range. Knepper (1974), on the basis of his regional analysis, found that structures associated with Ancestral Rocky Mountain orogeny are difficult to identify in central Colorado because the same area and same rocks were complexly folded and faulted during the Laramide orogeny and had later superimposed complex faulting associated with development of the Rio Grande rift. However, he did recognize faults and folds of late Paleozoic age and suggested that a number of the major Late Paleozoic faults had recurrent movement during the Laramide orogeny and evolution of the Rio Grande rift.

The Laramide orogeny represents a major orogenic event that effected Colorado in very late Campanian time (about 72 Ma) to middle or late Eocene (Tweto, 1980c). Tweto (1975) summarized the tectonic conditions leading up to and during the Laramide orogeny. Laramide uplift began in the southwest part of the southern Rocky Mountain region before marine deposition had ended in the northeastern part, and retreat of the last Cretaceous sea was concurrent with the general northeastward advance of the Laramide orogenic front (Tweto, 1975). The majority of Laramide uplifts were rejuvenated from the sites of the late-Paleozoic orogenic uplifts (Tweto, 1975 and 1980c). The Front Range, Park and Gore Ranges, and Wet Mountains are Laramide uplifts at the site of the earlier Front Range highland; the San Luis, Gunnison, and Uncompahgre Laramide uplifts are in the general area of the earlier San Luis highland. In contrast, a northwest-trending zone of Laramide uplifts including the Sangre de Cristo, Sawatch-Mosquito, Elk

Mountains, and White River uplifts formed in the area of the earlier trough between the old Front Range and Uncompahgre-San Luis highlands (Tweto, 1980c).

Significant magmatism was initiated during the Laramide orogeny and has continued through the Tertiary and Quaternary. Most of this Cenozoic magmatism and associated ore deposits are focused on the northeast-trending Colorado mineral belt (fig. 3). The belt consists of numerous intrusive porphyries and associated ore deposits initially thought to be predominantly Laramide in age, about 72 to 45 or 40 m.y. (Tweto and Sims, 1963). By about 1975, mappers found that the Colorado mineral belt magmatism was more complicated and included two distinct episodes of igneous activity, a Laramide episode between 70 to 55 m.y. and an Oligocene episode between 39 to 26 m.y. (Steven, 1975), or at least three interspersed populations of intrusions and ore deposits (Tweto, 1975). Three separate interpretations of the age spans of the three magmatic populations are in close agreement: the Laramide magmatic pulse from 70 to 50 m.y. (Tweto, 1975 and Cunningham and others, 1994) and 75 to 42 m.y. (Mutschler and others, 1987); the Middle Tertiary magmatic pulse from 40 to 25 m.y. (Tweto, 1975), 40 to 26 m.y. (Mutschler and others, 1987), and 45 to 25 m.y. (Cunningham and others, 1994); and the Late Tertiary magmatic pulse from 15 to 10 m.y. (Tweto, 1975), 15 to 4 m.y. (Cunningham and others, 1994), and 25 to 0 m.y. (Mutschler and others, 1987).

The record of volcanism associated with the Laramide magmatic pulse is chiefly in thick sequences of andesitic sediments preserved in the sedimentary basins flanking the Laramide uplifts (Tweto, 1975). The volcanic sediments and associated flows lie in a broad northeast-trending belt that generally flanks the Colorado mineral belt, and contemporaneous Laramide-aged intrusions in the form of stocks, sills and dikes are concentrated in a narrower belt within the broad volcanic belt (Tweto, 1975). The Laramide intrusions are focused along the northeast-trending Colorado mineral belt but also occur in a northwest-trending, transverse sub-belt (fig. 3) that crosses the area of the northern Sawatch Range (Tweto, 1977; Cunningham and others, 1994). This transverse sub-belt includes (from NW to SE) the about 62 Ma Fulford stock, the about 59.5 Ma East Lake Creek stock, the about 61.8 Ma West Cross Creek stock, the about 66.4 Ma West Tennessee Creek stock, and the about 70.0 Ma (McDowell, 1971; and Wrucke, 1974) Whitehorn granodiorite intrusion (Cunningham and others, 1994). The Twin Lakes

pluton in the northern Sawatch Range, a large Laramide intrusion with an indicated age of 63.8 +/- 1.4 Ma (Fridrich and others, 1998), is located just west of the northwest-trending sub-belt axis. If the Twin Lakes pluton is part of this sub-belt, then it together with the Whitehorn pluton represents the two largest exposed Laramide intrusions in Colorado. Their emplacement may have been influenced by northwest-trending structures along the about 85 mi long sub-belt. Tweto (1977) stated that the northwest-trending sub-belt of intrusions is paralleled by scattered but fairly persistent faults and associated porphyry dikes that reflect a major flaw in the deep basement.

The late Eocene surface is a widespread erosion surface of general low relief that developed on Precambrian rocks during an about 10 m.y. period of tectonic and magmatic quiescence (Epis and Chapin, 1975; Scott, 1975; Epis and others, 1980). The age of the late Eocene surface is bracketed by the ages of the oldest deposits resting on it (the Wall Mountain Tuff, about 36 to 37 Ma) and the youngest deposits beneath it (Denver Formation, South Park Formation, Dawson Formation, and Echo Park Alluvium). This bracketing suggests a late Eocene and possibly very earliest Oligocene time for initiation of this surface (Epis and Chapin, 1975). Shannon (1988) suggested that preservation of younger ash flow tuffs (Badger Creek Tuff and tuff of Tomichi Creek) on beveled Precambrian surfaces in the Sawatch Range indicates that the late Eocene erosion surface persisted as a modified erosion surface until at least 34 Ma and possibly until about 30 Ma when the surface was initially disrupted by Rio Grande rift extension.

The Middle Tertiary magmatic pulse produced the greatest volume of Cenozoic igneous rocks in Colorado and this magmatism was more widespread than the earlier Laramide magmatic pulse (Mutschler and others, 1987; and Cunningham and others, 1994). By about 40 Ma, large composite batholiths were emplaced beneath eroded Laramide uplifts in the Sawatch Range and San Juan Mountains (Steven, 1975). The Middle Tertiary magmatic pulse is also characterized by abundant volcanic rocks that are remnants of a widespread volcanic field that covered much of the Southern Rocky Mountains (Steven and Epis, 1968; Steven, 1975; McIntosh and Chapin, 2004). The composite volcanic field formed about 40 to 20 m.y. ago on the modified regional, late Eocene erosion surface. The volcanic rocks of the San Juan Mountains, West Elk Mountains, and the Central Colorado (previously referred to as Thirtynine Mile) volcanic

field are the largest remnants of the middle Tertiary volcanic field (fig. 3; Steven, 1975).

The Central Colorado volcanic field covers approximately 1,500 sq mi and is one of the larger remnants of the Southern Rocky Mountains middle Tertiary volcanic field (Steven and Epis, 1968; Steven, 1975; McIntosh and Chapin, 2004). The center of the Central Colorado volcanic field is approximately 40 mi east-northeast of Maysville (fig. 3). From about 37 to 28 Ma, the Central Colorado volcanic field was developed upon the late Eocene erosion surface (Epis and Chapin, 1974). The largely andesitic volcanic field represents the remnants of concurrently erupted volcanic units from two sources: (1) dominantly andesitic volcanic rocks derived from within the present area of the field (for example, Guffy center and Buffalo Peaks center) and (2) dominantly silicic ash-flow tuffs erupted from outside the field (Epis and Chapin, 1974). Five ash flow sheets have been identified: the Wall Mountain, Badger Creek, East Gulch, Thorn Ranch and Gribbles Park tuffs (Epis and Chapin, 1968 and 1974). No caldera sources have been identified on the east side of the Upper Arkansas Valley graben, and thus the sources of all the tuff units were suggested to be west of their present outcrop areas (Epis and Chapin, 1974).

During the earliest phase of the Middle Tertiary magmatic pulse, a linear zone of caldera and cauldron subsidence structures was initiated along the crest of the Laramide Sawatch uplift (fig. 4). The calderas and cauldrons include the 36 Ma Bonanza caldera (Varga and Smith, 1984), the 34.4 Ma Mount Aetna cauldron (Shannon and others, 1987a; and Shannon, 1988), and the 34 Ma Grizzly Peak cauldron (Fridrich and Mahood, 1984; and Fridrich, 1986). A potential fourth eroded caldera is postulated to be related to the 36.6 Ma Mount Princeton pluton (Shannon, 1988). More recent work based on $^{40}\text{Ar}/^{39}\text{Ar}$ dating has refined the ages for these caldera-forming events and recognized additional outflow tuffs and caldera sources (McIntosh and Chapin, 2004). The 37.5 Ma tuff of Triad Ridge is a newly recognized ash-flow tuff in the Trout Creek paleovalley, and the proposed 33.7 Ma Marshall Creek caldera occurs about five miles west-northwest of the Bonanza caldera (fig. 4). The new age determinations indicate the Sawatch Range calderas and the remnants of intracaldera and outflow tuffs have a 4.6 m.y. age span from 37.5 to 32.9 Ma.

Important elements (ring dikes, andesitic and quartz latitic volcanic rocks, and volcanic breccias) of a deeply eroded volcanic structure in the Southern Sawatch Range

were first documented on the geology map of the Monarch and Tomichi districts (Crawford, 1913). The detailed geological study of the Garfield 15' quadrangle (Dings and Robinson, 1957) shows the main elements of a large volcano-plutonic subsidence structure now referred to as the Mount Aetna cauldron (Shannon and Epis, 1987). Toulmin (1963) first suggested the presence of a volcanic subsidence structure near Mount Aetna. Toulmin (1975 and 1976) and Toulmin and Hammarstrom (1990) recognized megabreccias preserved in the collapse structure and proposed an earlier 3.1 to 3.7 mi diameter caldera in the south, followed by a larger 6.2 to 9.3 mi long trap-door type of collapse structure that was hinged on the north. Shannon (1988) delineated a nearly complete 8 by 16 mi elliptical main ring zone and a smaller 7 mi diameter nested collapse structure in the north (fig. 5). Shannon and Epis (1987) suggested a genetic correlation between the Mount Aetna cauldron and the outflow Badger Creek Tuff of the Central Colorado volcanic field. This correlation is based on spatial relations between the remnants of outflow Badger Creek Tuff and the Mount Aetna cauldron, similar ages, and similarities in the mineralogy and chemical composition of the intracauldron and outflow tuffs (Shannon and others, 1987a).

The Mount Aetna cauldron is located completely within the area of the older Mount Princeton pluton (fig. 5; Shannon, 1988). Crawford (1913) first applied the name Princeton Quartz Monzonite to the granitic rocks at the type locality on Mount Princeton. He also was the first to refer to the intrusion as a batholith. Stark and Barnes (1935) renamed the lithology Mount Princeton quartz monzonite and this usage has been adopted by subsequent workers (Dings and Robinson, 1957). Buddington (1959) cited the Mount Princeton batholith as an example of an epizonal pluton. Shannon (1988) interpreted the bulk of the Mount Princeton intrusion as the result of emplacement and crystallization of a single large magma body. The Mount Princeton intrusion is the largest exposed Cenozoic intrusion in Colorado. Although the intrusion is large enough (approximately 450 square miles) to be called a batholith (Best, 1982), the lack of a multiple intrusive, composite nature suggests the term pluton is more appropriate (Shannon, 1988).

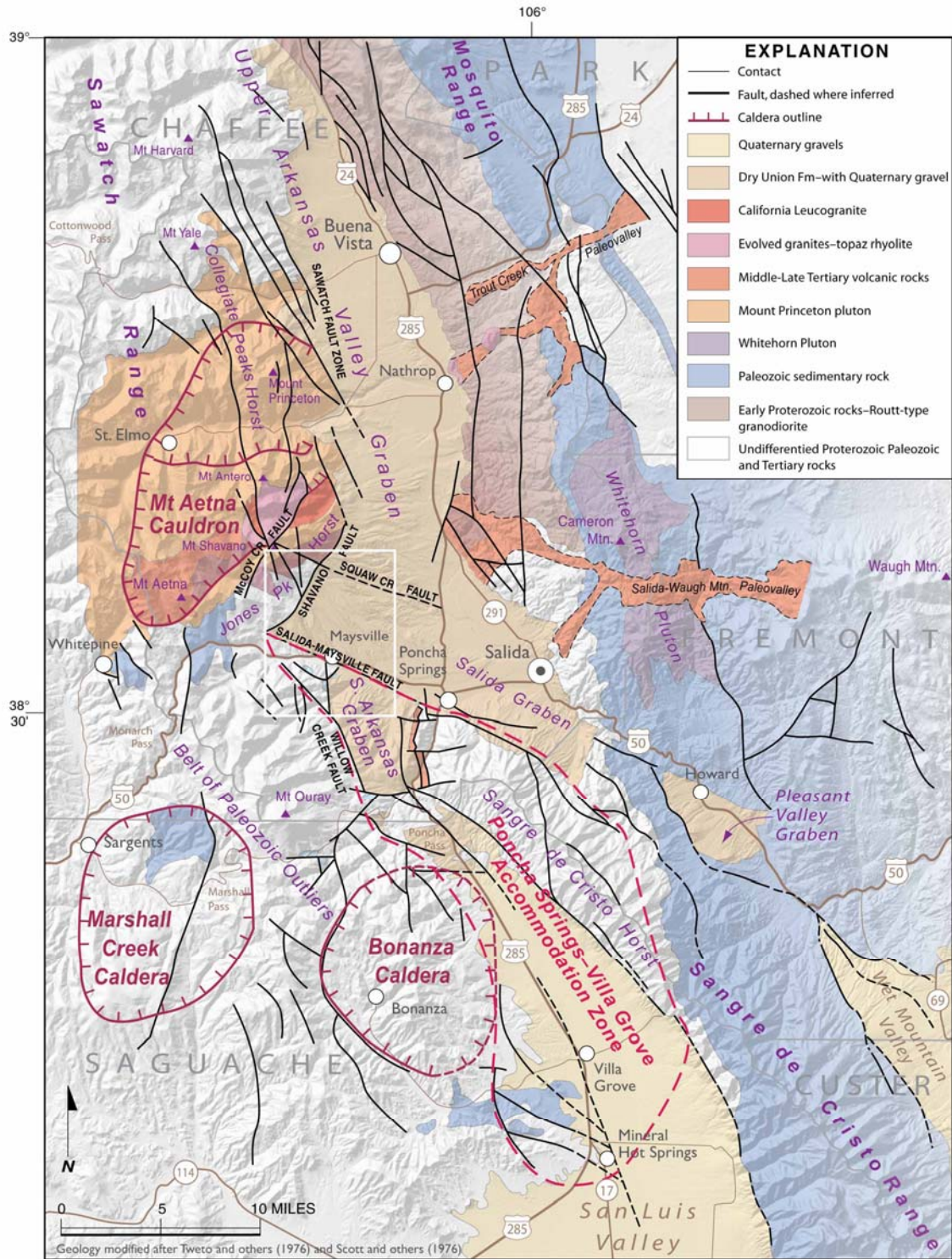


Figure 5. Detailed geologic-structural-tectonic setting of the southern Upper Arkansas Valley graben segment of the Rio Grande rift, central Colorado. Base geology from Tweto and others (1976) and Scott and others (1975); modified from sources discussed in text.

The Wall Mountain Tuff is the most widely distributed Tertiary ash flow unit of the Central Colorado volcanic field and was considered to be the oldest ash flow unit (Epis and Chapin, 1974). Chapin and Lowell (1979) suggested that the Wall Mountain ignimbrite traveled at least 87 mi, and remnants of the tuff indicate the sheet covered at least 6,460 sq mi. On the basis of a compilation of Wall Mountain Tuff occurrences (Tweto, 1979b), the distribution pattern of the Wall Mountain Tuff is a northeast-trending zone that is 87 mi long and up to 50 mi wide and that extends from the southern Upper Arkansas Valley, across the Front Range Uplift, to the Castle Rock area. The distribution pattern generally points back to the area between the Mount Aetna cauldron and the Bonanza caldera. Shannon (1988) suggested a preliminary correlation between the Wall Mountain Tuff and a postulated caldera structure that was associated with the Mount Princeton pluton. This tentative correlation was based on the spatial relation of the Wall Mountain Tuff and the Mount Princeton pluton, on the similarity of preliminary published and unpublished age determinations on the two units (average age 36.6 Ma), and suggested mineralogical and chemical links between the Wall Mountain Tuff and the heterogeneous roof zone of the Mount Princeton pluton. New observations at Cochetopa dome (volcanic subsidence structure) indicates the presence of Wall Mountain tuff, indicating that some of the ignimbrite flows traveled west-southwest off the Sawatch uplift and into the northern part of the San Juan volcanic field (Lipman, 2004, pers. com.; Lipman, 2007).

Most summaries of the Cenozoic magmatic history of Colorado indicate the end of the Middle Tertiary magmatic pulse at 25 to 26 m.y. (Tweto, 1975; Mutschler and others, 1987; and Cunningham and others, 1994). However, the beginning of the Late Tertiary magmatic pulse is variously interpreted to be 25 Ma (Mutschler and others, 1987) or 15 Ma (Tweto, 1975; Cunningham and others, 1994), suggesting a 1 to 10 m.y. gap between the two magmatic pulses. At about 25 to 30 m.y. ago the calc-alkaline magmatism peaked and the composition of the magmatism shifted to more silicic compositions as Rio Grande rift faulting began (Lipman, 1981).

The highly chemically evolved Climax-type porphyry-molybdenum systems formed between 33 and 25 m.y. ago in the area of the intersection of the Rio Grande rift

with the Colorado mineral belt (Bookstrom, 1981). The Climax-type systems are characterized by a bimodal rhyolite and minor lamprophyre association and were emplaced during a relatively atectonic period that preceded the basalt-dominant, bimodal basalt-rhyolite magmatism associated with the Rio Grande rift (Bookstrom and others, 1988). Thus, bimodal leucogranite-lamprophyre suites of Climax-type systems are part of Lipman's (1982) transitional volcano-tectonic assemblage that is associated with northwest-southeast-trending extensional faulting that preceded the dominantly basaltic, bimodal suites associated with north-south-trending extensional faults that were initiated about 20 m.y. ago.

The Late Tertiary magmatic pulse began about 25 to 20 m.y. ago and includes bimodal basalt-rhyolite magmatism that is temporally and spatially associated with the Rio Grande rift (Lipman, 1982; Mutschler and others, 1987). Mutschler and others (1987) stressed that the magmatism was concentrated in areas of active uplifts, along the axes of which rift basins developed. The Late Tertiary magmatic pulse includes high-silica rhyolite-granite systems that include the Mount Emmons, Colorado (about 17 Ma), and Questa, New Mexico, porphyry molybdenum deposits (about 24 Ma, Czamanske and others, 1990) and a number of Climax-like systems in Colorado (for example, the about 5.0 Ma Rico porphyry Mo deposit; Naeser and others, 1980 and Larson, 1987). The Mount Antero leucogranite intrusions, including the North Fork leucogranite intrusion in the Maysville quadrangle have Climax-like characteristics (Shannon, 1988).

The Rio Grande rift is mainly characterized by a north-northwest-trending zone of extension marked by a linear chain of half-graben, sedimentary basins between the Colorado Plateau on the west and the High Plains on the east (Chapin, 1971; Chapin and Cather, 1994). For a distance of about 340 mi, from near Socorro, New Mexico, to the vicinity of Leadville, Colorado, four main axial basins are arranged in a right-stepping en echelon pattern (Chapin and Cather, 1994). From south to north, the basins include the Albuquerque, Espanola, San Luis, and Upper Arkansas basins. The basins range from 50 to 150 mi in length, from 3 to 60 mi in width, and contain basin fill deposits up to 3 to 3.5 mi in thickness (Chapin and Cather, 1994). The axial basins are asymmetric half grabens, hinged down on one side with major fault boundaries on the opposing side. The sense of asymmetry shifts from basin to basin and in places within a basin. The transverse

boundaries between the basin segments are complex structural zones referred to as transfer faults (Gibbs, 1984) or accommodation zones (Bosworth and others, 1986). Tweto (1979a) estimated that subsidence of the Upper Arkansas Valley graben post-dated 29 Ma Oligocene volcanic rocks but may have pre-dated 28 Ma.

Chapin and Cather (1994) suggested that the Rio Grande rift is subdivided by a series of northeast-trending accommodation zones that developed along pre-existing transverse structural lineaments related to late Cenozoic clockwise rotation of the Colorado Plateau. The main accommodation zones include the Socorro, the Embudo, and the Tijeras accommodation zones. Two less understood accommodation zones include the Santa Ana accommodation zone, which separates the northern Albuquerque and Espanola basins in the central part of the rift, and the Villa Grove accommodation zone, which separates the San Luis and Upper Arkansas basins in the northern part of the rift (Chapin and Cather, 1994).

The distribution of preserved Miocene-Pliocene sedimentary rocks indicates a very complex pattern associated with the Upper Arkansas Valley and San Luis Valley segments of the rift (figs. 4 and 5). The upper portion of the valley fill in the Wet Mountain Valley, on the east side of the Sangre de Cristo Range, includes up to 1,000 ft of Miocene-Pliocene sediments and suggests that this basin is an eastern sub-basin of the San Luis Valley segment of the rift (Scott and Taylor, 1975 and Taylor, 1975). However, it is not clear if these basins were connected at one time and were divided by later uplift and tilting of the Sangre de Cristo Range (Taylor, 1975 and Lindsey and others, 1983). The Pleasant Valley graben is a small northwest-trending sub-basin between the Upper Arkansas Valley and Wet Mountain Valley basins; this sub-basin also contains Miocene-Pliocene (rift?) fill.

The Upper Arkansas Valley graben extends north for about 64 miles from the Salida area to just west of Leadville (fig. 4). It has an overall trend of N24°W, is up to 14 mi wide in the Salida-Maysville area, and tapers to as little as about 5 mi wide in the Leadville area. The structures that bound the west side of the Upper Arkansas Valley graben are not well exposed. The bounding structures are a complex series of right-stepping, en echelon faults that define the range front along the north-northwest-trending segment of the rift from Browns Creek to Pine Creek (Miller, 1999; McCalpin and

Shannon, 2005). Widmann and others (1998) reviewed the nomenclature for the Quaternary faults along the west side of the Upper Arkansas Valley graben. This zone of faults has been referred to as the Sawatch fault (Witkind, 1976; Kirkham and Rogers, 1981; and Ostenaar and others, 1981) and has been described as a segmented fault (Lettis and others, 1996; and Unruh and others, 1992) or a sectioned fault (Widmann and others, 1998). The Sawatch fault has been divided into northern and southern sections with the dividing line in the Twin Lakes area; the fault consists of more than 16 generally north-trending faults (Widmann and others, 1998). Thus, the zone of north-northwest-trending faults along the range front is informally referred to as the Sawatch fault zone (fig. 5; McCalpin and Shannon, 2005).

The orientation of the Sawatch fault zone changes to a N35°E orientation southeast of Mount Antero and produces a western flare in the south end of the Upper Arkansas Valley graben (figs. 4 and 5). This northeast-trending structural zone along the southeast flank of Mount Shavano has previously been included in the southern section of the Sawatch fault (Widmann and others, 1998). Observations presented in this report (see Structural Geology section) suggest that this northeast-trending structure is related to a northeast-trending horst block in the Sawatch Range rift-shoulder uplift. Consequently, we herein informally refer to this northeast-trending segment of the range-front fault zone as the Shavano fault zone.

The southern end of the Upper Arkansas Valley graben is a structurally complex area that Knepper (1974 and 1976) characterized as a “zone of intersecting structural trends” related to the intersection of faults related to the Upper Arkansas Valley graben with the faults related to the Sangre de Cristo horst and the San Luis Valley graben. He proposed that the early rift faulting was oriented north-south and progressively opened a north-south-trending Upper Arkansas Valley graben that was physically separate from the San Luis Valley graben. A later stage of rift faulting with northwest trend was then superimposed on the southern end of the Upper Arkansas Valley graben associated with uplift of the Sangre de Cristo horst block. The northwest-trending faulting has been suggested to be related to Neogene and Quaternary faulting, much of it after 5 to 7 m.y. ago (Taylor, 1975; Tweto, 1979a).

Van Alstine (1968) first recognized a structural trough, on the south side of the

South Arkansas River near Poncha Springs, that contains volcanic rocks and late Tertiary sedimentary rocks. He suggested the Tertiary trough forms a structural connection between the Upper Arkansas Valley and the San Luis Valley segments of the Rio Grande depression (rift). The sedimentary rocks in the trough were suggested to be Pliocene in age and related to the Dry Union Formation in the Leadville area. Van Alstine (1970) later referred to the late Tertiary structural trough as the San Luis-Upper Arkansas graben, discussed the major western bounding fault of the trough, and suggested that westward tilting of the graben sediments is possibly related to late Pliocene uplift of the Sangre de Cristo Range. He suggested that if the moderate westward dip of the Dry Union sediments in the graben persisted to the western fault boundary they might be more than 10,000 ft thick.

Knepper (1974 and 1976) included the San Luis-Upper Arkansas graben of Van Alstine (1970) in the area of his “zone of intersecting structural trends” and renamed it the South Arkansas tilted block. We informally refer to this small graben or half graben on the south side of the South Arkansas River as the South Arkansas graben in the remainder of this report (figs. 4 and 5). Knepper (1976) also showed the presence of a sub-graben feature, the Salida graben, in the eastern part of the southern Upper Arkansas Valley graben in the Salida area (fig 5). The Salida graben trends about N65°W and is about 10 mi long and 4-6 mi wide. Knepper (1974 and 1976) also showed the northwest-trending Pleasant Valley graben parallel to and southeast of the Salida graben. The two grabens are linked by a set of northwest-trending normal faults that defines their northeastern margins.

Numerous workers have remarked on the major north-northwest-trending lineament (almost north-south on the north end in the Maysville quadrangle) associated with the fault bounding the west side of the South Arkansas graben (Van Alstine, 1968; Knepper, 1976; Dippold, 1999). This north-south fault was referred to as the Willow Creek transfer fault by Dippold (1999). Since this fault zone generally parallels the overall trend of the Upper Arkansas Valley graben and does not meet the requirements of a cross fault or transverse rift structure it cannot be a transfer fault as defined by Gibbs (1984). Thus, we informally refer to this structure as the Willow Creek fault (fig. 5).

The west-northwest-trending fault that separates the South Arkansas graben from

the Upper Arkansas graben (fig. 5) was named the Salida-Maysville fault by Perry (1971). This fault extends to the east-southeast off the east edge of the Maysville quadrangle and merges with a set of faults that define the boundary between the Salida graben and the Sangre de Cristo horst. Knepper (1976) estimated a minimum of 2,000 to 3,000 ft of offset across this structural boundary.

The syn-rift sedimentary and volcanic deposits preserved in the axial basins of the Rio Grande rift are recommended to collectively be known as the Santa Fe Group (Chapin and Cather, 1994). This includes the entire syn-rift basin fill, both volcanic and sedimentary, ranging in age from late Oligocene to Quaternary, but excluding deposits that postdate entrenchment of the Rio Grande in early to middle Pleistocene time. The term Santa Fe Formation has been applied to the older rift fill in the San Luis Valley, as far north as the Villa Grove area (Scott and others, 1978). All of the older rift fill in the Wet Mountain Valley is referred to as Santa Fe Formation (Scott and Taylor, 1975) and has been subdivided into upper and lower Santa Fe Formation (Scott and others, 1978).

The earliest mention of the sedimentary deposits in the Upper Arkansas Valley was by Hayden (1869), who regarded them as Pliocene lake deposits and referred to them as the “Arkansas marls.” They were correlated with the “Santa Fe marls.” The earliest descriptions of the deposits in the Leadville mining district were by Emmons (1886) and Emmons and others (1927). They described a series of “lake beds” that were only exposed in mine workings and were thought to have accumulated in a broad glacial lake that was produced by damming of the Arkansas River at Granite by glacial moraines. The deposits were described as chiefly interstratified clay and sand with only a few layers of calcareous material and occasional layers of gravel.

Van Alstine and Lewis (1960) described the probable lower Pliocene sediments near Salida as consisting of gray, yellow, brown, pink and red interbedded clays, silts, sands, and gravels. The sediments are poorly consolidated, except for some well-cemented calcareous lenses of gravel and sand and an argillaceous siltstone, and dip generally less than 10 degrees in various directions. The mammalian fossils described indicated an early Pliocene age for the deposits. Tweto (1961) named the Pliocene sediments the Dry Union Formation for occurrences at the type locality in Dry Union gulch about 5 mi south of Leadville. He mentioned the presence of minor, interbedded

volcanic ash of Pliocene age and suggested that the Dry Union Formation probably underlies most of the Arkansas Valley from Leadville to Salida and downstream to near Howard. The Dry Union Formation is part of the Santa Fe Group (Chapin and Cather, 1994).

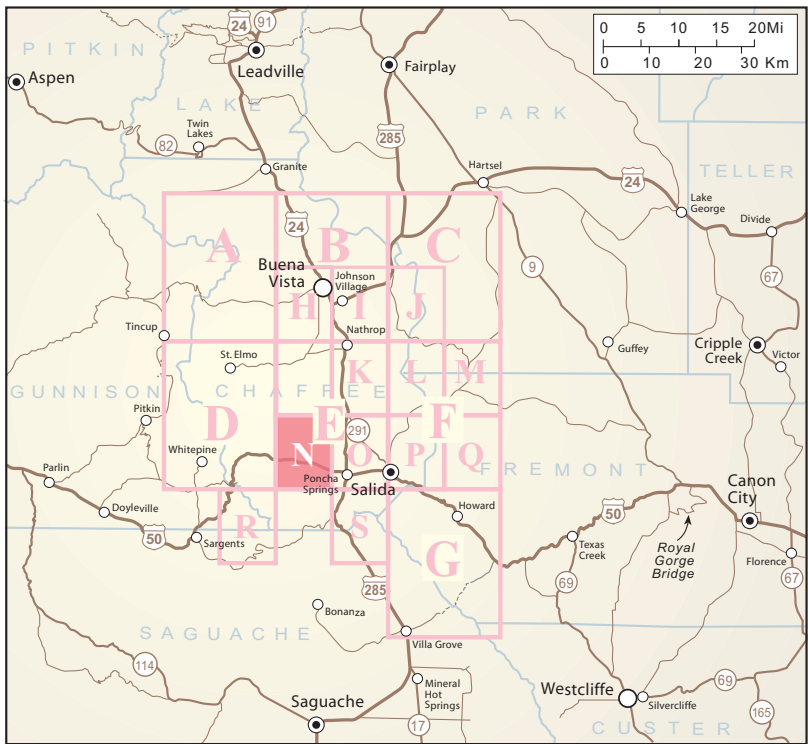
Volumetrically minor, air-fall, volcanic ash beds have been recognized in the Dry Union Formation and Quaternary gravels in the Salida area. Van Alstine (1968 and 1970) first mentioned the presence of volcanic ash beds in the Dry Union Formation in the South Arkansas graben sequence, but no locations or descriptions were provided. Van Alstine (1974) mentioned four localities of volcanic ash: three in the Salida West quadrangle (Poncha Springs SE) and one in the Maysville quadrangle. Scott and others (1975) showed three additional volcanic ash localities in the Poncha Springs 15-minute quadrangle. Five additional volcanic ash localities in the Dry Union Formation in the badlands area south of Droney Gulch and west of Highway 285 in the northwest part of the Salida West quadrangle were described by Denesha (2003). A compilation and description of nine Miocene-Pliocene volcanic ash localities (eight previously recognized and one new from this study) and three Quaternary volcanic ash localities are provided in the Discussion Section.

PREVIOUS STUDIES

Previous studies presented in published geologic 15-minute and 7.5-minute quadrangle maps of the region in and around the Maysville quadrangle are summarized in figure 6. The earliest published geologic map that includes parts of the Maysville quadrangle was related to a comprehensive study of the Monarch and Tomichi mining districts by R.D. Crawford, published as the 4th Bulletin of the Colorado Geological Survey in 1913. Crawford (1913) provided a 1:62,500-scale map and the report included the earliest descriptions of the Proterozoic sillimanite-bearing gneisses, Paleozoic sedimentary rocks, Mount Princeton and Mount Aetna intrusive rocks, and the Mount Antero granites.

Another excellent early study includes the Dings and Robinson (1957) Garfield

15-minute quadrangle, which is adjacent to the western boundary of the Maysville quadrangle. They provided detailed descriptions of many of the main lithologic units that are present in the Maysville quadrangle including the Proterozoic rocks, Paleozoic sedimentary rocks, and a wide variety of Tertiary intrusive rocks. Additional descriptions of Paleozoic sedimentary rock units in the adjacent Monarch district are given by Robinson (1961). Sharp (1976) completed a detailed study of the Mount Antero granite and included a 1:24,000 scale geologic map of an approximately 42 sq mi area that



15-Minute Quadrangle (1:62,500) Maps:

- A. Mount Harvard** (USGS) geologic map (Brock and Barker, 1972),
- B. Buena Vista** (USGS) geologic map (Scott, 1975)
- C. Antero Reservoir** (Colorado School of Mines) geologic map (De Voto, 1971)
- D. Garfield** (USGS) geologic map (Dings and Robinson, 1957)
- E. Poncha Springs** (USGS) geologic map (Scott and others, 1975)
- F. Cameron Mountain** (USGS) geologic map (Wrucke and Dings, 1979)
- G. Howard** (USGS) reconnaissance geologic map (Taylor and others, 1975)

7.5-Minute Quadrangle (1:24,000) Maps:

- H. Buena Vista West** (CGS) geologic map (McCalpin and Shannon, 2005)
- I. Buena Vista East** (CGS) geologic map (Keller and others, 2004)
- J. Castle Rock Gulch** (CGS) geologic map (Wallace and Keller, 2003)
- K. Poncha Springs NE (Nathrop)** (USGS) geologic map (Van Alstine, 1969)
- L. Cameron Mountain** (CGS) geologic map (Wallace and Lawson, 1998)
- M. Gribbles Park** (CGS) geologic map (Wallace and others, 1999)
- N. Maysville** (CGS) geologic map (This Map)
- O. Poncha Springs SE (Salida West)** (USGS) geologic map (Van Alstine, 1974)
- P. Salida East** (CGS) geologic map (Wallace and others, 1997)
- Q. Jack Hall Mountain** (CGS) geologic map (Wallace and others, 2000)
- R. Marshall Pass Mining Dist (Phalone Peak)** (USGS) geologic map (Olson, 1983)
- S. Bonanza NE (Poncha Pass)** (USGS) geologic map (Van Alstine, 1975)

Figure 6. Location of the Maysville 7.5-minute quadrangle (N) and index of previously completed 15-minute (1:62,500 scale) and 7.5-minute (1:24,000 scale) geologic quadrangle mapping in the region.

straddles the corners of the Mount Antero, St. Elmo, Maysville, and Garfield quadrangles.

The most complete and detailed previous coverage of the geology and structure of the Maysville quadrangle area was included as the southwest quadrant of the geologic map of the Poncha Springs 15-minute quadrangle by Scott and others (1975). This map also included some information from Kouter (1969), Knepper (1974), and Limbach (1975). It provided excellent descriptions of many of the main rock units and accurately depicted the main elements of the geology and structure of the quadrangle. It was invaluable during the course of our investigations.

The Maysville area is included in the 1:250,000-scale regional geologic compilation of the Montrose 1° x 2° quadrangle (Tweto and others, 1976). Other important regional studies that are not part of quadrangle maps include the structure and tectonic studies by Perry (1971) and Knepper (1974 and 1976). Knepper's treatment of the complex structure was a major step in developing a comprehensive structural and tectonic framework for the region. Additional studies by Russell (1950), Kouter (1969), Dippold (1999), Xu (2001), and Denesha (2003) provide descriptions of lithologies and structure of parts of the Maysville quadrangle and adjacent Mount Ouray and Salida West quadrangles.

The Proterozoic rocks in the southwest quadrant of the Maysville quadrangle are part of the regional Gunnison-Salida belt of Early Proterozoic supracrustal rocks (Bickford and Boardman, 1984 and Bickford and others, 1989). Boardman (1976 and 1986), Bickford and Boardman (1984), and Boardman and Condie (1986) provided detailed descriptions of the supracrustal rocks near Salida. Boardman (1986) described a 13,000 ft thick northern section and a 5,600 ft thick southern section, both with similar stratigraphic and lithologic character. The sections consist of interlayered metavolcanic and metasedimentary rocks and abundant gabbro-diorite sheets. The volcanic rocks represent a bimodal mafic-felsic volcanic suite. Mafic volcanic rocks (tholeiitic basalt to basaltic andesite) are predominantly volcanoclastic and include massive breccia units, sedimentary sequences with calcareous matrix, laminated volcanoclastics, and minor flows and pillow breccias (Bickford and Boardman, 1984). The felsic volcanic rocks are also dominantly volcanoclastic with dacite to rhyolite compositions. The difference

between the northern and southern sections is mainly in the degree of preservation of primary textures and the development of metamorphic fabrics (Boardman, 1976). The southern section is poorly foliated and retains abundant primary textures while the northern section is strongly foliated, resulting in the destruction of most primary textures. The grade of metamorphism is similar in the two sections, middle to upper amphibolite facies; but a slightly higher metamorphic grade is suggested by the presence of sillimanite in the northern section adjacent to a large intrusion of the Routt Plutonic Suite (Trout Creek). Boardman (1976) suggested that strong evidence links the development of metamorphic fabrics and destruction of primary protolith textures in the supracrustal rocks to the intrusion.

Small intrusions of coarsely porphyritic to foliated granodiorite-quartz monzonite (Xgd and Xgdf) in the Layered Gneiss Complex in the west part of the Maysville quadrangle are similar to, and considered to be satellite bodies of, the Denny Creek batholith, which forms a large intrusive body in the southern Mosquito Range (Trout Creek body) and the central Sawatch Range (Tweto, 1987). Bickford and others (1989) reported a U-Pb zircon age of 1,672 Ma for the Trout Creek body in the southern Mosquito Range.

Regional studies of Proterozoic base-metal sulfide occurrences by Sheridan and Raymond (1984) and Heimann and others (2005) include descriptions of lithologies and mineralization at the Bon Ton mine in the Maysville quadrangle. Knight (1981) provided detailed descriptions of the sillimanite-bearing gneiss sequence in the Cinderella and Bon Ton mine area, which straddles Green Creek along the southern boundary of the Maysville quadrangle. He described three subunits of the sillimanite-bearing gneisses and at least three stratabound Zn-Cu mineralized horizons associated with calc-silicate-bearing metamorphic rocks.

METHODS

The present study focuses on the geologic mapping in the Maysville 7.5-minute quadrangle at a scale of 1:24,000. The geologic map (plate 1), the Correlation of Map Units (plate 2), and three geologic cross sections and quadrangle oblique view (plate 3) accompany this report. Field work in the Maysville quadrangle was undertaken during the summer of 2005 and some field checking and follow-up geologic mapping was carried out during the summer of 2006. Bedrock mapping was completed by James R. Shannon (Colorado School of Mines). Bedrock rock was mapped on an enlarged U.S. Geological Survey topographic base at a scale of 1:12,000 and later compiled on to 1:24,000-scale base maps. Field control was maintained with a handheld Garmin GPSmap 60C. Position accuracy is estimated to be 12 to 60 ft, at best. Bedrock contacts were digitized in 2-D with ESRI ArcView at the Colorado Geological Survey. Specific locations of sites discussed in this report are given in UTM coordinates (Datum NAD27, zone 13, in meters). Appendix I contains the Maysville quadrangle point-file data base with location information and structure data. A number of geologic units, including Proterozoic dikes (Xmd) and lithologic units (Xq and Xag), and Tertiary dikes (Ta, Trp, Tr, Tcf, and Tqlp) and lithologic units (Td2v and Td2ls) are shown on the geologic map (plate 1) and geologic cross sections (plate 3) with exaggerated thickness.

The classification of igneous rocks described in this report is based on the International Union of Geological Sciences (IUGS) Subcommittee on the Systematics of Igneous Rocks (Streckeisen, 1973, 1976 and 1979). Where whole-rock chemical analyses are available the rocks are chemically classified using the R_1R_2 -diagrams of De la Roche and others (1980). The mean composition of igneous rock families (from De la Roche and others, 1980) are used for whole-rock chemical comparisons. The formal names Mount Aetna Quartz Monzonite, Mount Pomeroy Quartz Monzonite and Mount Princeton Quartz Monzonite will not be used in this report because they are not classified as quartz monzonite with current IUGS nomenclature and chemical classifications of De la Roche and others (1980). Plagioclase compositions were approximated optically using the Michel-Levy (1877) statistical method.

Surficial deposits were mapped by James P. McCalpin (GEO-HAZ Consulting)

on U.S. Forest Service color aerial photographs (1:24,000 scale) taken in September 1997. The annotated photos were scanned and imported into ERDAS Imagine Stereo Analyst where they were photogrammetrically corrected and rendered in 3-D by Colorado Geological Survey personnel. Line work was digitized directly from ERDAS Imagine Stereo Analyst (by Shannon) and exported as ESRI shapefiles. Geological editing and final map production was completed by Tom Neer at Digital Data Services, Inc., Lakewood, Colorado.

The Quaternary deposits of the Maysville quadrangle are generally not well exposed, due to the lack of artificial and natural vertical exposures. Therefore, the thickness of most units is estimated and descriptions of physical characteristics such as texture, stratification, and composition are based on observations at a small number of localities. Particle size is expressed in terms of the modified Wentworth scale (Ingram, 1989), and sorting is expressed in the terminology of Folk and Ward (1957). 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. The distribution and inter-relationships of surficial deposits are accurately depicted on the geologic cross sections (plate 3), but thicknesses are exaggerated for diagrammatic purposes.

Figure 7 shows the geologic time chart adopted by the Colorado Geological Survey which follows recommendations of the Geological Survey of Canada (Okulitch, 2002), with modification of some age boundaries according to recommendations of the International Commission on Stratigraphy (2005). The nomenclature for eras, periods, and epochs and the corresponding age boundaries summarized in figure 7 are used in this report. Numerical ages have not been obtained for any of the surficial units in the Maysville quadrangle. The ages assigned to surficial units are estimates based principally on stratigraphic relations, position in the landscape, degree of erosional modification, differences in degree of weathering and soil development, and correlations with deposits elsewhere in the region whose ages have been determined by numerical-dating methods. For example, middle and early Pleistocene alluvial units are correlated with nearby deposits in the Nathrop quadrangle that contain dated volcanic ashes (Van Alstine, 1969).

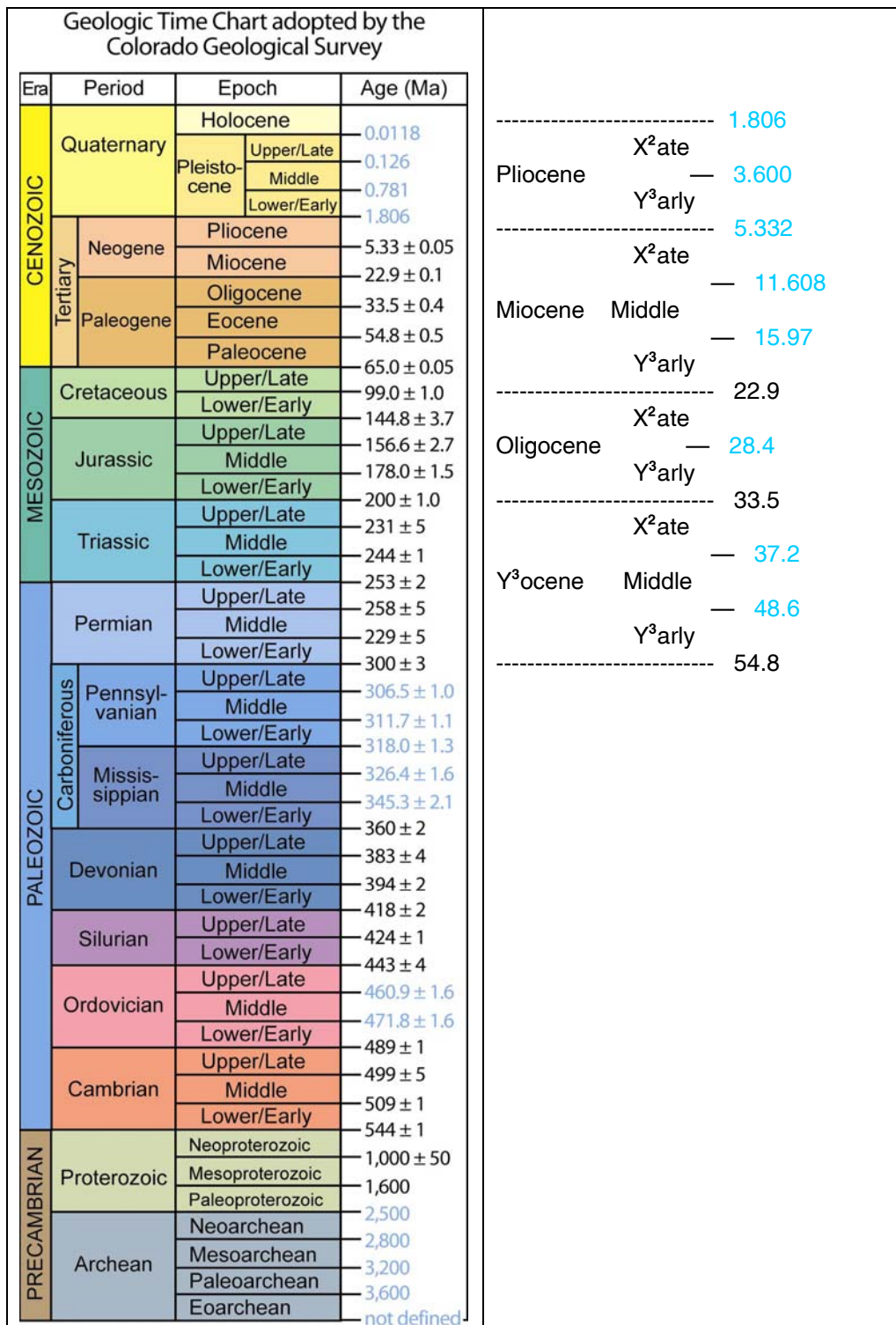


Figure 7. Geologic time chart used for this report. Numerical ages shown in black are from the Geological Survey of Canada (Okulitch, 2002); ages in blue are from the International Commission on Stratigraphy (2005).

We use fractional map units on the geologic map. For Quaternary deposits, if the surface map unit is thinner than 5 ft and/or discontinuous we map a “fractional” map unit, shown by a map unit abbreviation that lists the upper (surficial) deposit in the numerator and the underlying (bedrock) deposit or unit in the denominator (for example, Qco/Td or Qc/Xgdf). This usage has been adopted by the Colorado Geological Survey on recent 1:24,000 scale geologic maps.

The concept of fractional lithologic units is expanded to bedrock units for the Maysville quadrangle specifically to assist in characterizing complexities of the Proterozoic terrane. Extremely poor exposure and extensive mixing of rock float hamper the interpretation of the various Proterozoic units. Limited outcrop suggest that a lot of the mixed lithologies are related to both interlayering of the lithologies and structural complexities. For fractional bedrock units the predominant lithology is in the numerator and successively less abundant lithologies (but greater than 25 percent) are in the denominator (for example, Xmfs/YXgp and Xag/Xcs/Xbfg). Fractional units are also used for showing the distribution of mappable broken rock zones which are structurally superimposed on the complex Proterozoic lithologies (for example, BR/Xag and BR/Xgdf).

ACKNOWLEDGMENTS

This mapping project was funded jointly by the Colorado Geological Survey and U.S. Geological Survey through the STATEMAP program of the National Cooperative Geologic Mapping Program under agreement No. 05HQAG0064.

The senior author thanks the Colorado Geological Survey for additional support related to seven whole-rock chemical analyses, twelve geochemical analyses, one $^{40}\text{Ar}/^{39}\text{Ar}$ age determination, 18 thin sections, and 6 polished sections that were used for this study. These additional studies and data significantly improve the quality of the report.

The authors thank the many private land owners on the Maysville quadrangle who

granted us access to their land for mapping purposes. Of special note is Mrs. Norma Friend, owner of the ranch at the mouth of Little Cochetopa Creek.

We thank Terry Klein and Ed DeWitt from the U. S. Geological Survey for peer reviews of the manuscript and Jane Ciener for the technical review. Matt Morgan with the Colorado Geological Survey was of great assistance during the ERDAS digitizing of the preliminary geologic contacts. We thank Larry Scott with the Colorado Geological Survey for preparation of report digital figures. We also thank Digital Data Services and especially Tom Neer for preparation of the final digital geology map (plate 1), Correlation of Map Units (plate 2), and geologic cross sections (plate 3).

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Quaternary (surficial) deposits cover the largest surface area of the Maysville quadrangle. The combined Quaternary deposits are estimated to cover about 40 percent of the area, mostly in the central, west-central and east-central parts of the map area. Quaternary deposits shown on the map are generally more than 5 ft thick.

HUMAN-MADE DEPOSITS

af Artificial fill (latest Holocene) – Unsorted silt, sand, and rock fragments deposited during human construction. Mapped only at the dam impounding Fooses Lake. The average thickness of the unit is less than 30 ft. Artificial fill may be subject to settlement when loaded if not adequately compacted.

GLACIAL DEPOSITS – Gravel, sand, silt, and clay deposited by ice along glaciated valleys in the Sawatch Range (from north to south, Squaw Creek, North Fork South Arkansas River, South Arkansas River).

Qpt Pinedale till, undivided (late Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines in (from north to south) Squaw Creek, North Fork, Cree Creek, South Arkansas River, and Green Creek. May also include localized lenses of material transported by melt-water adjacent to ice and post-glacial alluvium in stream courses too small to map. Deposits are light-olive-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix. Clasts are typically angular to rounded and unweathered. Small kettle holes and hummocky topography are common. Soils comprised of moderately well-developed A-horizon and weakly developed C-horizon. Lack of clast weathering, limited soil development, and hummocky surface morphology suggest a late Pleistocene age (Pinedale equivalent, 15-35 thousand years, ka). Maximum thickness is unknown.

Qpty Pinedale till, younger (late Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines. May also include localized lenses of material transported by melt-water adjacent to ice. Deposits are light-olive-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty-sand matrix. Clasts are typically angular to rounded and unweathered. Small kettle holes and hummocky topography are common. Soils comprised of moderately well-developed A-horizon and weakly developed C-horizon. Lack of clast weathering, lack of soil development, and very hummocky surface morphology suggest a late Pinedale age (15-22? ka). Mapped only in the North Fork, where unit forms a ground moraine. Maximum thickness is unknown, but roadcuts along County Road 240 expose a thickness of at least 33 ft in places.

Qbt Bull Lake till, undivided (middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines. Moraines lie adjacent to and outside of Pinedale moraines at Squaw Creek, North Fork, Cree Creek, and South Arkansas River. Deposits are yellowish-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix (fig. 8). Most clasts are angular to subangular and little weathered, but Mount

Princeton quartz monzonite fragments are rounded and partly disintegrated. Some boulders are more than 15 ft in diameter. Generally, exposed boulders are half or more buried below surface of moraine. Moraine is only slightly hummocky and crest is rounded. Soils are moderately developed and have a weakly developed argillic B-horizon. Degree of clast weathering, soil development, and surface morphology suggest a middle Pleistocene (Bull Lake, 130-160 ka) age. Maximum thickness is unknown but may be as much as 200 ft in moraines at South Arkansas River.



Figure 8. Road-cut exposure of Bull Lake Till (Qbt).

Qbty Bull Lake till, younger (late middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines. Mapped at (1) Squaw Creek at the range front, where it lies downslope of Pinedale till; (2) North Fork, where it lies outside the Pinedale moraines; and (3) Cree Creek, where it forms the north lateral moraine from the South Arkansas River glacier. Deposits are yellowish-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix. Most clasts are angular to subangular and little

weathered, but Mount Princeton quartz monzonite fragments are rounded and partly disintegrated. Some boulders are more than 15 ft in diameter. Generally, exposed boulders are half buried below surface of moraine. Moraine is only slightly hummocky and crest is rounded. Soils are moderately developed and have a weakly developed argillic B-horizon. Degree of clast weathering, soil development, and surface morphology suggest a late middle Pleistocene (Bull Lake, 60-130 ka) age. Maximum thickness is unknown but may be as much as 66 ft.

Qbto Bull Lake till, older (middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines. Mapped at (1) Squaw Creek at the range front, where it lies downslope of younger Bull Lake till; (2) on the west side of Walden Gulch, where ice spilled eastward out of the North Fork; and (3) between Cree and Lost Creeks, where it forms the north lateral moraine from the South Arkansas River glacier. Deposits are yellowish-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix. Most clasts are angular to subangular and weathered, but Mount Princeton quartz monzonite fragments are generally disintegrated (grussified). Some boulders are more than 8 ft in diameter. Generally, exposed boulders are 50-75% buried below surface of moraine. Moraine is smooth rather than hummocky and crest is rounded. Soils are moderately developed and have an argillic B-horizon. Degree of clast weathering, soil development, and smooth surface morphology suggest a middle Pleistocene (Bull Lake, 130-160 ka) age. Moraines are displaced by Quaternary fault scarps at Squaw Creek. Maximum thickness is unknown.

Qpbt Pre-Bull Lake till, undivided (early to middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in terminal and lateral moraines. Moraines lie far from present streams, outside Bull Lake moraines, and generally form erosional remnants at the head of the range-front piedmont at Squaw Creek, Walden Gulch, North Fork, Cree Creek, and South Arkansas River. At the head of Blank Gulch this till grades into the head of contemporaneous outwash (Qpbo). Deposits are yellowish-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder,

pebble, and cobble gravel in a silty sand matrix. Most clasts are angular to subangular and weathered, but Mount Princeton quartz monzonite fragments are generally disintegrated (grussified). Surface boulders are rare, and those exposed are more than 75% buried below surface of moraine. Moraine surface is very smooth and crest is very broad and gentle. Soils are strongly developed and have an argillic B-horizon. Degree of clast weathering, soil development, smooth surface morphology, and disconnection from present valley axes suggest an early Pleistocene age. Maximum thickness is unknown but may be more than 100 ft in the graben at the range front between the North Fork and Lost Creek, where unit is buried by younger colluvium (Qco/Qpbt).

Qpbt2 Pre-Bull Lake till, younger (early to middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice in ground (?) moraines. Deposits lie far from present streams, outside Bull Lake moraines, and generally form smooth erosional remnants at the head of the range-front piedmont at Squaw Creek, Walden Gulch, North Fork, Cree Creek, and South Arkansas River. Forms a high pediment surface west of the North Fork. At the head of Blank Gulch this till grades into the head of contemporaneous outwash (Qpbo). Deposits are yellowish-gray, poorly sorted, unstratified or poorly stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix. Most clasts are angular to subangular but very weathered and pitted. Surface boulders are minor, and those exposed are more than 75% buried below surface of moraine. Moraine surface is very smooth and crest is very broad and gentle. Soils are strongly developed and have an argillic B-horizon. Degree of clast weathering, soil development, smooth surface morphology, and disconnection from present valley axes suggest an early Pleistocene age. Maximum thickness is unknown but may be as much as 100 ft near the range front, thinning downslope.

Qpbt1 Pre-Bull Lake till, older (early to middle Pleistocene) – Heterogeneous deposits of gravel, sand, silt, and clay deposited by ice possibly in ground moraines. Mapped only between the North Fork and Lost Creek. Deposits lie far from present streams, outside Bull Lake moraines, and generally form very high erosional remnants on the range-front. Deposits are yellowish-gray, poorly sorted, unstratified or poorly

stratified, matrix-supported, boulder, pebble, and cobble gravel in a silty sand matrix. Most clasts are angular to subangular, weathered, and pitted. Surface boulders are minor, and those exposed are more than 75% buried below surface of moraine. Moraine surface is very smooth and crest is very broad and gentle. Soils are strongly developed and have an argillic B-horizon. Degree of clast weathering, soil development, smooth surface morphology, and disconnection from present valley axes suggest an early Pleistocene age. Maximum thickness is unknown but may be as much as 50 ft.

PERIGLACIAL DEPOSITS – Deposits formed in cold environments by freeze-thaw action, solifluction, and nivation. Includes talus deposited by gravity processes (rockfall, creep) and talus fans deposited by both gravity and debris-flow processes.

Qrg Rock glacier deposits, undivided (Holocene) – Poorly sorted angular to sub-angular boulders, cobbles, gravel, and sandy silt in a matrix of firn or glacier ice. Mapped only in the cirque southeast of Mount Shavano. The outer part of the rock glacier is typically clast supported, matrix free, and composed of angular to subangular, predominantly boulder-sized rock fragments. Downslope movement is the result of internal deformation of the firn or ice core. Rock glaciers commonly have a lobate or tongue-like morphology and form in cirque basins where sediment supply is abundant. Includes rock glaciers that are generally inactive, but may contain some small areas of later Holocene reactivation too small to map. Probably contains an ice core. Maximum thickness about 60 ft.

Qrgy Rock glacier deposits, younger (middle to late Holocene) – Poorly sorted angular to sub-angular boulders, cobbles, gravel, and sandy silt in a matrix of firn or glacier ice. Mapped only where North Fork crosses western quadrangle boundary. The outer part of the rock glacier is typically clast supported, matrix free, and composed of angular to subangular, predominantly boulder-sized rock fragments. Downslope movement is the result of internal deformation of the firn or ice core. Rock glaciers commonly have a lobate or tongue-like morphology and form in cirque basins where

sediment supply is abundant. Frontal slope is at the angle of repose. Boulders on top, sides, and front are lichen free, so deposits are inferred to have moved recently. Probably contain ice cores. Maximum thickness about 33 ft.

Qrgo Rock glacier deposits, older (early to middle Holocene) – Poorly sorted angular to sub-angular boulders, cobbles, gravel, and sandy silt in a matrix of firn or glacier ice. Mapped only at the head of Como Creek. The outer part of the rock glacier is typically clast supported, matrix free, and composed of angular to subangular, predominantly boulder-sized rock fragments. Downslope movement is the result of internal deformation of the firn or ice core. Rock glaciers commonly have a lobate or tongue-like morphology and form in cirque basins where sediment supply is abundant. Frontal slope is below the angle of repose. Boulders on top, sides, and front are covered with lichen and/or trees, so deposits are inferred to be stationary. Probably does not contain an ice core. May be covered with younger talus and colluvium on edges. Maximum thickness about 33 ft.

Qt Talus deposits, undivided (Holocene) – Angular, cobbly and bouldery rubble as much as 6 ft in diameter. Mapped at the base of oversteepened glacial valley sidewalls in the cirques of both branches of Squaw Creek. Deposits are derived from bedrock that was transported downslope by gravity principally as rockfalls, rock avalanches, rock topples, and rockslides. Downslope movement may have been locally aided by water and freeze-thaw action. Unit typically lacks matrix material near the surface, but dissected talus reveal significant matrix at depth. Surface is partly vegetated, indicating that most of the surface is no longer receiving active deposition. Thickness is probably less than 15 feet. Talus areas are subject to rockfall, rock-topple, and rockslide hazards.

Qta Talus deposits, active (late Holocene to Historic) – Angular, cobbly and bouldery rubble as much as 6 ft in diameter. Mapped at the base of oversteepened glacial valley sidewalls in the cirques of both branches of Squaw Creek and in the North Fork. Also found on open slopes above timberline west of the summit of Mount Shavano and in three long gullies that descend south from the Shavano massif to the North Fork. Deposits are derived from bedrock that was transported downslope by gravity principally

as rockfalls, rock avalanches, rock topples, and rockslides. Downslope movement may have been locally aided by water and freeze-thaw action. Unit typically lacks matrix material near the surface, but dissected talus reveal significant matrix at depth. Lack of surface vegetation indicates that rubble deposition is continuing in modern times.

Thickness is probably less than 33 feet. Talus areas are subject to rockfall, rock-topple, and rockslide hazards.

Qti Talus deposits, inactive (Holocene) – Angular, cobbly and bouldery rubble as much as 6 ft in diameter. Mapped only northwest of the summit of Mount Shavano and in the North Fork near the western quadrangle boundary. Deposits are derived from bedrock that was transported downslope by gravity principally as rockfalls, rock avalanches, rock topples, and rockslides. Downslope movement may have been locally aided by water and freeze-thaw action. Unit typically lacks matrix material near the surface, but dissected talus reveal significant matrix at depth. Limited surface vegetation indicates that rubble deposition is no longer continuing in modern times. Thickness is probably less than 33 feet. May be subject to rockfall, rock-topple, and rockslide hazards in extreme events (storms, earthquakes).

Qtf Talus fan deposits, undivided (Holocene) – Angular, cobbly and bouldery rubble as much as 6 ft in diameter deposited in steep cones marked by a prominent axial gully. Mapped in cirques of both branches of Squaw Creek. Deposits are derived from bedrock that was transported downslope by both rockfalls and debris flows. Axial gully is typically flanked by prominent debris-flow levees. Unit typically lacks matrix material near the surface, but dissected talus reveal significant matrix at depth. Unvegetated surface indicates that unit has received recent active deposition. Thickness is probably less than 15 feet. Talus fan areas are subject to rockfall and debris flows.

Qtfo Talus fan deposits, older (late Pleistocene and Holocene) – Angular, cobbly and bouldery rubble as much as 6 ft in diameter deposited in steep cones marked by a prominent axial gully. Mapped in only one location, in the cirque of the western branch of Squaw Creek. Deposits are derived from bedrock that was transported downslope by

both rockfalls and debris flows. Axial gully is typically flanked by prominent debris-flow levees. Unit typically lacks matrix material near the surface, but dissected talus reveal significant matrix at depth. Limited surface vegetation indicates that unit no longer routinely receives active deposition. Thickness is probably less than 15 ft. Older talus fan areas may be subject to rockfall and debris flows in extreme precipitation events.

Qs Solifluction deposits (late Pleistocene and Holocene) – Angular to subrounded pebbles, cobbles, and large boulders in a chiefly sandy matrix deposited in alpine and sub-alpine basins. Mapped in only two locations above timberline southeast of Mount Shavano. Solifluction deposits result from the slow downslope flow of surficial deposits that are water saturated and subject to seasonal freezing. Frost creep and melt-water transport are also important factors in the formation of these deposits. This type of slope movement involves a slow, downslope plastic deformation of the soil and surficial deposits. Deposits are characterized by hummocky terrain, ground cracks and fissures up to several inches wide, and numerous seeps and springs. On open hillslopes solifluction also may produce lobes or *terraces*, with small ledges or benches up to about 5 ft high, due to differential movement of surficial material. Average thickness is typically less than about 16 ft. These deposits may be susceptible to future downslope movement and shallow groundwater.

ALLUVIAL DEPOSITS – Silt, sand, and gravel in stream channels, flood plains, terraces, small debris fans, and sheetwash areas. The topographic relationships between the various terrace levels of the South Arkansas River, and with their associated moraines, are shown in figure 9.

Qal Stream-channel, flood-plain, and low-terrace alluvium (Holocene) – Deposits are mostly clast-supported, pebble, cobble, and locally boulder gravel in a sandy silt matrix. The deposits are locally interbedded with and commonly overlain by sandy silt and silty sand. Clasts are subangular to well rounded and are of varied lithologies reflecting the diverse types of bedrock within their provenance. Unit includes modern

stream-channel deposits of all perennial streams, adjacent flood-plain deposits, and low-terrace alluvium that lie a maximum of 10 ft above modern stream level (fig. 10). The largest mapped areas are in the channels and flood plains of perennial streams (South Arkansas River and North Fork). Smaller areas lie in the channels of intermittent streams. In the upper reaches of Squaw Creek and the other creeks draining the range front, the deposits are very bouldery and display debris-flows levees and swales at the surface. Deposits may be interbedded with colluvium or debris-fan deposits where the distal ends of fans extend into modern river channels and flood plains. Maximum thickness about 33 ft. Areas mapped as alluvium may be prone to flooding and sediment deposition. The unit is typically a good source of sand and gravel.

Qat Low stream terrace alluvium (Holocene) – Deposits are mostly clast-supported, pebble, cobble, and locally boulder gravel in a sandy silt matrix. Mapped in South Sand Creek, lower Squaw Creek, and an unnamed drainage in Section 19, T50N, R8E near the central eastern map boundary. The deposits are locally interbedded with and commonly overlain by sandy silt and silty sand. Clasts are subangular to well rounded, and their varied lithologies reflects the diverse types of bedrock within their provenance. This unit includes alluvium of low terraces above the modern flood plain, but below Pinedale outwash terraces. Maximum thickness probably <20 ft.

Qpo Pinedale outwash deposits, undivided (late Pleistocene) – Yellowish-gray crudely stratified alluvium containing well-rounded to subrounded boulders, cobbles, pebbles, and sand. Mapped in the South Arkansas River and in North Fork, where it can be traced to terminal moraines. Also mapped in Pass Creek, in extreme southeastern corner of map area, where contemporaneous terminal moraines lie off the map area to the southwest. Composed of Tertiary igneous rocks and Proterozoic metamorphic and igneous rocks. Soil at top is weakly developed. Forms most of the valley floor of the South Arkansas River downstream from Maysville, in a terrace 15-20 ft above stream level. Potentially commercial source of gravel. Thickness probably 10-30 ft.

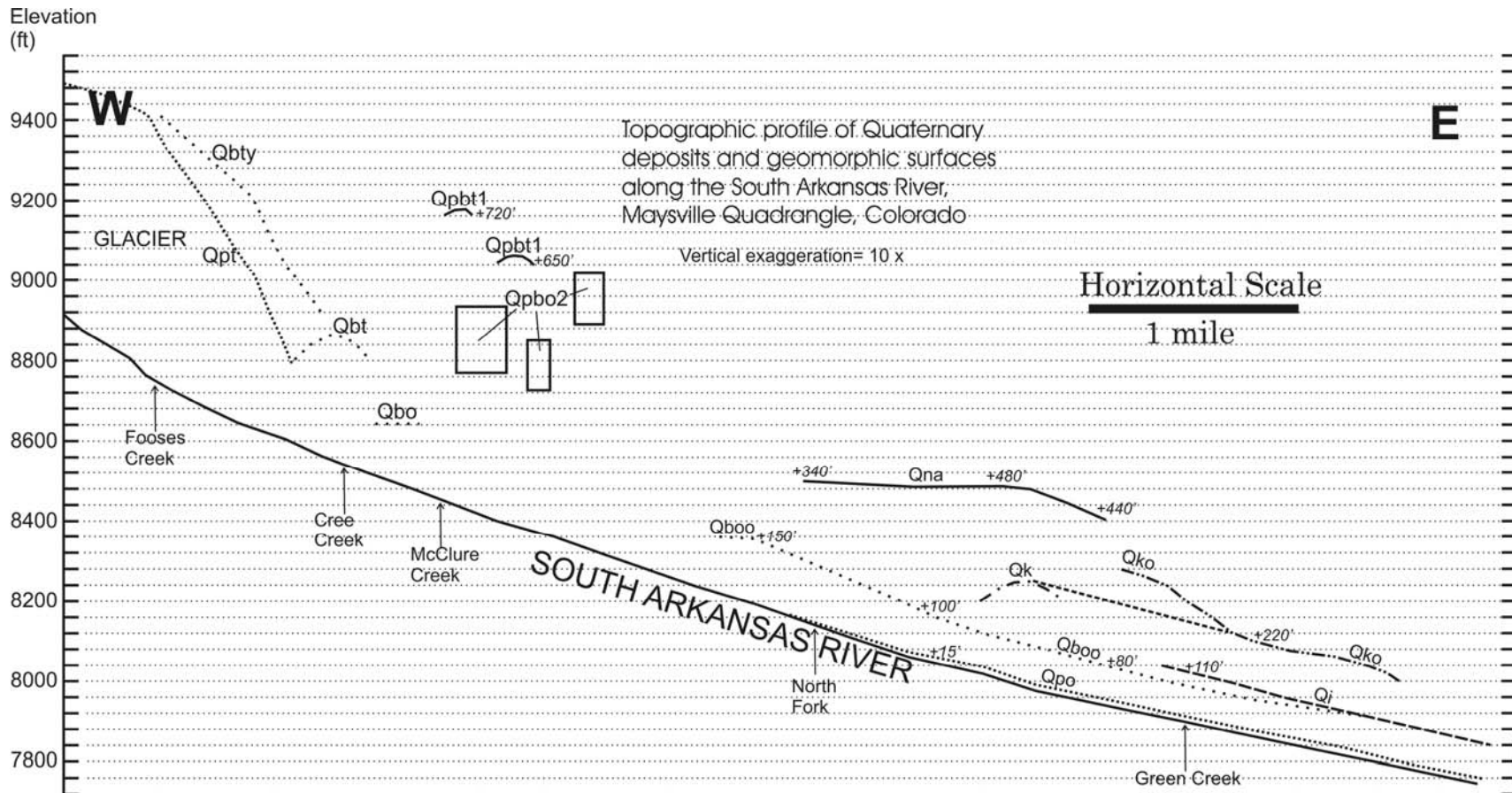


Figure 9. Longitudinal topographic profile of Quaternary terraces and moraines of the South Arkansas River. Vertical exaggeration is 10x. Terraces are common only downstream of Maysville, where the glaciated North Fork enters the South Arkansas River. Moraines in the North Fork are not shown because they descend toward the viewer, perpendicular to the plane of section. Numbers in italics indicate heights of terraces above modern river level.

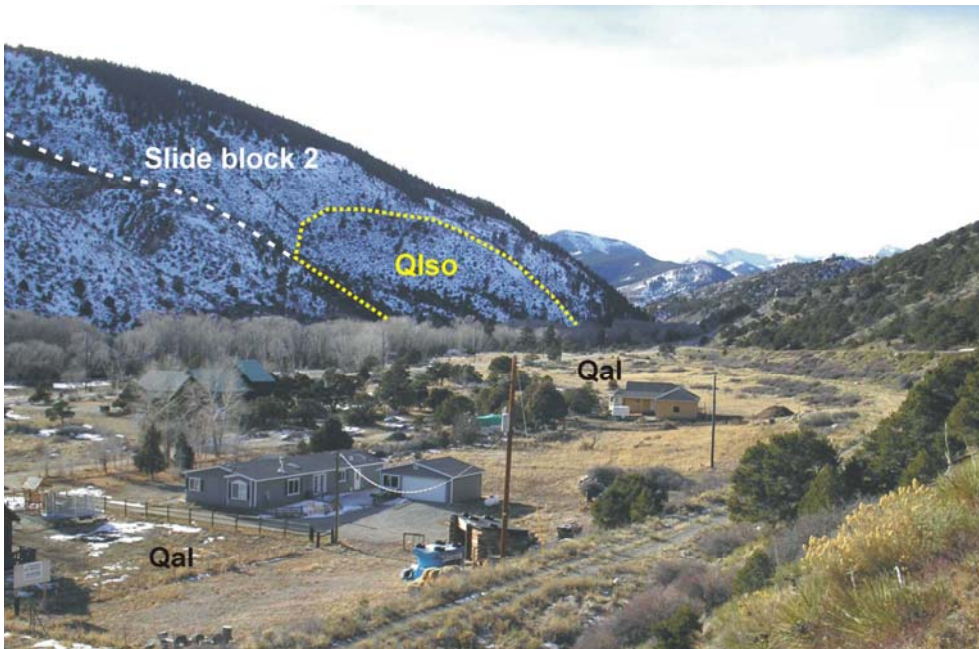


Figure 10. View west up South Arkansas River valley overlooking west Maysville. Showing broad alluvial flood-plain (Qal) and wedge failures Slide Blocks II (2) and III (Qiso) in distance.

Qbo Bull Lake outwash deposits, undivided (middle Pleistocene) – Brownish-gray to light-gray, sandy, bouldery alluvium. Mapped at the head of Walden Gulch, in lower Cree Creek, on the west side of the lower North Fork (Maysville Cemetery), and on the northern side of the South Arkansas River downstream of the confluence with the North Fork. Boulders average about 10 inches in diameter, but some are larger than 4 ft and are well rounded to subrounded, fairly well sorted, and fairly well stratified. Composed of Tertiary igneous and Proterozoic metamorphic and igneous rocks. Some pieces of Mount Princeton quartz monzonite are disintegrated; other rock types are only slightly weathered. Soil at top is moderately well developed. Potential commercial source of gravel. Thickness generally about 20 ft but may be up to 40 ft thick beneath Maysville Cemetery surface.

Qboy Bull Lake outwash deposits, younger (late-middle Pleistocene) – Brownish-gray to light-gray, sandy, cobbly alluvium. Mapped only on the northern side of the South Arkansas River, downstream from Maysville, where it forms a terrace about 20

feet below the Qboo terrace (fig. 11). Clasts are well rounded to subrounded, fairly well sorted, poorly stratified, with a sand matrix. Composed of Tertiary igneous and Proterozoic metamorphic and igneous rocks. All rock types are slightly weathered. Soil at top is moderately well developed. Commercial source of gravel. Thickness less than 33 ft.

Qboo Bull Lake outwash deposits, older (middle Pleistocene) – Reddish-brown to light-brown, sandy, cobbly alluvium. Mapped in two locations: (1) on the northern side of the South Arkansas River, downstream from Maysville, where it forms a terrace about 20 ft above the Qboy terrace (fig. 11); and (2) on the western side of upper Walden Gulch, where it was deposited by the eastern ice-marginal drainage of the Bull Lake glacier of the North Fork. Clasts are well rounded to subrounded, fairly well sorted, poorly stratified, with a sand matrix. Composed of Tertiary igneous and Proterozoic metamorphic and igneous rocks. Clasts of Mount Princeton quartz monzonite are disintegrated; other rock types are only slightly weathered. Soil at top is moderately well developed. Forms the most continuous terrace on the north side of the South Arkansas River, which lies 80 ft above (downstream) to 160 ft above (upstream, west of Maysville) the modern stream. Commercial source of gravel. Thickness at least 33 ft.



Figure 11. View west up South Arkansas River valley showing Bull Lake outwash older (Qboo) and younger (Qboy) terraces.

Qpbo Pre-Bull Lake outwash deposits (early Pleistocene) – Reddish-brown, sandy, cobbly alluvium. Mapped only on the range-front piedmont between the heads of Placer Creek, Blank Gulch, and Walden Gulch. Clasts are well rounded to subrounded, fairly well sorted, poorly stratified, with a sand matrix. Composed of Tertiary igneous rocks. Clasts of Mount Princeton quartz monzonite are disintegrated. Soil at top is strongly well developed. Grades into pre-Bull Lake till at the head of the range-front piedmont. Gravel is too weathered and decomposed to be of commercial value. Thickness at least 20 ft.

Qpbo2 Pre-Bull Lake outwash deposits, younger (early Pleistocene) – Reddish-brown, sandy, cobbly alluvium. Mapped only on the north side of the South Arkansas River, east of the mouth of Lost Creek, where two small terrace remnants lie 360-480 ft above river level. Clasts are well rounded to subrounded, fairly well sorted, poorly stratified, with a sand matrix. Composed of Tertiary igneous rocks. Clasts of Mount Princeton quartz monzonite are disintegrated. Soil at top is strongly developed. Gravel is too weathered

and decomposed to be of commercial value. Thickness at least 20 ft.

Qi Illinoian (?) alluvium (middle Pleistocene) – Brownish-gray boulder alluvium, well rounded to subrounded. Composed of igneous and metamorphic rocks and some siliceous sedimentary rocks. Soil at top is strongly developed. Mapped in the South Arkansas River near the eastern quadrangle boundary, where it forms a terrace 20-40 ft above the Qboo terrace, and on the western side of Walden Gulch. Equivalent to unit Qg4 of Van Alstine (1969) and correlated to the Illinoian glacial stage of the midwestern USA. Thickness at least 20-40 ft.

Qgo Older gravel deposits, undivided (early to middle Pleistocene) – Yellowish gray to yellowish-orange, fairly well-stratified alluvium containing well-rounded to subrounded fragments of igneous and metamorphic rocks. Mapped along Sand Creek and Squaw Creek. Forms dissected terrace-like surfaces underlain by bouldery gravel 60-120 ft above stream level, downstream from pre-Bull Lake till. Probably composed mostly of pre-Bull Lake outwash, but may also contain older till and local younger alluvial deposits. Thickness probably more than 66 ft.

Qk Kansan (?) alluvium, undivided (middle Pleistocene) – Yellowish-gray to yellowish-orange, fairly well-stratified alluvium containing well-rounded to subrounded fragments of igneous and metamorphic rocks. Mapped along Blank Gulch, Walden Gulch, and on valleys walls of the South Arkansas River. North of Buena Vista, contains type-O Pearlette ash, a marker volcanic bed with origin in Yellowstone National Park (Lava Creek B tuff, age 620 ka). Soil at top is strongly developed. Forms a terrace about 220-250 ft above stream level and small pediment surfaces graded to that level on the range-front piedmont. Equivalent to unit Qg3 of Van Alstine (1969) and correlated with the Kansan glacial stage of the Midwestern USA. Thickness probably more than 20 ft.

Qk3 Kansan (?) alluvium, younger (middle Pleistocene) – Yellowish-gray to yellowish-orange, fairly well-stratified alluvium containing well-rounded to subrounded fragments of igneous and metamorphic rocks. Mapped only in the South Arkansas River

valley near the eastern map boundary, between Walden Gulch and Blank Gulch. Soil at top is strongly developed. Partly equivalent to unit Qg3 of Van Alstine (1969) and correlated with the Kansan glacial stage of the Midwestern USA. Thickness probably more than 20 ft.

Qk2 Kansan (?) alluvium, middle (middle Pleistocene) – Yellowish-gray to yellowish-orange, fairly well-stratified alluvium containing well-rounded to subrounded fragments of igneous and metamorphic rocks. Mapped only in the South Arkansas River valley near the eastern quadrangle boundary, between Walden Gulch and Blank Gulch. Soil at top is strongly developed. Partly equivalent to unit Qg3 of Van Alstine (1969) and correlated with the Kansan glacial stage of the Midwestern USA. Thickness probably more than 20 ft.

Qk1 Kansan (?) alluvium, older (middle Pleistocene) – Yellowish-gray to yellowish-orange, fairly well-stratified alluvium containing well-rounded to subrounded fragments of igneous and metamorphic rocks. Soil at top is strongly developed. Forms a terrace on the north side of the South Arkansas River 250 ft above stream level. Partly equivalent to unit Qg3 of Van Alstine (1969) and correlated with the Kansan glacial stage of the Midwestern USA. Thickness probably more than 20 ft.

Qna Nebraskan (?) alluvium, undivided (early Pleistocene) – Light-brown to gray, poorly sorted, poorly stratified, deeply weathered, sandy bouldery gravel. Forms the largest sections of high pediment surfaces on the range-front piedmont. Possibly includes outwash from pre-Bull Lake glaciers. Soil at top is strongly developed. Partly equivalent to unit Qg2 of Van Alstine (1969). Thickness possibly as much as 80 ft.

Qna2 Nebraskan (?) alluvium, younger (early Pleistocene) – Light-brown to gray, poorly sorted, poorly stratified, deeply weathered, sandy bouldery gravel. Forms the youngest and most distal part of the high pediment surfaces on the range-front piedmont and is mapped only east of Walden Gulch. Possibly includes outwash from pre-Bull Lake glaciers. Soil at top is strongly developed. Partly equivalent to unit Qg2 of Van Alstine

(1969). Thickness possibly as much as 80 ft.

Qna1 Nebraskan (?) alluvium, older (early Pleistocene) – Light-brown to gray, poorly sorted, poorly stratified, deeply weathered, sandy bouldery gravel. Forms a small part of the distal high pediment surfaces on the range-front piedmont, west of Walden Gulch. Possibly includes outwash from pre-Bull Lake glaciers. Soil at top is strongly developed. Partly equivalent to unit Qg2 of Van Alstine (1969). Thickness possibly as much as 80 ft.

Qn Nussbaum (?) alluvium (early Pleistocene) – Brownish-gray to pale-brown, crudely stratified, poorly sorted bouldery alluvium. Composition varies widely depending on source. Deeply weathered; soil at top is very strongly developed. Forms the highest pediment surface on the range-front piedmont; lies about 80 ft above the Nebraskan (Qna) pediment surface. Mapped in only two locations, a large area of pediment between Squaw Creek and Placer Creek, and a narrow pediment surface north of Squaw Creek near the eastern quadrangle boundary. Equivalent to unit Qg1 of Van Alstine (1969). Thickness probably as much as 20 ft.

COLLUVIAL DEPOSITS – Silt, sand, and gravel on valley sides and floors. Material mobilized, transported, and deposited primarily by gravity, but movement commonly assisted by sheetwash, rillwash, freeze-thaw action, and debris flows resulting in units too small to map.

Qc Colluvium (late Pleistocene and Holocene) – Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Generally unsorted to poorly sorted and contains angular to subangular clasts. Includes weathered bedrock fragments that have been transported downslope primarily by gravity. Mapped mainly in small areas at the base of steep slopes in major canyons but also above timberline south of Mount Shavano. Deposits derived from glacial or alluvial deposits contain rounded to subrounded clasts. Clast

lithologies are variable and dependent upon types of rocks occurring within the provenance area. Locally, this unit may include debris-fan deposits that are too small or too indistinct on aerial photography to be mapped separately. Colluvium commonly grades into and interfingers with alluvial, debris-fan, landslide, talus, glacial, and sheetwash deposits. Maximum thickness probably about 30 ft; however, thickness may vary. Areas mapped as colluvium are susceptible to future colluvial deposition and locally are subject to debris flows, rockfall, and sheetwash. Colluvial deposits may be a potential source of aggregate.

Qco Colluvium, older (middle to late Pleistocene) – Generally unsorted to poorly sorted deposits containing rounded to subrounded clasts eroded from the moraine front. Includes weathered bedrock fragments that have been transported downslope primarily by gravity. Mapped only at the base of the younger Bull Lake terminal moraine (Qbty) of Squaw Creek. Maximum thickness is about 33 ft.

Qls Landslide deposits, undivided (late Pleistocene to Holocene) – Chaotically arranged debris ranging from clay to boulder size (diamicton). Mapped in three locations. At the head of an unnamed drainage east of McClure Creek, long narrow landslides in a gully are derived from highly fractured Proterozoic rock in the largest mega-slide block. On the ridge between Cree Creek and Lost Creek, at the range-front fault north of Lost Creek, landslide is derived from fractured Proterozoic rock of the Shavano fault zone. On the west branch of Squaw Creek, two large landslides composed of till are derived from the front of the Pinedale terminal moraine, where it overlies the Sawatch fault zone. Surface is commonly hummocky, and source area of landsliding is generally identifiable (on map, top of scarp area is indicated by thick dashed lines with ticks in direction of sliding). Larger landslide deposits may be more than 50 ft thick.

Qlsy Landslide deposits, younger (late Pleistocene to Holocene) – Chaotically arranged debris ranging from clay to boulder size (diamicton). Mapped only at the head of an unnamed drainage east of McClure Creek. Surface is hummocky, and source area of landsliding is easily identifiable (on map, top of scarp area indicated by thick dashed

lines with ticks in direction of sliding). May be more than 33 ft thick.

Qlso Landslide deposits, older (middle? to late Pleistocene) – Mapped on the south valley wall of the South Arkansas River, both west and east of McClure Creek (fig. 10). The latter landslide is a wedge failure of relatively intact Proterozoic rock, sliding northward on the intersection between northwest- and northeast-striking normal faults. As shown in figure 10, this landslide is the youngest, smallest, and lowest wedge failure (Slide Block III) at the base of a large area of progressively larger, inferred bedrock wedge failures (Slide Blocks I, II) that extend up to elevation 10,200 ft (those inferred gravity slide blocks are not composed of rubbilized landslide deposits, so are mapped as Proterozoic bedrock). The landslide mass may be more than 100 ft thick. Also mapped on the west side of Lost Creek, where the failed source material is Dry Union Formation.

ALLUVIAL AND COLLUVIAL DEPOSITS – Gravel, sand, and silt deposited by both alluvial and colluvial processes in debris fans, stream channels, flood plains, and lower reaches of adjacent hillslopes. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes are predominant on debris fans and along the hillslope-valley floor boundary.

Qac Alluvium and colluvium, undivided (late Pleistocene to Holocene) – A mixture of alluvial deposits of ephemeral, intermittent, and small perennial streams, and of colluvial deposits deposited from valley sides. Alluvium is typically composed of poorly to well sorted, stratified, interbedded, pebbly sand, sandy silt, and sandy gravel. Colluvium ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to relatively well-sorted sand composed of disintegrated granitic rocks (grus). Clast lithologies vary and are dependent upon the bedrock or surficial unit from which the deposit was derived. Mapped as long narrow deposits in the valley bottoms in most of the drainages incised into the range-front piedmont north of the South Arkansas River. Mapped at the head of Lost Creek (west-central quadrangle boundary), where deposit occupies a large area shaped like an alluvial fan. Also mapped south of the South

Arkansas River in parts of Redman Creek, Green Creek, Willow Creek, and McClure Creek. Interfingers with and is gradational with stream alluvium (Qal), alluvial-fan deposits (Qf), and colluvium (Qc). Maximum thickness is approximately 20 ft.

Qaco Alluvium and colluvium, older (late Pleistocene) – Consists of unsorted, clast-supported, pebble to boulder gravel in a sparse coarse sand matrix. Unit includes a mixture of alluvial deposits along Squaw Creek downstream from the Bull Lake terminal moraine and other deposits too small to map, including minor outwash terraces, colluvium derived from older till, sheetwash deposits, and small landslides. Individual facies could not be mapped due to their small size and due to the dense forest and steep slopes along this reach of Squaw Creek. Maximum thickness is approximately 20-40 ft.

Qf Alluvial-fan deposits, undivided (late Pleistocene to Holocene) – Moderately sorted, sand- to boulder-size gravel in undissected, fan-shaped deposits derived from tributary streams. Mapped where narrow, steep, intermittent and ephemeral tributaries debouch into wider, lower-gradient master stream valleys. Unit is mapped where deposition has occurred over a long time period, beginning (in places) as early as early to middle Pleistocene and continuing into the Holocene. Deposits typically composed of both matrix-supported beds (debris flow facies) and clast-supported beds (streamflow facies), often interbedded. Clasts are mostly angular to subround with varied lithologies dependant upon local source rock. Sediments are deposited by debris flows, hyperconcentrated flows, streams, and sheetwash. Debris-fan deposits commonly grade from boulder- and cobble-size fragments at the head of the fan to sandier deposits near the fan terminus. Maximum estimated thickness is less than 33 ft. Extreme precipitation events may trigger future deposition on alluvial fans. Debris-fan deposits may be prone to collapse when wetted or loaded.

Qfy Alluvial-fan deposits, younger (Holocene) – Moderately sorted, sand- to boulder-size gravel in undissected, fan-shaped deposits derived from tributary streams. Mapped principally along the outer edges of the Pinedale outwash terrace of the South Arkansas River downstream from the North Fork (fig. 12) and atop Pinedale till in the

North Fork. Deposits typically composed of both matrix-supported beds (debris flow facies) and clast-supported beds (streamflow facies), often interbedded. Clasts are mostly angular to subround with varied lithologies dependant upon local source rock. Sediments



Figure 12. View of younger alluvial fan deposits (Qfy) on south side of South Arkansas River.

are deposited by debris flows, hyperconcentrated flows, streams, and sheetwash. Deposit overlies and thus post-dates Pinedale outwash and till deposits. Maximum thickness may exceed 16 ft. Extreme precipitation events are likely to trigger future deposition on these young alluvial-fan deposits. Fan deposits may be prone to collapse when wetted or loaded.

Qfo Alluvial-fan deposits, older (middle to late Pleistocene) – Moderately sorted, sand- to boulder-size gravel in dissected, fan-shaped deposits derived from tributary streams. Deposits typically composed of both matrix-supported beds (debris flow facies) and clast-supported beds (streamflow facies), often interbedded. Clasts are mostly

angular to subangular. Deposits generally predate the Pinedale glaciation and lie 66 ft or more above modern streams. Maximum thickness is at least 16 ft.

Qfol Mixed landslide and alluvial-fan deposits, older (middle to late Pleistocene) –

Poorly sorted, sand- to boulder-size gravel in a fan-shaped deposit downslope from landslide deposits between the two branches of Squaw Creek. Deposit is poorly exposed but is thought to contain multiple generations of flow-type landslide deposits (earthflows and debris flows), lateral spreads, and landslide deposits reworked by running water. Deposit probably represents the distal facies of landslide and flowslide deposits from landslide failure of saturated till on the steep terminal moraine fronts overlying active traces of the Shavano fault zone. Maximum thickness is unknown but is inferred to be at least 16 ft.

Qfvo Alluvial-fan deposits, very old (early to middle Pleistocene) –

Moderately sorted, sand- to boulder-size gravel in small erosional remnants of very old alluvial fans. Mapped on the south side of the South Arkansas River, where small terrace-like remnants lie 350-400 ft above the river between Green Creek and Pass Creek. Also mapped on the drainage divide west of lower Willow Creek. Deposits are poorly exposed and may include components of both alluvial fans shed from Dry Union Formation terrane and of mainstream gravels of the ancestral South Arkansas River. Deposits possibly correlative with Nebraskan alluvium (Qna2) of the range-front piedmont, based on height above streams. Maximum thickness is at least 16 ft.

TERTIARY ROCKS AND DEPOSITS

Tertiary sedimentary and igneous rocks cover a large part (approximately 31.1 percent) of the Maysville quadrangle. Igneous rocks are only a small percentage of this (about 3.1 percent). Tertiary sedimentary rocks are represented by the Dry Union Formation (Td and Td2), which covers the largest surface area (estimated about 28 percent) of any single lithologic unit in the Maysville quadrangle. The Dry Union

Formation is part of the Santa Fe Group (Chapin and Cather, 1994).

Dry Union Formation– The Dry Union Formation in the Maysville quadrangle includes two separate sequences that represent different stratigraphic horizons: (1) the Upper Arkansas graben sequence (Td); and (2) the South Arkansas graben sequence (Td2). The two sequences are structurally separated by the west-northwest-trending Salida-Maysville fault. Significant differences between the two sequences include the overall character of the sediments and the presence of very fine-grained clay beds (Td2c) and detached landslide sheets (Td2ls) in the South Arkansas graben sequence.

In the Nathrop quadrangle, Van Alstine and Lewis (1960) and Van Alstine (1974) reported two fossil localities that indicated an early Pliocene age (equivalent to lower Ogallala of Nebraska) for the part of the Dry Union exposed along the eastern part of the Upper Arkansas graben. In contrast, fossils reported by Powers (1935) near Salida (in the Salida graben) led Van Alstine and Lewis (1960) to suggest that the Dry Union Formation there may be slightly younger in age (equivalent to upper Ogallala). Both of these localities are on the eastern side of the graben, and the ages may support that the youngest preserved Dry Union Formation (Td) is in the Salida sub-graben. Xu (2001) and Xu and others (2001) conducted tephrochronological studies on two of the volcanic ash layers southwest of Salida. They suggest the source for a white biotite-bearing dacitic ash is the Basin and Range. A second ash, a gray vitric tuff, has compositions typical of the 8.5 to 10.5 Ma Twin Falls volcanic field. The tentative late Miocene age for the volcanic ash layers are a little older than the Pliocene or upper Pliocene age indicated by fossils from the same general locality.

The South Arkansas graben sequence (Td2) has a slightly older age indicated by mammal fossils and preliminary age determinations on volcanic ash beds. Van Alstine (1974) described fossil horse teeth that indicate a late Miocene age (U.S.G.S. vertebrate fossil locality D750) from the Maysville quadrangle (from Elephant Rock area). Hubbard and others (2001) reported ages, based on tephrochronology, of two volcanic ash layers from near Little Cochetopa Creek in the Maysville quadrangle. The two ash layers yielded ages of 13.3 +/- 0.2 and 14.2 +/- 1.4 Ma, suggesting a middle Miocene age that is slightly older than the late Miocene age based on mammal fossils. Thus, structural

relations, age constraints from fossils (Van Alstine, 1974), and tentative tephrochronological age determinations on volcanic ash beds (Xu, 2001; Xu and others, 2001; Hubbard, and others, 2001) suggest that the South Arkansas graben sequence (Td2) is middle Miocene near the base and is older than the Upper Arkansas graben sequence (Td) with indicated late Miocene, Pliocene, or upper Pliocene ages.

Td Upper Arkansas graben sequence (Miocene? and Pliocene) – Consists of white, pinkish-white, orangeish-tan, and light-greenish-gray, very fine-grained siltstone, minor fine-grained sandstone, with minor, thin, discontinuous pebble conglomerate to boulder conglomerate lenses (fig. 13). The siltstone and conglomerate are generally very poorly indurated to unconsolidated. Bedding varies from massive siltstone sequences to moderately well-bedded siltstone-conglomerate sequences. Bedding is generally on the order of inches to feet. The pebble to boulder conglomerate beds are relatively thin discontinuous lenses that range up to about 5 ft thick and up to hundreds of feet long.

Minor thin beds of gritty siltstone to sandstone and pebble conglomerate are moderately indurated and are more resistant to weathering. Very poorly to moderately indurated beds are normally cemented with calcium carbonate. The more indurated zones are controlled by bedding horizons and no cementation is visibly controlled by structures.

The Dry Union Formation (Td) in the Maysville quadrangle is preserved in the southwestern corner of the Upper Arkansas graben. The sequence is preserved between the northeast-trending Shavano fault zone on the northwest and the west-northwest-trending Salida-Maysville fault on the southwest; the sequence forms a large trapezoidal area in the west-central part and northeast quadrant of the Maysville quadrangle (plate 1). It is present as a series of narrow to broad bands that form a semi-radiating pattern that converge, or point back to, the northeast-trending Shavano fault zone at the range front in the area of the North Fork and Squaw Creek.

The best exposures of the Upper Arkansas graben sequence (Td) are in a north-trending zone of rugged badlands topography that is present in the western part of the Salida West quadrangle and that extends along the northeastern edge of the Maysville quadrangle. Most areas of the unit are adjacent to and beneath thin layers of glacial outwash and Quaternary gravel that cap semi-flat ridge piedmont surfaces developed on

the Dry Union Formation. These capping gravels produce a concentrated boulder lag that drapes over and contaminates areas of underlying Dry Union Formation and hamper recognition of outcrops. Observations are also hampered by the development of thick soils and dense timber, which generally increase in thickness and density towards the west and the Sawatch Range front. Consequently, the further west in the Dry Union sequence the less understood the characteristics of the formation.

Ten orientations of bedding in the Upper Arkansas graben sequence (Td) were found in the Maysville quadrangle. Nine are along the eastern margin of the quadrangle. The orientations are variable over relatively short distances and the dip directions also change. The dip of bedding ranges from 5 to 26 degrees and is predominantly west, southwest, and northwest. Near the south end of the graben on the east side of the North Fork, the orientation of bedding in a small area of badland pinnacles is north-south with a 12° west dip. These observations together with other bedding orientations from the Salida West quadrangle indicate that the Dry Union Formation in the southern Upper Arkansas graben does not have consistent bedding orientations and is probably warped by gentle broad flexures or is locally deformed and rotated by faulting.

Subtle variations in the nature of the interbedded conglomerate lenses exist across the piedmont area. North of Squaw Creek the conglomerate clasts are commonly up to 2 ft and locally up to 6 ft in size and consist of 40 to 60 percent Tertiary volcanic rocks (flow rocks and minor welded tuff) and hypabyssal intrusive rocks, 10 to 25 percent Mount Aetna quartz monzonite, 10 to 25 percent Mount Princeton quartz monzonite, and 0 to 7 percent Proterozoic rocks (Xgd and Xag). South of Squaw Creek the conglomerate clasts are typically less than 6 inches and consist of 65 to 80 percent Proterozoic rocks (Xgd and Xag), 10 to 15 percent Mount Princeton quartz monzonite, 5 to 10 percent Mount Aetna quartz monzonite, and 0 to 5 percent Tertiary volcanics. These variations are interpreted to be related to different levels of stratigraphic exposure with higher proportions of Tertiary volcanic rocks, hypabyssal intrusions, and Mount Aetna ring dikes at deeper stratigraphic levels of the Dry Union that record removal of the higher levels (volcanic and hypabyssal rocks) of the caldera system. Higher stratigraphic levels of Dry Union have predominantly Proterozoic rocks and Tertiary plutonic rocks. The exposures of different stratigraphic levels of Dry Union Formation are interpreted to be

related to the inferred Squaw Creek fault (see Structure Section).



Figure 13. Road-cut exposure of Dry Union Fm Upper Arkansas Valley graben sequence (Td). Interbedded siltstone and small-clast to pebble conglomerate.

Td2 South Arkansas graben sequence (middle to upper Miocene and Pliocene?) –

Consists of white, cream, tan, orangish or greenish, very fine-grained siltstone, conglomerate, and clay beds. Contains some sandstone and gritty layers. The rocks are generally poorly to medium bedded, and bedding is relatively medium scale, typically on the order of tens of inches to tens of feet. Graded bedding is generally absent, but crude, large-scale grading is associated with some conglomerate beds. The conglomerates are typically matrix supported and locally almost clast supported, especially in the western part of the graben (fig. 14). The conglomerate clasts are typically much larger in the South Arkansas graben sequence than in the Upper Arkansas graben sequence. The conglomerate layers tend to be 1 to 4 ft thick in the eastern part of the graben and up to hundreds of feet thick in the western part. The blocks are typically subangular and range from 1 to 6 ft but in the west part of the graben blocks are commonly up to 10 to 12 ft in

size. The largest block observed is about 20 ft in size.

Throughout the South Arkansas graben, the conglomerate clast compositions are predominantly Proterozoic lithologies including amphibolite gneiss (Xag), granite and pegmatite (YXgp) and mafic amphibolite and meta-gabbro. The larger blocks are usually granite and pegmatite (YXgp). However, conglomerate clast compositions that are related to stratigraphic level vary significantly east-west across the graben. The conglomerates contain abundant (10 to 40 percent) clasts of Paleozoic sedimentary rocks and Tertiary volcanic rocks in the Pass Creek area in the east part of the graben. In contrast, Tertiary volcanic rocks are completely lacking and Paleozoic sedimentary rocks are rare in the west part of the graben.

The South Arkansas graben sequence is preserved in a 9,000 ft by 18,000 ft rectangular area in the southeast quadrant of the Maysville quadrangle (plate 1). It is in fault contact (poorly exposed) with the Proterozoic basement along the Willow Creek fault in the west and in fault contact (concealed) with Quaternary gravels along the Salida-Maysville fault. The South Arkansas graben sequence is unconsolidated to weakly indurated and is poorly exposed. Minor weak carbonate cement is locally developed and caliche is locally common as boulder-clast coatings and thin horizons in the sediments. Localized thin discontinuous layers of gypsum-rich grit and some thin iron oxide rich horizons may represent paleosols (?). The best exposures of the South Arkansas graben sequence are in a few road cuts along the Green and Willow Creek roads and in the low hills with narrow incised gulches, on the south side of the South Arkansas River in the southeast part of the quadrangle.

Limited exposures of the Dry Union Formation in the west part of the South Arkansas graben indicate a relatively consistent north-south strike and shallow (13° to 19°) dip to the west. Better exposures in the eastern part of the South Arkansas graben show more variable bedding orientations. Overall the beds strike north-south to northeast with shallow to moderate (15° to 38°) dips to the northwest. Locally the bedding is oriented north-northwest with similar dips to the southwest. In the area of the third Paleozoic rock landslide sheet (Td2ls) in the NW^{1/4}, Section 12, T49N, R7E the bedding is predominantly east-west to northeast with shallow to moderate (14° to 49°) dips north.



Figure 14. Crude bedding in coarse conglomerate in highest levels of exposure of the Dry Union Formation South Arkansas graben sequence (Td2). Note large block size and locally almost clast-supported character.

In the eastern part of the graben, exposures are better and show the presence of an unusual association of thick, clay-rich beds (Td2c) interlayered with the more typical siltstones. In addition, this sequence also has horizons of detached, Paleozoic sedimentary rock landslide sheets (Td2ls) and a local area of “pond sediments” containing fossil charophytes, ostracodes, gastropods, and pelecypods (Van Alstine, 1970).

Td2c Clay bed series (middle to upper Miocene?) – Clay beds are generally greenish to greenish-gray, very fine-grained clay to fine silt. They are unconsolidated and massive, but locally display fine, faint bedding laminations. Exposures of individual clay beds range from about 10 to 60ft thick and they are locally interlayered with the more typical siltstone. Clay beds lack any in-place conglomerate layers, but surfaces are typically littered with the clasts from surrounding thin conglomerate beds.

The clay beds are spatially associated with two horizons of Paleozoic landslide sheets (Td2ls) and two volcanic ash beds (Td2v) in the lower part of the Dry Union Formation (Td2) in the eastern part of the South Arkansas graben (plate 1). They are exposed over a zone about 3,300 ft wide with a suggested true thickness of about 1,800 ft. The clay beds are concentrated in two main sub-parallel zones that trend about N20°E. The eastern zone is about 1,200 ft wide with an estimated true thickness of about 650 ft. It is exposed for about 3,000 ft along strike but it is not certain if it crosses Pass Creek and extends past the south boundary of the quadrangle. The western zone is about 800 ft wide with an estimated true thickness of about 500 ft (150 m). It extends for about 4,000 ft along strike and becomes difficult to trace in the boulder-covered steeper slopes to the south. Clay beds may have a significant component of volcanic ash.

Td2v Volcanic ash (middle to upper Miocene?) – Two volcanic ash beds are mapped in the South Arkansas graben sequence in the southeast corner of the Maysville quadrangle. The first volcanic ash bed locality was located by Van Alstine (1974) in the SW¼, NW¼, Section 7, T.49N., R.8E. (locality 4; see Structural Geology section). A second volcanic ash bed found during this study is present about 1,800 ft west of the first locality in the NE¼, Section 12, T.49N., R.7E. (locality 4A, see Structural Geology section).

The volcanic ash is white to very light gray, very fine-grained, and ranges from massive to strongly fissile (fig.15). Most of the ash layers are clean with little or no evidence of detrital contamination. Hand samples indicate the lack of discernable biotite or other mafic minerals. One thin section of volcanic ash from Section 7 was examined for this study. The ash exhibits vitroclastic texture and consists of about 98 percent of elongated fragments of glass bubble walls (fig. 16). Most of the fragments are tabular with only a small percentage showing flaring ends. This suggests that the glass vesicles were relatively large and possibly highly flattened. The elongated bubble walls are strongly aligned parallel to faint bedding laminations. The volcanic ash exhibits minor fine-scale bedding laminations produced by variations in the size of the bubble wall fragments. Crystal fragments contribute about 1 to 2 percent of the ash, including remnant biotite grains that are completely altered to clay, and minor hornblende,

microcline, and muscovite. The latter crystal fragments are detrital contaminants from Proterozoic rocks.



Figure 15. Subcrop of fissile volcanic ash bed (Td2v) in the Dry Union Formation South Arkansas graben sequence.

The volcanic ash bed at the Section 7 locality is well exposed and was traced for about 1,200 ft along strike (fig. 17). Discontinuous outcrop and subcrop indicate the ash bed is about 3.0 to 3.5 ft thick. The map pattern has an overall strike of about N35°E with a broad warping with the convex side to the west. Individual bedding orientations indicate 25° to 37° dips mainly to the northwest, but dips locally change to the west-southwest. The orientation of the ash bed is parallel and conformable with bedding in the surrounding Dry Union Formation siltstones, clay beds, and conglomerates. On the basis of tephrochronological studies, Hubbard and others (2001) determined ages of 13.3 +/- 0.2 Ma and 14.2 +/- 1.4 Ma on two volcanic ash locations from this same general area.

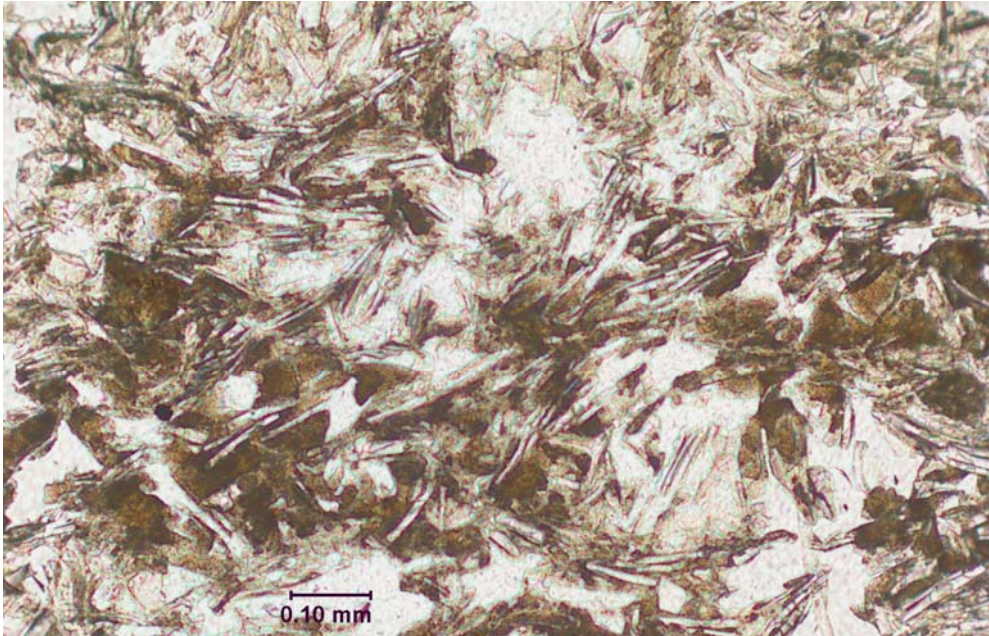


Figure 16. Photomicrograph of volcanic ash (Td2v) from the Dry Union Formation South Arkansas graben sequence (Td2). Note abundance of elongated shards (white) that suggest elongated, stretched vesicles. Plane light.

The volcanic ash bed at the second locality in Section 12 is discontinuously exposed for about 400 ft. Variations in thickness suggest that there may be two ash beds, one about 1 foot thick and the second about 2 inches thick. The overall map pattern suggests the thicker ash bed is oriented about N24°E, but individual orientations show strikes ranging from east-northeast to east-west to northwest and dips of 14° to 49° to the north and northeast. The ash beds are apparently disrupted by small open folds and possibly by faulting. Another outcrop of an ash layer about 1.0 ft thick is present about 1,100 ft to the southwest, suggesting 1,500 ft of strike length. The outcrop has abundant crystal and small lithic clasts, indicating significant detrital contamination. The volcanic ash bed in Section 7 is located near the stratigraphic top of the eastern clay bed zone and the volcanic ash bed in Section 12 is at a stratigraphically central position in the western clay bed zone.



Figure 17. View of eastern volcanic ash bed (Td2v) in the Dry Union Formation South Arkansas graben sequence (Td2). Section 7 locality (Locality 4, Table 4).

Td2ls Landslide sheets and blocks (middle to upper Miocene?) – One of the most geologically intriguing features of the South Arkansas graben is the occurrence of allochthonous Paleozoic sedimentary rock blocks described by Van Alstine (1970 and

1974). They are present in three zones in the eastern part of the graben. The eastern zone (in the Salida West and Poncha Pass quadrangles) and the central zone (in the Salida West, Maysville, and Mount Ouray quadrangles) were identified and described by Russell (1950) and Van Alstine (1970). A third zone (western zone) of detached landslide blocks that lies to the west of the two previously recognized zones (plates 1 and 3) was identified in the Maysville quadrangle during this study.

The central zone has the best exposures and the most complete section of Paleozoic sedimentary rocks. The largest and best exposure is at Elephant Rock (named by Kansas State University students) just outside the western boundary of the Maysville quadrangle. Van Alstine (1970) detailed descriptions of the landslide blocks are excellent and can hardly be improved upon here. He described an about 300 ft thick section including the Manitou, Harding, Fremont, and Chaffee Formations in the Elephant Rock area. The Paleozoic blocks are made up predominantly of crackled and brecciated dolomite and limestone with predominantly angular fragments set in a highly indurated matrix of crushed carbonate rock cemented by fine to coarsely crystalline calcite.

Observations made during this study indicate that in terms of length to thickness aspect most of the outcrops of Paleozoic rocks are more aptly described as landslide sheets. The landslide sheets typically display coherent large-scale bedding features between the different carbonate formations and especially between interlayered brecciated carbonate and unbrecciated quartzite beds. The carbonates beds are preferentially brecciated in comparison to the quartzite beds. The degree of brecciation of carbonate beds is variable and there are wide variations in breccia textures including clast size, clast-size sorting, degree of disruption of internal bedding, presence of chert nodules, amount of carbonate cement, and clast to matrix relationships (fig. 18). The horizons of sheets are characterized by lateral zones of small to large block conglomerate that were emplaced at the same time. These lateral horizons of landslide blocks include large blocks up to 10 to 12 ft in size of both brecciated and unbrecciated Paleozoic carbonate rocks, unbrecciated Paleozoic quartzite and Proterozoic rocks, and a smaller component of unbrecciated Tertiary volcanic rocks including welded ash-flow tuff.



Figure 18. Close-up view of intensely shattered Paleozoic dolomite (gray) and minor chert (white) from the central Paleozoic landslide sheet (Td2ls) in the Dry Union Formation South Arkansas graben sequence (Td2).

The conglomerate beds in the Dry Union Formation stratigraphically above the central zone of landslide sheets and blocks locally contain up to about 30 percent blocks and clasts of Paleozoic carbonate and quartzite. Some of these blocks are shattered and, in general, the percent of shattered blocks and the total percentage of Paleozoic blocks and clasts decreases up section.

The central zone of landslide sheets-blocks is situated on the west side of the mouth of Little Cochetopa Creek (figs. 2 and 19). It is an almost continuous zone of outcrops and concentrated float that extends for about 5,200 ft including about 2,200 ft in the Salida West quadrangle and about 3,200 ft across the southeast corner of the Maysville quadrangle. It terminates, or is lost under cover, about 1,000 ft from the southern edge of the Maysville quadrangle, but additional sheets and blocks of brecciated Paleozoic carbonate are present about 6,000 ft south, suggesting the zone is discontinuous. Overall the zone is a minimum of 800 ft wide and trends about N32°E. Bedding orientations of shattered carbonates at Elephant Rock and in the Maysville

quadrangle are about N23°E with 32° dip to the northwest, similar to bedding in the surrounding Dry Union Formation. The central zone of landslide sheets and blocks is spatially associated with the stratigraphically lower part of the eastern clay bed zone.



Figure 19. Outcrop of central Paleozoic landslide sheet (Td2ls) in the Dry Union Formation South Arkansas graben sequence. The middle dark gray dolomite bed is intensely shattered. Moderate dip is to west.

The western zone of brecciated Paleozoic landslide sheets-blocks found during this study is about 4,000 ft northwest of the central zone. The western zone is about 800 ft long and oriented about N25°E. Slabs of brecciated carbonate dip about 32° northwest. The western zone of landslide sheets and blocks is spatially associated with the stratigraphic central part of the western clay bed zone. Van Alstine (1970) calculated that the eastern zone is about 700 ft and the central zone is about 2,600 ft above the base of the Dry Union Formation at the east edge of the South Arkansas graben. A cross section for this study (section B-B'-B'', plate 3) indicates the eastern horizon is a minimum of 600 ft, the central horizon is a minimum of 2,000 ft, and the western horizon is a minimum of 3,500 ft above the lowest exposed horizon of the Dry Union Formation.

A major remaining problem is determining if the three landslide sheet and block horizons represent three separate landslide events or if a single major event formed one horizon that has been subsequently disrupted and repeated by block faulting. A fault duplication model requires that the inferred faults must have had up to the west offset, which is not compatible with the location of the landslide sheets in the east part of the half graben where faulting should have down to the west offsets. The relationship of the detached landslide sheets and volcanic ash beds suggests a complex lake-bed sequence that potentially recorded three catastrophic landslide events and at least two and possibly four volcanic ash eruptions. Determining the distribution and ages of the volcanic ashes may help constrain models for the emplacement of landslide sheets.

TERTIARY IGNEOUS ROCKS – A wide variety of Tertiary igneous rocks cover an estimated 3 to 4 percent of the total surface area and ten percent of the exposed bedrock area of the Maysville quadrangle. They are almost exclusively in the northwest quadrant of the quadrangle except for possible minor Tertiary dikes (Ta) in the southwest quadrant. These igneous rocks include portions of large intrusions and stocks and abundant dikes. No igneous rocks related to the Laramide magmatic pulse have been recognized in the Maysville quadrangle.

Strictly speaking, all of the Tertiary igneous rocks are related to the Middle Tertiary magmatic pulse; most are associated with the Mount Princeton pluton and the Mount Aetna cauldron magmatic events. Igneous rocks related to the subsequent

transitional assemblage with affinities to the Late Tertiary magmatic pulse are also represented and include intrusions and dikes associated with the Mount Antero leucogranite magmatic event. These are part of a bimodal leucogranite-lamprophyre association that may be part of an early rift-related magmatic event (Shannon and others, 1987b; Shannon, 1988; McCalpin and Shannon, 2005). The rhyolite dikes are part of a regional swarm of bimodal dikes that extend for over 13.5 mi along the east flank of the southern Sawatch Range (Shannon, 1988). The Mount Antero leucogranite intrusions have affinities with A-type granites and characteristics of Climax-like intrusions (Shannon, 1988).

Other than minor, thin, airfall volcanic ash beds (Td2v) in the Dry Union Formation, no Tertiary volcanic rocks are exposed in the Maysville quadrangle. Tertiary volcanic rocks only occur as clasts in the Tertiary Dry Union Formation (Td and Td2) and Quaternary tills and gravels. These clasts may have been derived predominantly from the Mount Aetna cauldron area. Tertiary volcanic rocks probably occur in the subsurface, below the Dry Union Formation (Td2) along the floor of the South Arkansas graben in the southeastern part of the Maysville quadrangle (section B-B'-B'' plate 3). Remnants of the Wall Mountain Tuff may be preserved at depth along the floor of the Upper Arkansas graben in the subsurface of the eastern and northeastern parts of the Maysville quadrangle. This is mainly supported by the westward projection of the main Salida-Waugh Mountain paleovalley, which intersects the east margin of the Upper Arkansas graben in the Browns Canyon area (fig.5).

Rift-related magmatism (~29.8 Ma) – Two leucogranite intrusions (Tnfg and Tcm) and a swarm of rhyolite dikes (Trp and Tr) related to the highly evolved Mount Antero leucogranites are present in the northwest quadrant of the Maysville quadrangle. They constitute an estimated 1 percent of the surface area. Parts of both intrusions cut the Mount Princeton pluton, and the dikes cut Proterozoic rocks. The dikes extend into the southern part of the Mount Antero quadrangle where they also cut the Mount Princeton pluton.

Tr Rhyolite dikes (early to late Oligocene?) – Two aphyric rhyolite (Tr) dikes are present in the northwest quadrant of the Maysville quadrangle. The dikes are part of a northeast-trending set of dikes including rhyolite porphyry (Trp), rhyolite (Tr), fine-grained granite (Tcf), and quartz latite porphyry (Tqlp) that cut Proterozoic rocks in the Maysville quadrangle and extend into the southern part of the Mount Antero quadrangle where they cut the Mount Princeton pluton.

The rhyolite dikes are light gray, aphyric, and aphanitic, and consist of an extremely fine-grained quartz-feldspar mosaic intergrowth. They are generally massive and have minor irregular flow layering developed at some contacts. The dikes are not well exposed but occur as concentrated float zones. The small angular float rock is typically lost or overwhelmed in the coarse block talus characteristic of the Proterozoic granodiorite (Xgdf) host.

Two segments of a probable 4,500 ft long continuous aphyric rhyolite dike cut Early Proterozoic granodiorite (Xgdf) about 4,000 ft east-southeast of Shavano Lake. The dike does not crop out and occurs as narrow concentrated float zones that suggest thicknesses of less than ten feet and a northeast strike with a moderately steep dip to the northwest. A second aphyric rhyolite dike is present along the main northeast-trending range-front structure (Sawatch fault zone) north of Squaw Creek. Concentrated rhyolite porphyry dike (Trp) float is almost continuous along this 6,000-foot-long fault zone and aphyric rhyolite (Tr) is present at two localities at the center and north end of the structure. The aphyric rhyolite occurs as minor subcrop and as concentrated float suggesting dike thicknesses up to about 10 ft.

The field relations suggest that the fault zone has a rhyolite porphyry dike and locally a composite rhyolite porphyry-aphyric rhyolite dike along it. The relative ages of the rhyolite porphyry and aphyric rhyolite dikes was not established, but their presence as subparallel dikes and presence in the same conduits suggests a similar age. Much of the aphyric rhyolite along the Sawatch fault zone is brecciated. Two types of breccia are present including (1) an annealed, partly open, crackle breccia that may represent a late-stage hydrothermal breccia and (2) a tectonized-silicified breccia suggesting continued fault movement along the structure after the rhyolite dike was emplaced.

Trp Rhyolite porphyry dikes (early to late Oligocene?) – At least four rhyolite porphyry dikes are present in the northwest quadrant of the Maysville quadrangle (plate 1). They cut Early Proterozoic gneisses (Xhig, Xag and Xgp) and granodiorite (Xgdf). The rhyolite porphyry dikes range from whitish to light pinkish gray and are generally massive. They have porphyro-aphanitic texture with variable, moderate to high phenocryst contents (30 to 45 percent). Quartz phenocrysts (12 to 15 percent) are generally euhedral (1 to 3 mm) and commonly have a slight smoky color. Alkali-feldspar phenocrysts (7 to 12 percent) are subhedral to euhedral (2 to 4 mm) and plagioclase phenocrysts (8 to 15 percent) are generally subhedral (1 to 3 mm)). Small biotite phenocrysts (1 to 3 percent) are typically intergrown with, or partly replaced by muscovite. The dikes are characterized by trace to 2 percent accessory orangeish garnet and trace to 1 percent fine disseminated magnetite. Orangeish garnet appears to be a primary accessory mineral disseminated in the rhyolite but also locally occurs as fine coatings on fracture surfaces suggesting some is late magmatic or deuteric.

Two rhyolite porphyry dikes occur in a northeast-trending set subparallel to aphyric rhyolite (Tr), fine-grained granite (Tcf) and quartz latite porphyry hybrid (Tqlp) dikes. The main dike occurs in three segments, suggesting a continuous or nearly continuous dike for about 11,500 ft across the Maysville quadrangle and continuing for another 6,500 ft in the Mount Antero quadrangle. The central portion of this dike, on the ridges north and south of Squaw Creek (fig. 20), is composite consisting of both rhyolite porphyry (Trp) and fine-grained granite (Tcf). Outcrops of the dike show thicknesses ranging from 10 to 35 ft, and some concentrated, large block float zones are up to 150 ft wide. Exposed contacts indicate that the dike strikes from N2° to 37°E with dips from 35° to 68°NW. The overall orientation is about N25°E with a 50°NW dip.

The second northeast-trending rhyolite porphyry dike occurs as an almost continuous float zone for about 6,000 ft along the range front associated with the Sawatch fault zone north of Squaw Creek. Similar rhyolite porphyry float on the Blank Mine adit dump, about 7,000 ft southwest, suggests that a rhyolite porphyry dike was also emplaced along the Sawatch fault zone in that area. North of Squaw Creek, two outcrops of the rhyolite porphyry are present but no contacts are exposed. A rib of silicified rhyolite porphyry breccia at the northern Maysville map boundary trends N45°E and is the same

as the overall N47°E trend of the Sawatch fault zone.

A second set of northwest-trending rhyolite porphyry dikes consists of two 1,500 to 3,000 ft long dikes, about 6,000 ft southeast and 11,000 ft east of Mount Shavano. The dikes are similar to the northeast-trending rhyolite porphyry dikes but are thinner and generally have lower phenocryst content. One subcrop and the narrow float zones suggest the dikes are about 5 to 10 ft thick. The relative ages of the two rhyolite porphyry dike sets, the aphyric rhyolite dikes, and the quartz latite porphyry hybrid dikes could not be established by cross cutting relationships. The main northeast-trending rhyolite porphyry dike cuts the Mount Princeton pluton less than 1,000 ft north of the northern boundary of the Maysville quadrangle.



Figure 20. View of Shavano Lake in Squaw Creek glaciated valley overlooking the southern Upper Arkansas Valley graben. Note Tertiary rhyolite dike (Trp) in distance.

Table 1. Whole-rock chemical analyses of select igneous rocks from the Maysville quadrangle, Colorado. Sample locations are given in Appendix 1. [Commercial analyses by ALS-Chemex, Sparks, Nevada (Certificate RE05113617). XRF analyses.]

	Trp Dike	Tnfg	Tqlp Dike	Tmpp	Tqm	Ta Dike	Ta Dike
SiO ₂	75.82	76.05	58.53	61.68	57.42	54.01	60.91
Al ₂ O ₃	13.71	12.62	16.23	16.92	16.27	15.04	15.06
Fe ₂ O ₃ ¹	0.73	0.58	7.49	5.93	8.14	8.02	5.47
CaO	0.30	0.31	4.57	3.36	5.57	3.88	3.18
MgO	0.03	0.04	3.33	2.33	2.77	5.02	2.83
Na ₂ O	4.32	3.76	3.60	3.59	2.83	3.12	4.10
K ₂ O	4.41	4.40	3.26	3.28	2.86	4.01	3.17
Cr ₂ O ₃	0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01
TiO ₂	0.06	0.08	1.14	0.84	1.05	1.11	0.77
MnO	0.08	0.06	0.07	0.10	0.13	0.13	0.10
P ₂ O ₅	0.01	0.01	0.53	0.25	0.30	0.54	0.35
SrO	<0.01	<0.01	0.11	0.07	0.05	0.08	0.06
BaO	<0.01	0.01	0.18	0.15	0.12	0.28	0.20
LOI ²	0.27	0.34	0.88	1.44	0.66	4.72	3.32
TOTAL	99.75	98.26	99.92	99.94	98.17	99.98	99.53

Trp dike	05-542	Oligocene rhyolite porphyry dike
Tnfg	05-575A	Oligocene North Fork leucogranite intrusion
Tqlp dike	05-258	Eocene (?) quartz latite porphyry hybrid dike
Tmpp	05-504	Eocene Mount Pomeroy subunit
Tqm	05-821	Eocene (?) quartz monzodiorite intrusion
Ta dike	05-03	Tertiary (?) andesite hybrid dike
Ta dike	05-680	Tertiary (?) andesite hybrid dike

¹ Total Fe as Fe₂O₃

² LOI- Lost On Ignition (volatiles)

One age determination on the rhyolite porphyry dikes in the Mount Antero region was reported by Limbach (1975). A K-Ar whole rock age determination of 25.4 +/- 1 Ma for a rhyolite porphyry dike in Chalk Creek was recalculated (Shannon, 1988) by using revised constants from Dalrymple (1979) as 26.1 +/- 1 Ma.

Table 1 gives a whole rock chemical analysis (sample 05-542) of the main northeast-trending rhyolite porphyry dike. The analysis indicates an alkali rhyolite composition (De la Roche and others, 1980) with a very high SiO₂ content (75.82 percent), and high Na₂O content (4.32 percent) and K₂O content (4.41 percent). This analysis is very similar to a sample of rhyolite porphyry dike from the Buena Vista West quadrangle (McCalpin and Shannon, 2005) except for slightly higher Al₂O₃ and Na₂O contents. The chemistry of the rhyolite porphyry dike is also very similar to the North Fork leucogranite (sample 05-575A, table 1).

Tcf California leucogranite-rhyolite dikes (early Oligocene?) – These porphyritic, fine-grained, biotite granite-rhyolite dikes (Tcf) are white to light gray and have variable texture with generally moderate phenocryst content and aplitic groundmass with a 0.1 to 0.5 mm grain size. In general, the phenocrysts tend to be less euhedral and the groundmass is coarser in the fine-grained granite-rhyolite dikes (Tcf) in comparison to the rhyolite porphyry dikes (Trp). The distinction between phenocrysts and groundmass is also less clear than in the rhyolite porphyry, because of the coarser and variably textured groundmass. The overall phenocryst content varies from about 20 to 40 percent with 8 to 15 percent quartz (1 to 3 mm), 7 to 12 percent alkali feldspar (1 to 3 mm), 5 to 12 percent plagioclase (1 to 2 mm), 2-4 percent biotite-muscovite (0.5 to 2.0 mm), 1 to 3 percent orangeish garnet (0.2 to 2.0 mm), and 0.5 to 2 percent magnetite.

Two dikes of porphyritic, fine-grained, biotite granite-rhyolite (Tcf) are mapped in the northeast corner of the Maysville quadrangle (plate 1). In addition, numerous 1 to 5 ft thick dikes are present in the area around the summit of Mount Shavano and are especially abundant around the California leucogranite intrusion (Tcm) in Squaw Creek. One dike occurs as a 4,000 ft long, arcuate, northeast-trending dike crossing the ridge just north of the summit of Mount Shavano; the dike extends for another 2,500 ft into the southwest corner of the Mount Antero quadrangle. The dike is 8 to 20 ft thick and strikes

about N27°E and dips 74°NW. It cuts the Mount Princeton pluton (Tmpp) and comes within about 400 ft of the California leucogranite intrusion (Tcm).

The second dike occurs as a composite dike along the central portion of the main northeast-trending rhyolite porphyry dike (Trp) that straddles Squaw Creek. For about 4,500 ft, this dike is composite, consisting of two phases present in the same dike structure. One phase is moderate-high phenocryst, rhyolite porphyry (Trp) with an aphanitic groundmass and the other phase is a moderate phenocryst, aplite to fine-grained granite. The dike is poorly exposed and is expressed by a mappable concentrated float zone. One float sample showed a sharp contact between the two phases, suggesting a composite dike rather than a zoned dike with the quenched rhyolite phase being the earlier intrusion.

Shannon (unpublished data, 1981) conducted a modal analysis (2,000 points on slab stained for alkali feldspar) of the California fine-grained granite-rhyolite dike from the composite Trp-Tcf dike just within the boundaries of the Maysville quadrangle and about 3,800 ft west of Shavano Lake. The total mode shows about 24.5 percent quartz, 40.6 percent alkali feldspar, 34.3 percent plagioclase, 0.3 percent biotite-muscovite, and 0.3 percent magnetite. According to IUGS classification, California fine-grained granite-rhyolite dikes are granite b. However, if plagioclase is albitic (An 5 or less) the rock would have a modified classification of alkali-feldspar granite (Ramsay and others, 1985). In general, the fine-grained granite dikes tend to have higher biotite-muscovite, garnet, and magnetite contents in comparison to the rhyolite porphyry dikes (Trp).

Tcm California leucogranite (early Oligocene?) – Most of this intrusion is in the Mount Antero quadrangle but a small sliver (about 400 feet long and less than 100 feet wide) is present on the north boundary of the Maysville quadrangle, about 2,500 feet west of Shavano Lake. The 2,000 by 900 foot rectangular intrusion of medium-grained biotite-garnet leucogranite (Tcm) occurs in the head of Squaw Creek. This body was considered to be a satellite body of the main California leucogranite intrusion in Browns Creek in the Mount Antero quadrangle (Shannon, 1988). The western contact is well exposed and is a north-northwest-trending fault contact between leucogranite and the Mount Princeton pluton (Tmpp). The eastern contact is not exposed but is also interpreted to be a north-

northwest-trending fault. Thus, field relations suggest that the leucogranite is exposed in a narrow horst block.

The California leucogranite is a white, medium-grained, equigranular, biotite-garnet granite. Unpublished data from Shannon (1984) included a modal analysis (2010 points on slab stained for alkali feldspar) on a sample of the satellite California leucogranite intrusion from the Mount Antero quadrangle (about 1,400 feet north of the northern boundary of the Maysville quadrangle). The mode showed 27.0 percent quartz, 35.3 percent alkali feldspar, 35.2 percent plagioclase, 1.4 percent biotite-muscovite, 0.6 percent magnetite, and 0.4 percent garnet. Orange to reddish garnet is conspicuous in most samples of the California leucogranite and locally ranges up to about 2.0 percent of the rock. Mineral separates on samples of the California leucogranite intrusion from the Mount Antero quadrangle indicate the accessory mineral suite includes garnet, magnetite, ilmenite, monazite, fluorite, zircon, and rare tourmaline. The California leucogranite is classified as granite b (IUGS classification) or alkali-feldspar granite (Ramsay and others, 1985) depending on the composition of the plagioclase.

Shannon (1988) compiled whole-rock chemical analyses of the main California intrusion in the Mount Antero quadrangle, including four samples of fine-grained granite border unit and dikes (Tcf) and two samples of medium-grained leucogranite (Tcm). The analyses show similar chemistry of alkali granite compositions (De la Roche and others, 1980) with very high SiO₂ (75.5 to 78.3 percent), K₂O (4.1 to 5.5 percent), and Na₂O (3.4 to 4.6 percent). Overall higher silica and rubidium contents in the California leucogranite compared with the Mount Antero leucogranite suggest a chemically, slightly more-evolved composition.

The California leucogranite is younger than the Mount Princeton pluton (Tmpp, Tmpm and Tmpk phases), the Mount Aetna quartz monzonite ring dikes (Tma), and the Mount Antero leucogranite intrusion on the basis of cross-cutting relationships in the Mount Antero quadrangle (Shannon, 1988). The relative ages of the California and North Fork leucogranite intrusions could not be established by cross-cutting relations. Shannon (1988) suggested the similar mineralogy and chemistry of these intrusions support that they were emplaced close to the same time and just after the Mount Antero leucogranite.

Two age determinations on the California leucogranite intrusion in the Mount

Antero quadrangle have been reported. A K-Ar biotite age determination of 29.9 +/- 1.1 Ma reported by Coolbaugh (1985) was recalculated (Shannon, 1988) using the revised decay constants from Dalrymple (1979) as 30.7 +/- 1.1 Ma. A fission-track zircon age determination of 29.3 +/- 2.8 Ma was reported by Shannon (1988), who suggested a mean age of 29.8 Ma for the Mount Antero leucogranites (Mount Antero, California and North Fork intrusions). The age was based on the average of 6 K-Ar and 2 fission track ages on the leucogranites and 7 fission-track ages on older intrusions (Mount Princeton and Mount Aetna) that were thermally reset during intrusion of the leucogranites. Recent high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ dating (McIntosh and Chapin, 2004) includes two samples from Mount Antero (probably the Mount Antero leucogranite intrusion) that provide a mean of four (two biotite and two muscovite) ages of 29.59 +/- 0.13 Ma for the Mount Antero leucogranite.

Tnfb North Fork leucogranite border (early Oligocene?) – The North Fork leucogranite is an irregular, slightly elongated E-W, approximately 1,200 by 6,000 ft intrusion that straddles the western boundary of the Maysville quadrangle with the Garfield quadrangle. An approximately 3,500 by 6,000 ft area of the eastern part of the intrusion is well exposed on the north side of the North Fork in the Maysville quadrangle. It has a well-developed border zone of fine-grained, biotite leucogranite (Tnfb) and a medium-grained, biotite leucogranite (Tnfg) interior.

The North Fork fine-grained leucogranite border (Tnfb) is white, pinkish white or orangish tan with an equigranular, 0.5 to 1.5 mm grain size (fig. 21). It is similar to California fine-grained leucogranite border and dikes but lacks the ubiquitous garnet that is present in the California intrusion. No modal analyses are available for samples of the North Fork border, but estimated mineral modes are similar to the California border with about 20 to 25 percent quartz, 35 to 42 percent alkali feldspar, 35 to 40 percent plagioclase, and 0.5 to 1.0 percent biotite-muscovite. The North Fork border contains minor, irregular quartz-feldspar-biotite pegmatite segregations and local zones with small, 2 to 10 mm miarolitic cavities. Minor disseminated pyrite is associated with miarolitic zones and minor quartz-pyrite veins are locally present.

The fine-grained leucogranite (Tnfb) occurs as a 100 to 400 ft thick border zone

on the North Fork leucogranite intrusion. The border unit forms an arcuate outcrop pattern along the eastern and northeastern part of the North Fork intrusion. The southern contact of the intrusion is concealed in the floor of the North Fork valley; it is not known if it is an intrusive or fault contact with the Proterozoic rocks. A zone of fine-grained leucogranite forms a border rind around a large pendant of Proterozoic rocks (Xag, Xq, Xgd, Xgdh) that occur along the west edge of the Maysville quadrangle. This pendant and another zone of Proterozoic pendants on the ridge on the west side of McCoy Creek in the Garfield quadrangle suggest that the roof zone of the North Fork intrusion is dipping southward into the North Fork valley. Dikes of fine-grained leucogranite are common in the contact zone of the North Fork intrusion in the Maysville quadrangle (with Proterozoic rocks) and in the Garfield quadrangle (with Tmpp). The dikes are generally 1 to 20 feet thick, but range up to 80 feet thick in McCoy Creek in the Garfield quadrangle. The North Fork fine-grained leucogranite dikes are distinguished from the California fine-grained leucogranite dikes by the lack of accessory garnet.



Figure 21. Slabs of North Fork border (Tnfb, left) and leucogranite (Tnfg, right) stained for alkali feldspar.

Tnfg North Fork leucogranite (early Oligocene?) – The North Fork leucogranite (Tnfg) forms the interior phase of the North Fork intrusion. The North Fork leucogranite (Tnfg) is a white to pinkish-white, equigranular, medium-grained biotite leucogranite (fig. 21) that is most similar in appearance to the California leucogranite (Tcm). A modal analysis (2,070 points on slab stained for alkali feldspar) on a sample of North Fork leucogranite from the western part of the intrusion in the Garfield quadrangle (1,600 feet west of the Maysville quadrangle boundary) indicates 26.8 percent quartz, 40.0 percent alkali feldspar, 31.3 percent plagioclase, 1.8 percent biotite-muscovite, and 0.1 percent magnetite (Shannon, unpublished data, 1988). The granite is classified as granite b (IUGS classification) or alkali-feldspar granite (Ramsay and others, 1985), depending on the composition of the plagioclase. The North Fork leucogranite has mineralogical characteristics that are transitional between the Mount Antero leucogranite and the California leucogranite. The North Fork leucogranite contains only minor garnet that is generally localized in zones close to the fine-grained granite border phase and the margins of the intrusion. In addition, the North Fork leucogranite has accessory apatite similar to that present in the Mount Antero leucogranite but lacking in the California leucogranite (Shannon, 1988). It also contains accessory magnetite, ilmenite, monazite, fluorite, and zircon.

A whole-rock chemical analysis (sample 05-575A, table 1) of the North Fork leucogranite (Tnfg) from the Maysville quadrangle was obtained for this study. The sample was collected from the eastern part of the intrusion, immediately interior to the border zone. The sample is chemically classified as alkali granite (De la Roche and others, 1980) and has elevated SiO_2 , Na_2O , and K_2O , and has low Fe_2O_3 , CaO and MgO . Shannon (1988), in a compilation of whole-rock chemical analyses of the Mount Antero leucogranites, provided an analysis of the North Fork granite (from London, 1987, written communication). The analysis is very similar to the above sample and included trace element analyses for Rb (335 ppm), Nb (45 ppm), and Sr (75 ppm). The major- and trace-element character of the North Fork leucogranite is similar to the whole group of chemically evolved granites and rhyolites associated with the Mount Antero leucogranite system.

A small 400 by 400 foot body of North Fork leucogranite is present along the western edge of the Maysville quadrangle about 3,500 ft north of the main body. It is the end of an about 3,500 ft long, 500 to 700 ft thick, arc-shaped, dike-like extension on the north side of the intrusion; the extension extends northward along the eastern edge of the Garfield quadrangle and enters the western edge of the Maysville quadrangle in upper McCoy Creek about 3,500 feet west-southwest of the summit of Mount Shavano. Most of this extension consists of medium-grained leucogranite (Tnfg). The eastern part of the North Fork leucogranite intrusion in the Maysville quadrangle intrudes Proterozoic rocks (Xhig, Xag and YXp) and the western part of the intrusion in the Garfield quadrangle intrudes the Mount Princeton pluton (Tmpp). On the basis of mapping talus block float, the northern extension of the North Fork intrusion cuts the northeast-trending Proterozoic-Mount Princeton pluton contact about 400 feet west of the western edge of the Maysville quadrangle.

Two earlier studies attempted age determinations on the North Fork leucogranite intrusion. Pulfrey (1971) reported a K-Ar biotite age of 30.8 +/- 1.1 Ma, which was recalculated (Shannon, 1988) with revised decay constants from Dalrymple (1979) as 31.6 +/- 1.1 Ma. Shannon (1988) conducted fission-track dating analyses on a sample of North Fork leucogranite from the western part of the intrusion in the Garfield quadrangle. A fission-track zircon age of 20.0 +/- 2.7 Ma and a fission-track apatite age of 19.7 +/- 2.7 Ma were interpreted to record reset uplift-cooling ages for this part of the Sawatch Range. Recent high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ dating by McIntosh and Chapin (2004) included eight samples of 'Mount Antero Granite'. On the basis of rough sample location information, one sample appears to be from the North Fork leucogranite intrusion. The alkali-feldspar age of 28.65 +/- 0.53 Ma and altered biotite age of 29.12 +/- 0.18 Ma from the same sample were rejected as inaccurate or imprecise.

Miscellaneous magmatism (late Eocene to early Oligocene ?) – This grouping of intrusive rocks includes minor quartz latite porphyry (Tqlp) that occurs as dikes in the northwest quadrant of the Maysville quadrangle. The dikes occur in the same area as the aphyric rhyolite (Tr) and rhyolite porphyry (Trp) dikes in a swarm that parallels the range

front and Shavano fault zone.

Tqlp Quartz latite porphyry hybrid dikes (late Eocene to early Oligocene?) – At least two and possibly three quartz latite porphyry dikes are part of the zone of dikes crossing the southeast flank of Mount Shavano. The quartz latite porphyry dikes are medium to dark gray and very fine-grained (fig. 22). Minor outcrop/subcrop and narrow concentrated float zones indicate the dikes are about 1 to 6 ft thick. The hand-sample and petrographic character of the quartz latite porphyry suggests affinities with the Mount Aetna cauldron ring dikes (Tma). The rock also has a hybrid character imparted by a relatively mafic-rich appearing groundmass (about 0.2 mm grain size) and a variable population of larger crystals. The mafic groundmass predominantly consists of well-developed, flow-aligned, subhedral plagioclase laths with about 10 to 20 percent amphibole and biotite. The subhedral, lath character of the plagioclase in the groundmass is never observed in Mount Aetna ring dikes and is more characteristic of andesitic and basaltic composition rocks. The larger crystals include a population (4 to 8 percent) of subhedral amphibole crystals interpreted to be primary phenocrysts and a variable population (from less than 1 percent to more than 18 percent) of rounded and resorbed-appearing crystals of alkali feldspar, quartz, plagioclase, and biotite. It is these larger crystals, especially the presence of alkali feldspars (locally with rapakivi overgrowths) to 0.80 inch size that impart a Mount Aetna ring-dike character (fig. 22). The larger, rounded crystals are clearly phenocrysts (or xenocrysts of phenocrysts) that have been partly, and variably resorbed in the dike. Most of the large plagioclase crystals have reaction coronas suggesting they are also xenocrysts, but some that lack reaction coronas may be primary phenocrysts.

Three segments of one quartz latite porphyry hybrid dike indicate a nearly continuous dike for about 12,000 ft across the Maysville quadrangle. The dike is within 500 to 1,200 ft east of and subparallels the main northeast-trending rhyolite porphyry dike (Trp). Minor float suggest the dike may extend another 3,000 ft to the southwest to the North Fork valley. The dike is poorly exposed and occurs as narrow concentrated float zones with an overall trend of N36°E. Two outcrops of quartz latite porphyry hybrid dikes indicate N28°E 56°NW (about 3,000 ft east-southeast of Shavano Lake) and

N12°E, 62°NW (about 6,000 ft southeast of Mount Shavano) orientations. This is similar to the overall trend of N25°E 50°NW of the main northeast-trending rhyolite porphyry dike (Trp) and is also subparallel to the southeast margin of the Mount Aetna cauldron ring zone (Shannon, 1988).

Three thin sections of quartz latite porphyry dikes (two from Maysville quadrangle and one from Mount Antero quadrangle) were studied. The quartz latite porphyry has accessory magnetite, sphene, apatite, and allanite, which is the typical suite of accessory minerals in the Mount Princeton pluton and the Mount Aetna intrusions. All three samples also show microscopic evidence of late magmatic, potassic alteration including secondary matted biotite replacing amphibole and local, patchy replacement of the groundmass by alkali feldspar.



Figure 22. Billets and slabs of Tertiary quartz latite hybrid dikes (Tqlp) stained for alkali feldspar showing range of textures and xenocryst contents.

A whole-rock chemical analysis of one sample of quartz latite porphyry dike is given in table 1. This sample has less than 1 percent xenocrysts, but it is not clear if this is due to less xenocrysts incorporated or more complete resorption of xenocrystic phenocrysts in this dike. The sample is chemically classified as a latite and plots close to the boundary with dacite (De la Roche and others, 1980). A comparison of the composition of the quartz latite porphyry dikes with the average composition of two types of Mount Aetna ring dikes and the average composition of andesibasalt (table 2) indicates that the overall composition of the quartz latite porphyry is compatible with mixing of an intermediate composition magma with a Mount Aetna-related magma.

Table 2. Whole-rock chemical comparison of quartz latite porphyry hybrid dike with Mount Aetna ring dikes and average andesibasalt. [Tmaqmp and Tmaqlp analyses by X-Ray Assay Laboratories, Don Mills, Ontario; Tqlp analysis by ALS-Chemex, Sparks, Nevada.]

	Tmaqmp	Tmaqlp	Tqlp Dike	Andesibasalt
SiO ₂	67.7	67.5	58.53	53.44
Al ₂ O ₃	14.8	15.0	16.23	16.93
Fe ₂ O ₃	3.25 ¹	3.30 ¹	7.49 ¹	3.75
FeO	-	-	-	5.58
CaO	2.17	2.50	4.57	8.36
MgO	1.07	1.00	3.33	4.76
Na ₂ O	3.91	3.69	3.60	3.04
K ₂ O	4.64	4.51	3.26	1.24
TiO ₂	0.45	0.46	1.14	1.19
MnO	0.06	0.06	0.07	0.15
P ₂ O ₅	0.20	0.20	0.53	0.23
H ₂ O ⁺	1.08	1.16	0.88 ²	0.86
H ₂ O ⁻	-	-	-	0.52
TOTAL	99.3	99.38	99.63	100.05

Tmaqmp	84-81-3	Mount Aetna Type 2 quartz monzonite porphyry ring dike (Shannon, 1988)
Tmaqlp	85-42c	Mount Aetna Type 3 quartz latite porphyry ring dike (Shannon, 1988)
Tqlp Dike	05-258	Tertiary quartz latite porphyry hybrid dike
Andesibasalt	-	Average andesibasalt- CLAIR database, 918 analyses (De la Roche and others, 1980)

¹ Total Fe as Fe₂O₃

² Reported as LOI- Loss On Ignition (volatiles)

The age of the quartz latite porphyry dikes is uncertain. The dikes cut the Proterozoic rocks (Xgdf, Xag, Xhig, and Xgp) on the southeast slopes of Mount Shavano. In the Maysville quadrangle, projected float trends of quartz latite porphyry hybrid and rhyolite porphyry (Trp) dikes intersect, but cross-cutting age relationships could not be established. Similar dikes, but with less evidence of xenocrysts, cross cut the Mount Princeton pluton in the Garfield quadrangle and cross cut the Mount Princeton pluton and Mount Aetna quartz monzonite ring dike in the Mount Antero quadrangle. Thus, field relations of the quartz latite porphyry hybrid dikes in the Maysville, Garfield, and Mount Antero quadrangles suggest a dike event that is younger than the Mount Princeton pluton and the Mount Aetna quartz monzonite porphyry ring dikes. The field relations, petrographic and chemical character of the quartz latite porphyry hybrid dikes suggest they represent a late-Mount Aetna magmatic event where an intermediate composition, andesitic magma locally mixed with phenocryst-bearing Mount Aetna magma.

Mount Aetna cauldron (~34.4 Ma) – The Mount Aetna cauldron represents a major magmatic event in the southern Sawatch Range. It is a highly eroded volcano-plutonic subsidence structure that represents the roots of a mid-Tertiary ash-flow caldera related to the middle Tertiary magmatic pulse. The Maysville quadrangle is situated almost entirely outside the southeastern margin of the Mount Aetna cauldron ring zone (fig. 4). The outermost ring zone cuts across the very northwestern corner of the Maysville quadrangle, about 2,500 ft northwest of the summit of Mount Shavano (plate 1). About 1,300 ft of the about 2,000 ft total width of the ring zone is in the Maysville quadrangle.

The ring zone is very poorly exposed on the steep southeast talus slope of Tabeguache Peak in the Maysville quadrangle. On the basis of float mapping, the Mount Aetna ring zone here includes a Mount Aetna quartz monzonite ring dike (Tma), flinty crush rock (Tfcr), and brittle-ductile ring shears (Trs). The southeastern ring zone predominantly dips steeply (70° to 80°) inward to the northwest, but some ring shears dip steeply outward to the southeast (Shannon, 1988). The southeastern Mount Aetna cauldron ring zone is truncated by the younger Mount Antero leucogranites about 4,500 ft

northeast of the northwest corner of the Maysville quadrangle.

The main ring-zone features generally exhibit systematic cross-cutting field relations: early brittle-ductile ring shears were followed by microbreccias and flinty crush rock, and then by intrusive breccias. All ring dikes were emplaced late and cut earlier-formed features. The only exception to this is minor ductile shearing cutting the inner Mount Aetna quartz monzonite ring dike in the Jennings Creek area in the Garfield quadrangle, about 7,500 ft west of the Maysville quadrangle western boundary. Shannon (1988) summarized three types of ring dikes associated with the Mount Aetna cauldron on the basis of occurrence patterns and textures. Type 1 ring dikes are fine-phenocryst (18 to 30 percent), pheno-andesite (IUGS) dikes with aphanitic groundmass that occur as irregular and discontinuous selvages on Type 2 and Type 3 ring dikes. Type 2 ring dikes are coarsely porphyritic (50 to 70 percent phenocrysts), pheno-quartz monzonite to granite b (IUGS) dikes that occur along the southwestern, southern and southeastern margins of the cauldron. Type 2 quartz monzonite porphyry also forms a 15,000 by 9,000 ft irregular resurgent intrusion that intruded the intracauldron volcanic rocks inside of the southern ring zone in the Garfield quadrangle. Type 3 ring dikes are medium- to coarse-porphyritic (30 to 40 percent phenocrysts) pheno-monzodiorite (IUGS) dikes that primarily occur around the Mount Aetna northern collapse structure. On the basis of whole-rock chemical analyses conducted by Shannon (1988) the Type 1 and Type 2 ring dikes have rhyolite compositions, the Type 3 ring dikes have rhyodacite compositions, and the resurgent intrusion has a granodiorite/rhyodacite composition (De la Roche and others, 1980).

Age determinations on the Mount Aetna cauldron were compiled by Shannon and others (1987a). The average of twenty fission-track age determinations (including two samples of thermally reset Mount Princeton quartz monzonite) and three K-Ar ages on Mount Aetna cauldron related rocks indicated an age of 34.4 Ma for the Mount Aetna cauldron magmatic event. More recent, high precision $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations by McIntosh and Chapin (2004) indicate a mean age of 33.81 +/- 0.11 Ma for five samples of the Badger Creek Tuff (outflow), a single age determination of 33.66 +/- 0.13 Ma for the Mount Aetna (Badger Creek equivalent) intracauldron tuff, and a mean age of 34.07 +/- 0.90 Ma for three samples of the Mount Aetna resurgent and ring-dike intrusions.

Tma Mount Aetna quartz monzonite porphyry ring dikes (late Eocene to early Oligocene) – Consists of a light-gray to light-pinkish-gray, distinctive highly phenocrystic, coarsely porphyritic rock. The Type 2 ring dikes are characterized by large, tabular alkali-feldspar phenocrysts to 1.5 inches, tabular plagioclase phenocrysts to 1.0 inch, quartz phenocrysts to 0.3 inch, and smaller hornblende and biotite phenocrysts to 0.2 inch in a medium-grained groundmass.

Modal analyses on the Mount Aetna cauldron ring dikes and resurgent intrusion were conducted by Shannon (1988). A modal analysis (1866 points on slab stained for alkali feldspar) on the main Mount Aetna ring dike from just northeast of Tabeguache Peak in the Mount Antero quadrangle showed 7.6 percent quartz, 17.4 percent alkali feldspar, 20.2 percent plagioclase, and 7.1 percent hornblende-biotite phenocrysts. Eight modal analyses of Mount Aetna quartz monzonite, including six samples from the resurgent intrusion and two samples of ring dikes, show the total phenocryst content to vary from 52.5 to 78.9 percent and the proportion of phenocrysts to be somewhat variable. Quartz phenocrysts show the largest variation, from 7.2 to 17.3 percent. The average of the eight modal analyses gives a total phenocryst content of 62.1 percent with 11.6 percent quartz phenocrysts, 19.0 percent alkali feldspar phenocrysts, 24.8 percent plagioclase phenocrysts, 5.9 percent biotite-hornblende phenocrysts, and 0.4 percent accessory magnetite. Thin-section analyses indicate the presence of accessory magnetite, sphene, apatite, and zircon in all samples and allanite in most. The average modes indicate the rock is classified as a pheno-granite b on the basis of phenocryst abundances (IUGS classification).

An approximately 2,200 ft long segment of Mount Aetna quartz monzonite porphyry ring dike is present in the northwest corner of the Maysville quadrangle. The dike does not crop out, but concentrated float indicates that it is about 200 to 300 feet thick. The float trend of the dike is about N38°E and the float pattern relative to topography (on the Maysville, Garfield and Mount Antero quadrangles) suggests a steep dip to the northwest. The ring dike in the northwest corner of the Maysville quadrangle is not the main ring dike along this part of the cauldron structure. This dike is an outer ring dike that extends for about 2,000 feet northeast in to the Mount Antero quadrangle, and

for about 7,500 feet southwest in to the Garfield quadrangle.

The main ring dike is approximately 200 feet northwest of the northwest corner of the Maysville quadrangle and is exposed along the summit ridge of Tabeguache Peak. It extends for more than five miles to the southwest and defines the Mount Aetna cauldron boundary. In the northwest corner of the Maysville quadrangle, about 1,000 feet separates the two ring dikes. Also, lithology in Mount Princeton pluton changes across the outer ring dike. The Mount Pomeroy subunit phase (Tmpp) is the dominant lithology in the Maysville quadrangle. The Mount Princeton finer-grained quartz monzonite (Tmpf) phase occurs in between the two ring dikes, suggesting that different levels of the intrusion are exposed on each side of the outer ring dike.

Tfcr Mount Aetna flinty crush rock (late Eocene to early Oligocene) – Flinty crush rock (FCR) consists of a dense, aphanitic, black to dark-gray rock with flinty fracture (fig. 23). It typically has fine color laminations, which mostly parallel the contacts but are locally disrupted and contorted. In thin section, FCR is a microbreccia with approximately 2 to 15 percent crystals (0.01 to 3.0 mm) in an aphanitic matrix. The crystals are of two types. Most abundant are crystal fragments, composite crystals, and small lithic fragments derived from the wallrock. The second type consists of small euhedral to subhedral microphenocrysts (0.5 to 1.0 percent; 0.01 to 1.0 mm) of plagioclase, hornblende, biotite, alkali feldspar, and quartz. Along the southeast ring zone, FCR has a very fine-grained (<0.05 mm) igneous matrix with randomly oriented, elongated hornblende or plagioclase microlites. The textures locally approach skeletal quench textures, but no glass or devitrification textures have been observed. A whole-rock chemical analysis of FCR (Shannon, 1988) shows very similar chemistry to the Mount Aetna Type 2 and Type 3 ring dikes, except for slightly lower Na₂O and slightly higher K₂O in FCR.

Flinty crush rock is a field term used by Clough and others (1909) for fine-grained, dike-like injections of “crushed rock” in the ring zone of the Glen Coe cauldron, Scotland. It is used here for similar features that are particularly well developed in three localities along the ring zone of the Mount Aetna cauldron (Shannon, 1988). Two of the localities are along the southeast ring zone and one of these includes the northwest corner

of the Maysville quadrangle and the area around Tabeguache Peak. FCR does not crop out in the Maysville quadrangle- but occurs as abundant float in the area between the two Mount Aetna ring dikes. The following description is based on occurrences in the Mount Antero, Garfield, and St. Elmo quadrangles. FCR is present in areas of intense ring shearing as dike-like injections of unusual microbreccia that cut and postdate brittle-ductile shearing. It forms 0.05 to 3.0 ft thick seams that are subparallel to the C-surface shear planes and highly irregular, discontinuous, lateral injections into the wallrock. These lateral injections are at high angles to, and rapidly thin away from, the main seams of FCR. They project outward into the extracauldron wallrock and inward into the cauldron block. The thicker, main FCR seams are invariably associated with ring dikes, along one or both sides of the dike. The ring dikes cut and contain inclusions of FCR.

The field relations and megascopic and microscopic character of FCR is essentially the same as pseudotachylites, which are generally interpreted to be the product



Figure 23. Coarse talus blocks of Mount Princeton finer-grained quartz monzonite (TmPf) with irregular flinty-crush rock (Tfcr, dark gray) bands related to the Mount Aetna cauldron ring zone.

of melts generated by frictional heating along brittle fault zones (Sibson, 1975). Flinty crush rock has also been interpreted to be the result of emplacement of a fluidized gas-liquid-solid system (Reynolds, 1956; Roberts, 1966; and Taubenack, 1967). Shannon (1988) interpreted FCR as the product of injection of phyrlic magma into the ring zone during shearing. It is considered to be a hybrid mixture of magmatic material and ultracataclastic material that was mobilized and injected into the ring zone and surrounding wallrocks. FCR may contain a component of pseudotachylite but any frictionally derived melts were overshadowed by phyrlic magma injected along the ring zone.

Trs Mount Aetna ring shears (late Eocene to early Oligocene) – Deformation in the Mount Aetna cauldron ring zone is characterized by both brittle and ductile fabrics developed as a braided network of shears and faults which outline the main and northern collapse structures (Shannon, 1988). The Mount Aetna ring shear zones (Trs) consist of shear bands that megascopically and microscopically exhibit evidence of ductile deformation resulting in development of protomylonite to orthomylonite fabrics and rare ultramylonite fabrics. The ductile shear bands are surrounded by marginal zones of deformed wallrock that behaved predominantly in a brittle manner. The brittle deformation is characterized by megascopic and microscopic fractures that offset grain boundaries and plagioclase twin lamellae. Other brittle deformation features include seams of microbreccia that are irregularly developed along shear bands. On a microscopic scale, rocks in the shear zones behaved inhomogeneously. The feldspars typically deform in a brittle manner, while quartz and mafic minerals show evidence of ductile flow and varying degrees of recrystallization. Local cross-cutting relationships between ductile and brittle deformation features suggest complex alternation of deformation mechanisms probably related to significant changes in strain rate in the dynamic ring zone during cauldron collapse (Shannon, 1988).

The Mount Aetna ring shears cut the Mount Princeton pluton and Proterozoic county rocks, both inside (cauldron block) and outside (extracauldron wall rocks) the ring zone. Mount Aetna ring shears are present in a concentrated float zone between the two

Mount Aetna ring dikes (Tma), one in the northwest corner of the Maysville quadrangle and the other one in the southeast corner of the St. Elmo quadrangle. The ring shear zones are described here because they are present as mappable zones of deformation textures that are superimposed on the older pre-collapse country rocks. They are usually spatially and genetically associated with ring dikes and flinty crush rock, and thus they are important elements used to define the Mount Aetna cauldron collapse structure.

S-C mylonite fabrics are locally well developed in the ductile shear zones. C-surfaces are the main shear planes and S-surfaces are the flattening foliations developed obliquely to the C-surfaces (Lister and Snoke, 1984). Shannon (1988) found ten localities around the Mount Aetna ring zone where S-C fabrics indicated the shear sense (Simpson and Schmidt, 1983). Nine localities, including four in the Tabeguache Peak area, indicated a shear sense compatible with cauldron subsidence (that is, cauldron block down).

Mount Princeton pluton (~36.6 Ma) – The southeast flank of the Mount Princeton pluton is present in a roughly 5,500 ft by 10,000 ft by 11,500 ft triangular area in the northwest corner of the Maysville quadrangle (plate 1). The Mount Princeton pluton is about 24 miles long and 14 miles wide and has an elliptical elongation in a N15° to 20°E direction (figs. 3 and 4). The approximately N55°E-trending southeastern contact extends for about six miles from near Clover Mountain in the central part of the Garfield quadrangle, through the northwest part of the Maysville quadrangle, and into the south part of the Mount Antero quadrangle where it is inferred to be truncated at the range-front Sawatch fault zone.

There is a 9.5 mi long and about 1.0 mi wide, N60°E-trending zone of Mount Princeton pluton rocks that occur outside the southeastern margin of the Mount Aetna cauldron collapse structure (figs. 4 and 5). This zone of Mount Princeton rocks is bounded on the northwest by the structural boundary and ring zone of the Mount Aetna cauldron. The southeastern boundary is an intrusive contact of the Mount Princeton pluton with older rocks, including a large area of Paleozoic sedimentary rocks south of Mount Taylor in the Garfield quadrangle and Early Proterozoic rocks in the northwest corner of the Maysville quadrangle. The Mount Princeton-Proterozoic contact is intruded

by the North Fork leucogranite (Tnfg) about 400 ft west of the Maysville quadrangle west boundary.

The Mount Princeton pluton is generally discordant to foliation and gneissic layering in Proterozoic rocks and to bedding in Paleozoic sedimentary rocks. Shannon (1988) reviewed the overall attitude of contacts along the margin of the pluton. Most of the pluton contacts are steep with the exception of the northern and southern margins, which plunge moderately to shallowly north and moderately south, respectively. The southeastern contact, including the segment crossing the northwest corner of the Maysville quadrangle, is nearly vertical to steeply inward (northwest) dipping. Within the Mount Princeton pluton (largely preserved in the Mount Aetna cauldron collapse structure in the St. Elmo quadrangle), low dips of broad, internal textural and compositional units suggest that the pluton had a relatively broad, flat roof that was gently tilted southward during collapse of the Mount Aetna cauldron.

Many previous workers have noted textural and compositional variations in the Mount Princeton pluton (Crawford, 1913; Dings and Robinson, 1957; Limbach, 1975; Sharp, 1976; R.P. Smith, 1979, unpublished reconnaissance map and 1981, personal communication; Shannon, 1988; Toulmin and Hammarstrom, 1990; and McCalpin and Shannon, 2005). Shannon (1988) described and delineated a number of systematic textural and compositional variations in the pluton. The pluton was divided into a border unit with three subunits and an interior unit with three subunits. The Mount Princeton border unit is mostly preserved in the Mount Aetna cauldron collapse structure in the southern part of the St. Elmo quadrangle.

The genetic relations of compositional-textural units along the roof of the Mount Princeton pluton have been variably interpreted and are problematic. The Mount Pomeroy quartz monzonite was interpreted as a separate earlier intrusion by Crawford (1913) and Dings and Robinson (1957). It is mainly preserved in the Mount Aetna cauldron collapse structure, in a 7 mile long and 0.5 to 1.5 mile wide, N60°E-trending zone. Toulmin (1976), Shannon (1988) and Toulmin and Hammarstrom (1990) suggested that the Mount Pomeroy quartz monzonite is a roof facies of the Mount Princeton pluton. Shannon (1988) suggested that the Mount Princeton border unit be defined as the broad zone of heterogeneous textures and compositions along the roof zone, and locally along

the margins of the pluton, including the Mount Pomeroy quartz monzonite. He recommended abandoning the formal name Mount Pomeroy quartz monzonite and applied the name Mount Princeton inner roof border subunit.

The Mount Pomeroy quartz monzonite problem is important to the geology of the Maysville quadrangle because it is the main textural unit of the Mount Princeton pluton in the quadrangle. New observations on the Mount Princeton pluton during mapping of the Buena Vista West quadrangle (McCalpin and Shannon, 2005) and during this study indicate that the Mount Pomeroy quartz monzonite problem is more complicated than initially interpreted (Shannon, 1988).

New descriptions of the Mount Princeton pluton along the northern contact zone, in the Buena Vista West quadrangle, were given in McCalpin and Shannon (2005). The marginal border zone exposed in the Buena Vista West quadrangle includes minor zones of alkali feldspar and plagioclase porphyritic subunits. The latter subunit has the same appearance, mineralogy, and texture as Mount Pomeroy quartz monzonite (Tmpp subunit). An attempt was made to simplify the nomenclature of Mount Princeton pluton units and subunits (McCalpin and Shannon, 2005). The Mount Princeton includes the following units: the Mount Princeton border unit (Tmpb); and the interior subunits -- Mount Princeton finer-grained quartz monzonite (Tmpf), Mount Princeton porphyritic K-feldspar (Tmpk), and Mount Princeton quartz monzonite (Tmpm); and the Mount Pomeroy subunit (Tmpp).

Observations from this study raise additional questions about the relationship between the Mount Princeton pluton and the Mount Pomeroy subunit. First, there is much more Mount Pomeroy subunit that occurs outside the southeastern margin of the Mount Aetna cauldron than previously recognized by Shannon (1988). It is in direct intrusive contact with Proterozoic rocks without evidence of other intervening border subunits. Secondly, another Tertiary intrusion (Tqm) in the west part of the Maysville quadrangle is similar to, and may be related to, the Mount Pomeroy subunit. The resolution of this problem is beyond the scope of this study, however, it is clear that a full understanding of the distribution of the Mount Pomeroy subunit and additional petrologic and geochemical studies are required. Consequently, in this report the Mount Pomeroy quartz monzonite is treated as a mappable unit and is referred to as the Mount Pomeroy subunit (Tmpp) of the

Mount Princeton pluton.

Age determinations on the Mount Princeton pluton and a potentially correlative volcanic unit, the Wall Mountain Tuff, were compiled by Shannon (1988). The average of six K-Ar ages, five fission-track ages, and one Pb/Th age on the Mount Princeton pluton is 36.6 Ma. The Pb/Th zircon age determination of 36.6 +/- 0.4 Ma (Ed DeWitt, 1987, written communication; Fridrich and others, 1998) may be the most reliable indication of the age of the Mount Princeton pluton because other age determinations may be partially reset by younger magmatism. The average of six K-Ar ages and three fission-track ages for the Wall Mountain Tuff is 36.6 Ma, the same as the indicated age of the Mount Princeton pluton. McIntosh and Chapin (2004) presented new high precision $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations for the Wall Mountain Tuff and the Mount Princeton pluton. The mean of five ages for the Wall Mountain Tuff is 36.69 +/- 0.09 Ma. New age determinations for the Mount Princeton pluton mostly record thermally reset ages associated with the Mount Aetna cauldron magmatic event (Chapin, 2003, personal communication).

Tmpp Mount Pomeroy subunit (late Eocene?) – The Mount Pomeroy subunit is present in a 400 to 1,000 ft long, 300 to 400 ft wide zone in the northwest corner of the Maysville quadrangle. It is separated by the outer ring dike of Mount Aetna quartz monzonite porphyry (Tma) from a small area of Mount Princeton finer-grained quartz monzonite subunit (Tmpf) in the very northwest corner of the quadrangle.

The Mount Pomeroy subunit is a medium-dark-gray to slightly purplish-gray, medium to coarse-grained rock (fig. 24). It is distinctly darker in color than all the other Mount Princeton pluton border and interior subunits. The rock is characterized by a slight porphyritic to seriate texture with abundant 3 to 10 mm tabular plagioclase grains, some 3 to 7 mm alkali feldspar grains and 2 to 4 mm hornblende-biotite grains. The plagioclase grains have a distinct medium-gray to purplish-gray color. The matrix is finer grained, about 0.5 to 2.0 mm and practically merges with the smaller sizes of the larger crystal population. It is distinctly more quartz- and alkali feldspar-rich (felsic) than the larger crystal population.

Modal analyses of the various Mount Princeton pluton subunits were compiled by

Shannon (1988). The average of seven analyses of the Mount Pomeroy subunit shows 20.9 percent quartz, 32.4 percent alkali feldspar, 34.9 percent plagioclase, 10.8 percent hornblende-biotite, and 0.8 percent magnetite. It has slightly less quartz and more alkali feldspar in comparison to other Mount Princeton subunits. The Mount Pomeroy subunit is classified as granite b (IUGS classification) on the basis of modal mineralogy. One thin section of Mount Pomeroy subunit from the Maysville quadrangle shows predominantly biotite with lesser hornblende as the mafic minerals and abundant accessory magnetite and sphene, and minor to trace allanite, apatite, and zircon. Plagioclase is andesine with about An 37 content (Michel-Levy method, 20 grains). Minor clinopyroxene, mantled by hornblende was noted in one sample of the Mount Pomeroy subunit (Shannon, 1988).

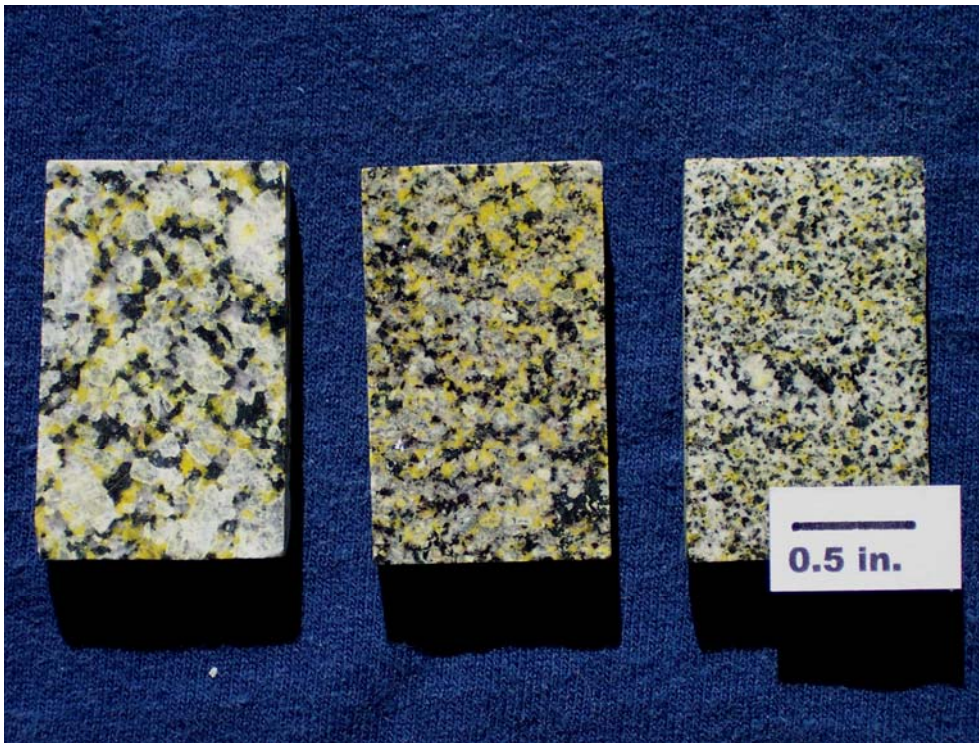


Figure 24. Billets of Mount Pomeroy subunit (Tmpp, left) in comparison to Tertiary quartz monzodiorite (Tqm) medium grained (middle) and fine grained (right) dike. Stained for alkali feldspar.

The southeastern contact of the Mount Pomeroy subunit is in intrusive contact with Early Proterozoic granodiorite (Xgdf) for about 10,000 ft across the Maysville quadrangle (plate 1). The contact trends about N60°E and extends from about 1,500 ft southeast of the summit of Mount Shavano to Lake Shavano along Squaw Creek. The overall relation between the contact and topography suggest that the Mount Pomeroy subunit contact is vertical to steeply inward (northwestward) dipping across the Maysville quadrangle. The contact is mostly discordant and oblique to foliations in the Early Proterozoic granodiorite (Xgd). No finer-grained, chilled textures are evident in the Mount Pomeroy subunit along the contact. Evidence for this being an intrusive contact is supported by dikes (2 to 100 ft thick) of Mount Pomeroy subunit that cut Proterozoic rocks along the contact zone.

Whole-rock chemical analyses were compiled on the various subunits of the Mount Princeton pluton (Shannon, 1988). Three analyses of the Mount Pomeroy subunit (from St. Elmo and Whitepine quadrangles) show the most within-group variation. A new whole-rock chemical analysis of the Mount Pomeroy subunit from the Maysville quadrangle is given in table 1. This sample has the lowest SiO₂ and K₂O contents and highest Fe-total and MgO contents compared to all Mount Princeton pluton samples. The sample is chemically classified (De la Roche and others, 1980) as tonalite. The tonalitic composition of the Mount Pomeroy subunit contrasts with the composition of the interior of the Mount Princeton pluton which is predominantly chemically classified as granodiorite.

Tmpf Mount Princeton finer-grained quartz monzonite subunit (late Eocene?) –

The Mount Princeton finer-grained quartz monzonite subunit is a light-gray to slightly pinkish-gray, medium- to coarse-grained equigranular rock (fig. 23). Plagioclase is white in contrast to the purplish-gray plagioclase in the Mount Pomeroy subunit. Biotite and hornblende, and relatively coarse and abundant accessory sphene, are conspicuous in hand sample. Thin section studies of this subunit showed minor clinopyroxene in one sample and accessory allanite, apatite, and zircon (Shannon, 1988). The average of three modal analyses showed 23.6 percent quartz, 29.3 percent alkali feldspar, 36.5 percent plagioclase, 9.8 percent hornblende-biotite, and 0.8 percent magnetite (Shannon, 1988),

indicating a granite b composition (IUGS classification). Specific sample location information is lacking for published and unpublished whole-rock chemical analyses thus it is difficult to determine if they include analyses on this subunit.

The Mount Princeton finer-grained quartz monzonite subunit is present in a 900 ft by 1,400 ft by 1,700 ft triangular area in the northwestern corner of the Maysville quadrangle. The relationships between this subunit and the Mount Pomeroy subunit are complicated by structures related to the Mount Aetna cauldron ring zone and younger Rio Grande rift related faulting. The general field relationships suggest that the Mount Princeton finer-grained quartz monzonite is structurally and stratigraphically below and interior to the Mount Pomeroy subunit. Thus, the finer-grained quartz monzonite subunit is slightly younger than the Mount Pomeroy subunit.

Miscellaneous magmatism (Late Cretaceous to late Eocene?) – In the Maysville quadrangle this group includes two lithologic units that have uncertain genetic relations to the other Tertiary igneous rocks described above. The first is a quartz monzodiorite intrusion (Tqm) that has a possible genetic relationship to the Mount Princeton pluton. This tentative correlation is supported by a $^{40}\text{Ar}/^{39}\text{Ar}$ age determination conducted for this study. The second lithologic unit includes a low-density andesitic dike (Ta) swarm in the Proterozoic terrane in the southwest part of the Maysville quadrangle. The overall characteristics of the andesite dikes suggest they may be Cretaceous, late Eocene, or early Oligocene, but no cross-cutting relations even support a post-Proterozoic age. The andesitic dikes are described here but an age assignment is uncertain.

Tqm Quartz monzodiorite (middle to late Eocene?) – A quartz monzodiorite dike-like body is present about 13,000 feet south of Mount Shavano, on the south side of the North Fork, in the western part of the Maysville quadrangle. The intrusion was first described by Crawford (1913) and a similarity to a quartz diorite intrusion in the Whitepine quadrangle was noted. Cross-cutting relations, showing the quartz diorite is younger than Paleozoic sedimentary rocks and is older than the Mount Princeton pluton, led Crawford to suggest the same pre-Mount Princeton age for the intrusion near the

North Fork. Dings and Robinson (1957) also described the same quartz diorite intrusions and came to the same conclusion, that collectively the quartz diorite intrusions are older than the Mount Princeton quartz monzonite.

The quartz monzodiorite is medium to dark gray, very fine to medium grained, and equigranular (fig. 24). Estimated modes indicate about 10 percent quartz (range 2 to 18 percent), 8 percent alkali feldspar (range 2 to 15 percent), 60 percent plagioclase (range 55 to 70 percent), 10 percent biotite, 8 percent hornblende (range 12 to 23 percent combined biotite and hornblende), 2 percent clinopyroxene (range trace to 8 percent), and 2 percent accessory minerals including magnetite, sphene, allanite, apatite, and zircon. Plagioclase, as subhedral-euhedral, tabular laths has a random orientation. Sample 05-821 has plagioclase with andesine (An 44) composition (Michel-Levy method, 17 grains). Sample 05-447A has more strongly zoned plagioclase with labradorite (An 55) cores and oligoclase (An27) rims. On the basis of estimated mineral modes the intrusion is predominantly quartz-monzodiorite with some quartz diorite and tonalite compositions (IUGS classification). The presence of zoned plagioclase with labradoritic cores also suggests quartz monzogabbro affinities. The mineralogy is variable, especially the amount of quartz and alkali feldspar, and clinopyroxene, which varies from trace to about 8 percent.

The quartz monzodiorite is an approximately 9,000-ft long, N35°E-trending, large dike-like body, about 500 to 1,800 ft wide, that extends from just off the west boundary of the Maysville quadrangle, southeast of Lost Mountain (in the Garfield quadrangle), across upper Lost Creek and into the North Fork valley. It makes relatively good outcrop, consisting of large spheroidal-weathered blocks. No contacts were observed, but the outcrop pattern relative to topography suggests a N-NE strike with a moderate dip to the NW. The grain size decreases from medium grained in the north to fine grained in the south. In addition, the grain size generally gets finer grained from east to west across the body. In the south, the western portion of the body (in the Garfield quadrangle) is very fine grained to almost aphanitic. The overall features suggest the body is chilled along the northwest contact.

There are three previously published whole-rock analyses of the quartz monzodiorite intrusion and one new analysis (sample 05-821; table 1) for this study. One

analysis by Crawford (1913), two analyses by Toulmin and Hammerstrom (1990), and one new analysis show significant major element variations in SiO₂ (55.00 to 61.90 percent), Al₂O₃ (16.27 to 18.26 percent), MgO (1.51 to 3.60 percent), CaO (5.10 to 6.52 percent), and K₂O (2.70 to 4.59 percent). Crawford's sample is monzodiorite, Toulmin and Hammerstrom's samples are tonalite and diorite, and the new sample is diorite based on the chemical classification of De la Roche and others (1980). The relatively wide variation in chemical composition corresponds with subtle but significant mineralogical and textural variations (best observed in stained slabs and thin sections) and appears to be a characteristic of the quartz monzodiorite intrusion.

The quartz monzodiorite is spatially associated with the Mount Princeton pluton and has mineralogical and textural characteristics that are similar to the Mount Pomeroy subunit. The quartz monzodiorite intrusion is roughly oriented about N35E and is about 9,000 ft southeast of and is subparallel to the N45E-trending Mount Princeton pluton contact. Both rocks are characterized by predominantly coarser-grained, distinctly medium-gray, tabular plagioclase grains in a finer-grained matrix enriched in quartz and alkali feldspar (fig. 24). Both are dominated by biotite and hornblende with minor and variable amounts of clinopyroxene. The quartz monzodiorite has more variation in mineral modes than the Mount Pomeroy subunit mostly related to the proportions of quartz, alkali feldspar and plagioclase, and the much higher abundance of plagioclase in the quartz monzodiorite. A comparison of whole-rock chemistry (sample 05-821 with sample 85-70 Tmpp from Shannon, 1988) shows significant chemical differences between the quartz monzodiorite and the Mount Pomeroy subunit. All of the major elements are different with SiO₂ varying the most, by about 8.0 percent and Fe₂O₃ by about 3.9 percent.

A sample (05-447A) of quartz monzodiorite from the Maysville quadrangle was submitted to the Geochronology Laboratory at the University of Alaska, Fairbanks. A ⁴⁰Ar/³⁹Ar plateau age of 32.4 +/- 0.3 Ma was determined by Layer and Drake (2006) on biotite from the monzodiorite. On the basis of the quality of the spectrum, Layer and Drake (2006) interpreted the age to reflect the cooling of the intrusive rock. This 32.4 Ma age is significantly younger than the average 36.6 Ma age of the Mount Princeton pluton and is in between the average ages of 34.4 Ma for the Mount Aetna cauldron and 28.9 Ma

for the Mount Antero leucogranites. The age determination does not support a genetic relation between the quartz monzodiorite and the Mount Princeton pluton and/or the Mount Pomeroy subunit. However, most attempts at age dating rocks in the Mount Princeton pluton area, including high precision $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations have shown significant problems with thermal resetting associated with the younger Mount Aetna cauldron and the Mount Antero leucogranites (see McIntosh and Chapin, 2004). It is suggested here that the 32.4 Ma age is probably a minimum age and that some or complete thermal resetting by younger intrusions is suspected.

Ta Andesite hybrid dikes (Late Cretaceous to late Eocene?) – Fourteen segments of andesite dikes are present in the southwest part of the quadrangle. The dikes cut all Early Proterozoic rock units, except the Early Proterozoic granodiorite (Xgd). Initially the andesite dikes were considered to be Proterozoic, but the lack of obvious metamorphic fabrics suggests that they might be younger Laramide or Tertiary intrusions. The dikes cut Proterozoic granite and pegmatite (YXgp) that is interpreted to be related to the 1.4 Ga Berthoud Plutonic Suite. Some of the dikes are present around Paleozoic sedimentary rock remnants and one dike strikes into the largest Paleozoic rock body but was not found cutting it. Thus, field relations indicate a post-1.4 Ga age and possibly a pre-Early Paleozoic age for the andesite dikes.

The andesite dikes rarely crop out and generally occur as concentrated to semi-concentrated, linear float zones. The length of andesite-dike segments ranges from less than 100 ft, up to 2,900-ft long. The pattern of dike segments suggests an at least 12,000-ft long, north-northeast-trending zone of dikes that extends from near Green Creek to the South Arkansas River. The zone of dikes is about 9,000 ft wide and includes a minimum of at least four dikes. The continuity of the dikes has been disrupted by predominantly northwest- and north-northwest-trending faults. The dikes range from about 2- to 20-ft thick, and most are about 4- to 6-ft thick. The thickest andesite dike is +20-ft thick and is exposed in a road cut on Highway 50 about 9,000-ft west of Maysville. Most of the andesite dikes exhibit narrow, 1 to 3 inch-thick, chilled, aphanitic margins and very fine-grained centers. The chilled margins locally exhibit fine-scale flow layering.

The andesite is medium to dark gray, but is also medium greenish gray and

locally tanish to pinkish gray. It contains two variable populations of larger crystals in a fine grained to aphanitic groundmass (fig. 25). A population of black, subhedral to euhedral crystals, mostly remnant hornblende grains, is interpreted to be phenocrysts. Another minor population of larger, subhedral to rounded crystals may be resorbed phenocrysts or xenocrysts. All hand samples of andesite are weakly to moderately magnetic (due to abundant fine, disseminated accessory magnetite) and most samples weakly effervesce with dilute HCl (due to the presence of carbonate alteration).

Three thin sections and seven slabs (stained for alkali feldspar) of different andesite dikes were prepared and studied. The main purpose was to evaluate the intensity of hydrothermal alteration and to see if any of the andesite dikes had suitable minerals for $^{40}\text{Ar}/^{39}\text{Ar}$ dating. The alkali-feldspar stained slabs show relatively abundant alkali-feldspar (estimated 5 to 18 percent) in the groundmass (fig. 25). With a binocular microscope, small amounts of quartz (estimated 1 to 4 percent) can barely be resolved. Hand sample and thin section studies indicate the lack of suitable minerals for age determinations.

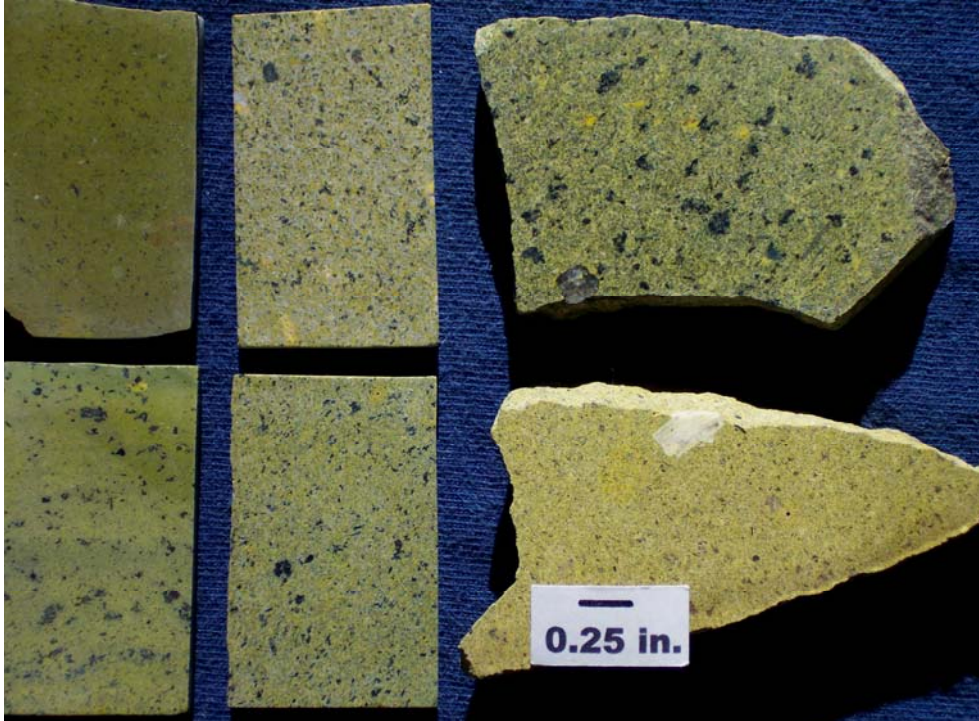


Figure 25. Billets and slabs of Tertiary (?) andesite hybrid dikes (Ta) showing variations in textures: chilled margins (left); dike interiors (middle) and xenocryst bearing (right). Stained for alkali feldspar.

Thin sections show the presence of about 8 to 12 percent, small subhedral, relict hornblende and clinopyroxene microphenocrysts and 1 to 2 percent plagioclase microphenocrysts in a very fine to fine-grained groundmass consisting of well-developed, elongated plagioclase laths with minor hornblende and disseminated magnetite. Mafic phenocrysts are almost completely altered and pseudomorphed by chlorite-carbonate-epidote intergrowths. Most outlines suggest hornblende and clinopyroxene as the predominant mafic phases, but many samples also have six-sided relict grains suggestive of olivine phenocrysts. Groundmass plagioclase laths are weakly to moderately flow aligned along with the larger elongated microphenocrysts. Alkali feldspar and quartz are difficult to resolve in the groundmass and occur as extremely fine intergrowths between fine plagioclase laths. Minor accessory apatite is present. There are no metamorphic fabrics or suggestions of a metamorphic overprint in hand sample or thin section. The dikes are classified as pheno-andesite on the basis of the phenocryst assemblage (IUGS classification). However, the abundance of alkali feldspar and small amounts of quartz in the groundmass indicate an unusual composition. The composition of the groundmass is more felsic and especially potassium-rich than is indicated by the intermediate to mafic composition suggested by the phenocryst assemblage.

About half of the andesite dikes contain a trace amount of a second population of larger (0.04 to 0.32 inch) crystals including quartz, alkali-feldspar and plagioclase grains. The crystals are distinctly rounded but usually have remnant shapes suggesting they were subhedral to euhedral phenocrysts. Quartz is the most common mineral and usually has narrow reaction rims of chlorite or very fine-grained alkali feldspar. Textures indicate that the crystals were in strong disequilibrium with the magma. One sample has a small remnant lithic inclusion of probable rhyolite. The mineralogical and textural relations suggest that the second larger crystal population is early-formed phenocrysts that were unstable with the remaining magma or are xenocrysts of phenocrysts from another source. The disparity between the composition indicated by the phenocryst assemblage and the groundmass together with the composition indicated by the xenocrysts suggests that the andesite dikes are the product of magma mixing or magma contamination.

Whole-rock chemical analyses on two andesite dikes from the Maysville

quadrangle (tables 1 and 3) were from chilled margins of the dikes, which tend to be less altered. These two analyses show unusual chemical characteristics, and significant differences indicate the dikes have variable chemistry. Both samples have very high LOI (3 to 5 percent) indicating abundant volatile water, probably related to strong hydrothermal alteration. Samples 05-03 and 05-680 are classified as latite and dacite, respectively, on the basis of the chemical classification of De la Roche and others (1980). Thus, the chemical characteristics of the andesite dikes show significant chemical variability most likely related to different degrees of contamination and/or magma

Table 3. Whole-rock chemical comparison of Tertiary (?) andesite hybrid dikes with average rhyolite and andesibasalt. [Commercial analyses by ALS-Chemex, Sparks, Nevada]

	Rhyolite	Ta-1	Ta-2	Andesibasalt
SiO ₂	71.66	54.01	60.91	53.44
Al ₂ O ₃	13.80	15.04	15.06	16.93
Fe ₂ O ₃	1.57	8.02 ¹	5.47 ¹	3.75
FeO	1.16	-	-	5.58
CaO	1.38	3.88	3.18	8.36
MgO	0.47	5.02	2.83	4.76
Na ₂ O	3.81	3.12	4.10	3.04
K ₂ O	3.89	4.01	3.17	1.24
TiO ₂	0.32	1.11	0.77	1.19
MnO	0.06	0.13	0.10	0.15
P ₂ O ₅	0.10	0.54	0.35	0.23
H ₂ O ⁺	1.29	4.72 ²	3.32 ²	0.86
H ₂ O ⁻	<u>0.65</u>	-	-	<u>0.52</u>
TOTAL	100.16	99.60	99.26	100.05
Rhyolite	-	Average rhyolite- CLAIR database, 293 analyses (De la Roche and others, 1980)		
Ta-1	05-03	Tertiary (?) andesite hybrid dike (latitic)		
Ta-2	05-680	Tertiary (?) andesite hybrid dike (dacitic)		
Andesibasalt	-	Average andesibasalt- CLAIR database, 918 analyses (De la Roche and others, 1980)		

1 Total Fe as Fe₂O₃

2 Reported as LOI- Loss On Ignition (volatiles)

mixing. The field relations and textures suggest that the andesite dikes are the product of a mafic (basaltic) to intermediate (andesitic) magma that interacted and assimilated varying amounts of a felsic magma (probably rhyolitic). Table 3 shows a whole-rock chemical comparison of two andesite hybrid dikes with average rhyolite and average andesibasalt.

Contact relationships with host Proterozoic rocks range from concordant to highly discordant with gneissic layering. Andesite dike orientations were measured at five locations: four locations have orientations N3° to 31°E with dips 75°NW to vertical and one location has a N12°W 79°SW orientation. The overall orientation of andesite dikes is about N20°E 80°NW and predominantly discordant to enclosing gneisses.

Small mines and prospects are sometimes associated with the andesite dikes that are generally moderately to strongly hydrothermally altered. The alteration is predominantly strong propylitic alteration characterized by replacement of mafic minerals by a chlorite-carbonate-epidote assemblage and replacement of plagioclase by saussurite. Locally, the dikes are affected by stronger quartz-sericite-pyrite alteration that is associated with quartz veinlets that cut the andesite. Another dike in a small mine has strong pervasive quartz-sericite-pyrite alteration with traces of remnant, disseminated pyrite and/or chalcopyrite. Locally, Cu-oxides and Mn-oxides impregnate the altered andesite. These relations suggest that some veins, hydrothermal alteration, and copper mineralization that are predominantly hosted in Proterozoic rocks are syn- or post-andesite dikes.

PALEOZOIC SEDIMENTARY ROCKS

Volumetrically, Paleozoic sedimentary rocks comprise a very minor (fraction of a percent) proportion of rocks in the Maysville quadrangle. They have four general occurrences: (1) remnants or outliers of down-folded and/or down-faulted wedges or keels of Paleozoic sedimentary rocks on the Proterozoic basement; (2) down-faulted

slices of Paleozoic sedimentary rocks along faults; (3) detached landslide sheets and blocks composed of Paleozoic sedimentary rocks in the Dry Union Formation; (4) clasts of Paleozoic sedimentary rocks in younger sedimentary rocks including the Tertiary Dry Union Formation and Quaternary glacial and gravel deposits. A description of detached Paleozoic landslide sheets and blocks (Td2ls) and distribution of Paleozoic clasts were given in the section on Dry Union Formation.

Crawford (1913) provided the earliest descriptions of the Paleozoic sedimentary rocks in the Monarch Pass area. He described a number of remnants of folded and faulted Paleozoic sedimentary rock in the Proterozoic rocks in the Monarch and Tomichi mining districts. Dings and Robinson (1957) mapped the same Paleozoic rock remnants in the Monarch Pass area, and a number of additional remnants in a 19 mile long zone extending to north of the Tincup mining district along the SW margin of the Mount Princeton pluton. The following Paleozoic sedimentary rock formations were identified by Dings and Robinson (1957) in the Garfield quadrangle: Late Cambrian Sawatch Quartzite; Early Ordovician Manitou Dolomite; Middle Ordovician Harding Quartzite; Middle and Late Ordovician Fremont Dolomite; Late Devonian Chaffee Formation; Mississippian Leadville Limestone; and Pennsylvanian and Permian Belden Shale and Minturn Formation. The erosional remnants of Paleozoic rocks are strongly folded and faulted and are largely preserved in synclines or remnants of the limbs of downfaulted anticlines. The major faults associated with the Paleozoic rock remnants are part of a larger zone of faults or deformation front that extends from the Aspen district, south-southeast to the Monarch district and possibly extending to the Kerber Creek area south of Bonanza (Dings and Robinson, 1957). The southern part of this deformation zone, with the Paleozoic outliers is summarized in figures 3 and 4. Dings and Robinson (1957, p.9) ascribed the chief period of folding and faulting to the Laramide orogeny and showed that the folds, faults and Paleozoic outliers are clearly truncated by the younger 36.6 Ma Mount Princeton pluton.

A large Paleozoic rock outlier is present in the Marshall Pass mining district about six miles south of Monarch Pass (Olson, 1983; Tweto and others, 1976). This indicates the zone of Paleozoic rock outliers is about 12 miles wide as it crosses the southern Sawatch Range. Small Paleozoic rock outliers are present at the southern end of the

South Arkansas graben, in the Droz Creek area, and on the east side of Marshall Pass (Kouther, 1969; Perry, 1971 and Dippold, 1999). The zone of outliers continues to the area just south of the Bonanza caldera where it is truncated and concealed by the San Luis Valley graben (Perry, 1971 and Tweto and others, 1976). Thus, the Paleozoic rock outliers occur in a N40°W-trending belt that is at least 50 miles long and about 12 miles wide. The Maysville quadrangle is along the east margin of this belt (fig. 4).

Or Paleozoic sedimentary rock remnants and fault slices (Ordovician and Mississippian?) – There are six Paleozoic rock bodies in the Proterozoic terrane in the southwest part of the Maysville quadrangle. The three largest are interpreted to be remnants of erosional or structural outliers that were folded or downfaulted into Proterozoic rocks. Two smaller bodies are thin slices of Paleozoic rocks along faults and the sixth occurrence is interpreted to be an intensely brecciated fault slice.

Of the six Paleozoic remnants in the Maysville quadrangle, only one shows intense brecciation. It occurs as a small mass (about 250 ft long) exposed in a window through the Quaternary gravels along the South Arkansas River on the east edge of Maysville. The relations of the Paleozoic remnant to Proterozoic basement rocks about 1,000 ft southwest and to the closest Dry Union Formation (Td) about 800 to 1,000 ft north are not evident. This locality is close to the intersection of two major, concealed fault zones: (1) the roughly north-trending Willow Creek fault, and (2) the west-northwest-trending Maysville-Salida fault.

The Paleozoic mass is composed of medium-gray, very fine-grained, massive to finely bedded limestone and cherty limestone and is probably Manitou Formation (?). The limestone is cut by irregular zones of brecciated limestone and also by a fault with N16°E and 75°NW to vertical orientation. Localized zones of intense shattering are similar to shattering in the Paleozoic landslide sheets (Td2ls) in the South Arkansas graben. Quaternary Bull Lake outwash deposits lap onto the Paleozoic mass and contain subrounded blocks of limestone up to 8 ft in diameter.

Three other Paleozoic remnants occur along the Willow Creek fault bounding the west edge of the South Arkansas graben at approximately 2,700 ft south-southwest, 6,000 ft southwest and 11,600 ft south of Maysville. The Paleozoic remnant about 2,700 ft

south-southwest of Maysville is a 900 ft by 900 ft by 1,200 ft triangular body consisting of light-bluish-gray to medium-gray, very fine-grained limestone with minor chert. This remnant may be Manitou Dolomite (?) or possibly Leadville Limestone(?). The limestone locally has fine bedding laminations that are generally oriented N-NE with moderate to steep dips to the SE and NW. There are localized zones of limestone breccia and shattered limestone that are associated with small fault zones and small mines and prospects. The brecciation appears to be tectonic and related to faults, but some could be related to minor dissolution and karsting. The relationship of the Paleozoic remnant to the surrounding rocks is not clear. Contacts on the south and east sides are interpreted to be fault contacts with Dry Union Formation (Td2). The northwest contact with Proterozoic rocks is concealed by a zone of colluvial blocks derived from the Dry Union Formation and may also be a fault.

The Paleozoic remnant about 6,000 ft southwest of Maysville is a 2,800 ft long and 700 to 1,000 ft wide, north-south elongated block of light- to dark-gray, very fine-grained, massive to thick-bedded dolomite with minor chert. The dolomite is darker gray in the south and lighter gray in the north and is probably Manitou Dolomite (?). There is no brecciation or shattering of this remnant. It is in fault contact (broken rock zone) with Proterozoic amphibolite gneiss with minor quartzite-metachert (Xq) along the western contact and is in fault contact (not exposed) with the Dry Union Formation (Td2) along the eastern contact. There are concentrations of well-rounded dolomite clasts in the Dry Union Formation immediately adjacent to the Paleozoic remnant.

The Paleozoic remnant about 11,600 ft south of Maysville consists of a very poorly exposed, 500 ft long, less than 50 ft thick, north-south elongated zone of light-gray, very fine-grained limestone. This remnant is an elongated sliver of Paleozoic carbonate that is along the poorly exposed Willow Creek fault. Brecciation or shattering of the limestone is not evident.

The largest Paleozoic remnant is a 2,400 ft by 1,000 ft, NW-elongated body that caps a small hill about 6,000 ft west-southwest of Maysville. The relationship of the contact pattern with topography suggests that this body has a relatively flat basal contact with the underlying hornblende gneiss (Xhig) and amphibolite gneiss (Xag). This remnant consists of light-gray, mostly massive-bedded limestone with minor chert and is

interpreted to be Manitou Dolomite (?) or possibly Leadville Limestone (?). Local fine-scale bedding laminations (fig. 26) in the northern part of the body have variable strike and generally steep dips (64° to vertical), suggesting the carbonates are folded. Brecciation or shattering of this Paleozoic remnant is not significant. Minor karst-like carbonate breccias are localized and are probably related to fault structures.

A small, elongated sliver of Paleozoic limestone is present in the gulch about 1,200 ft northeast of the largest outlier, just described. The sliver consists of a 600 ft long and less than 50 ft wide zone of concentrated float and minor subcrop of light-gray, very fine-grained limestone along the west side of the gulch. A $N20^\circ E$ -trending fault is postulated along this gulch and the sliver of limestone is interpreted to be a slice of Paleozoic rocks that was caught up in the fault zone.



Figure 26. Bedding laminations in Paleozoic limestone outlier about 6,000 ft west-southwest of Maysville.

There is one additional Paleozoic sedimentary rock occurrence in the Maysville quadrangle. Sharp (1976) mentioned blocks of mineralized Paleozoic dolomite and limestone that are present along the fault zone at the Blank mine. Observations during this study confirm the presence of minor mineralized limestone and limestone breccia associated with Proterozoic rocks on the upper mine working (caved shaft with moderate to large dump) of the Blank mine. There is no limestone on the surface and no evidence of remnants of Paleozoic outliers in this area, suggesting that the Paleozoic limestone occurs as a fault slice that was derived from a Paleozoic outlier that has been eroded.

In contrast to Van Alstine (1970), observations from this study indicate the Paleozoic remnants in the Proterozoic terrane in the Maysville quadrangle lack the intense shattering and brecciation that is displayed by the Paleozoic landslide blocks and sheets (Td2ls) in the South Arkansas graben sequence of the Dry Union Formation (Td2). None of the remnants appear to be detached and incorporated in the Dry Union Formation as suggested by Van Alstine (1970). The remnants are here interpreted as the deep roots of a larger Paleozoic down-folded and down-faulted outlier that was disrupted by multiple faulting events. Some of the remnants are slivers of Paleozoic rock that were caught up in the fault zones. It is further suggested that this proposed large Paleozoic outlier was the most likely source of the Paleozoic landslide sheets (Td2ls) that are incorporated in the Dry Union Formation (Td2) to the east.

PROTEROZOIC ROCKS

Early to Middle Proterozoic rocks comprise the main crystalline bedrock components of the Maysville quadrangle with about 29 percent of the surface area. They are dominated by rocks of the Early Proterozoic Gunnison-Salida metamorphic belt (Bickford and Boardman, 1984, and Bickford and others, 1989) that cover about 23 percent of the quadrangle surface area. Intrusive rocks of the Early Proterozoic Routt Plutonic Suite comprise an estimated 4 to 5 percent, and intrusive rocks related to the Early to Middle Proterozoic Berthoud Plutonic comprise about 0.5 to 1.0 percent of the

quadrangle surface area.

No ages have been determined for the Proterozoic rocks in or adjacent to the Maysville quadrangle. The classification of Proterozoic intrusions into Routt and Berthoud-types is based on mineralogical and textural characteristics and field relations in comparison to type descriptions of these intrusive suites by Tweto (1987). However, the classification of Routt-type intrusions is supported by limited age determinations in the Salida region (Bickford and others, 1989).

The Proterozoic rocks are exposed in the Sawatch Range rift-shoulder uplift on the west side of the Upper Arkansas Valley and South Arkansas grabens. They are present in two structural blocks in the western half of the quadrangle: a 24,000 ft long by 1,000 ft wide, N35° E-trending zone along the west margin of the Arkansas River Valley graben in the north; and a 18,000-ft by 15,000-ft zone along the west margin of the South Arkansas graben in the south. The relationship between the two structural blocks is unclear but they may be separated by the west-northwest extension of the Salida-Maysville fault, west of the Maysville quadrangle (See Structural Geology section).

Proterozoic intrusive rocks are divided into three groups: younger intrusions related to the Berthoud Plutonic Suite; a group of miscellaneous intrusions of uncertain age and relation to the Berthoud and Routt Plutonic Suites; and older intrusions related to the Routt Plutonic Suite.

BERTHOUD PLUTONIC SUITE (~1.40 Ga) – The Berthoud Plutonic Suite is represented by abundant, volumetrically minor but widespread dikes and small intrusions of coarse-grained pegmatite (YXp) and composite granite and pegmatite bodies (YXgp) that cut the older Early Proterozoic metamorphic and intrusive rocks. Pegmatite and granite and pegmatite dikes and sills are extremely abundant in the Proterozoic terrane in the southwest quadrant of the Maysville quadrangle. In the Proterozoic metamorphic rocks, no systematic criterion is recognized that could be used to distinguish whether the pegmatite-granite intrusions are related to the Routt- or Berthoud-type suites. Evidence for Berthoud-type granite pegmatites is supported by areas of abundant granite and pegmatite dikes cutting the two intrusions of Routt-type Early Proterozoic granodiorite

near the southwest margin of the quadrangle. These post-Routt-type granite and pegmatite intrusions may be related to a large Berthoud-type (Silver Plume-like) granite intrusion covering the southern part of the Garfield 15' quadrangle (Dings and Robinson, 1957).

YXgp Biotite granite and pegmatite (Early to Middle Proterozoic?) – Biotite granite is a white to pinkish-white, fine- to medium-grained, equigranular rock. It is leucocratic with less than 1 to 2 percent biotite and locally a trace of red garnet. It is classified as granite b on the basis of estimated mineral modes (IUGS classification).

Biotite granite usually occurs together with coarse-grained pegmatites as composite intrusive bodies (YXgp). The proportion of granite and pegmatite is variable, but pegmatite usually predominates. The granite and pegmatite bodies are abundant in the southwest part of the Maysville quadrangle where they cut all Early Proterozoic lithologies. The granite and pegmatite intrusions range from 1 to over 300 ft thick and tens of feet to over 1,200 feet long in bodies that are concordant and discordant to the enclosing gneisses. They generally make bold outcrops and persistent coarse-block float zones.

YXp Pegmatite (Early to Middle Proterozoic?) – Berthoud-type pegmatites are generally simple, unzoned, quartz-feldspar pegmatites usually containing minor biotite and/or muscovite and locally containing magnetite, red garnet, and minor black tourmaline. They are white to pinkish-white, coarse- to very coarse-grained rocks that lack foliations or preferred metamorphic fabrics. Quartz-alkali feldspar graphic intergrowths are locally present. The pegmatites occur as dikes and sills that cut all Early Proterozoic lithologies. They range from 1 to over 300 ft thick and tens of feet to over 1,200-ft long in bodies that are concordant and discordant to the enclosing gneisses. Pegmatites generally make bold outcrops and persistent coarse block float zones.

A zone of larger pegmatite intrusions is present on the ridge between Willow Creek and Green Creek, near the Bon Ton mine (plate 1). The pegmatites are greater than 200 ft thick and about 500 ft long and most were prospected with cat trenches or cuts. No exotic minerals were noted in these pegmatites and the purpose of the exploration is not

clear (possibly for alkali feldspar). Koutner (1969) mentioned the presence of beryl and trace scheelite in pegmatites in Proterozoic rocks south of the Maysville quadrangle. Smaller pegmatites are abundant throughout the Proterozoic terrane and over large areas it makes up the predominant rock float. Many of these pegmatites have been prospected and pegmatite material is ubiquitous on most of the waste dumps of the significant mines in the quadrangle.

A northeast-trending pegmatite with small prospect pits, about 4,000 ft southwest of Maysville, contains minor epidote group minerals including both zoisite and thulite (manganian zoisite) and possibly rhodochrosite (MnCO_3). Some pegmatite material on mine and prospect dumps contains disseminated chalcopyrite and secondary copper oxides and carbonates.

ROUTT PLUTONIC SUITE- MISCELLANEOUS INTRUSIONS (Early to Middle Proterozoic?) – This group of miscellaneous early Proterozoic intrusions includes diorite (Xd), gneissic granite and pegmatite (Xgp), and augite microdiorite (Xmd) with uncertain age relations to Denny Creek equivalent intrusions and/or to Berthoud-type intrusions.

Xd Diorite (Early Proterozoic?) – One roughly 750-ft diameter intrusion of diorite is present cutting Early Proterozoic gneiss about 9,000 feet southwest of Maysville. The diorite is dark gray, medium-grained (0.5 to 2.0 mm), equigranular and composed of black hornblende (about 55 percent) and white plagioclase (about 45 percent). At most, 1 to 2 percent of very fine-grained interstitial quartz is present and the rock lacks alkali feldspar, biotite, and magnetite. Thus, the rock is classified as a diorite on the basis of estimated modes (IUGS classification). The rock has a diffuse texture lacking well-formed plagioclase and hornblende crystals, possibly due to a weak metamorphic recrystallization.

The diorite intrusion occurs in amphibolite gneiss (Xag) and calc-silicate gneiss (Xcs) but no contacts are exposed. Minor concentrated pegmatite (YXp) float suggests that the diorite is cut by Early to Middle Proterozoic Berthoud-type pegmatite dikes (YXp). A concentrated float zone of Tertiary (?) andesite dike (Ta) is present along the

eastern contact of the diorite intrusion but cross-cutting relations could not be established. Neither chilling of the diorite or development of foliations near the float contacts is obvious. One outcrop near the margin of the intrusion shows minor mineralogical banding of plagioclase and hornblende that may be weak localized gneissic structure.

This diorite from the Maysville quadrangle is similar to the interior parts of Early Proterozoic quartz-diorite intrusions in the Buena Vista West (McCalpin and Shannon, 2005) and Buena Vista East quadrangles (Keller and others, 2004). The quartz diorite intrusions in these two quadrangles are mineralogically and texturally variable and have finer-grained textures and local development of foliation and gneissic structures near contacts.

Xgp Gneissic granite and pegmatite (Early Proterozoic?) – This unit consists of abundant sill intrusions of fine-grained granite with pegmatite that are spatially associated with a sequence of hornblende intermediate gneiss (Xhig). The two units are intimately interlayered (shown on plate 1 as a Xgp/Xhig fractional unit) and form a large 15,000-ft long and 2,000- to 3,000-ft wide crescent-shaped zone crossing the North Fork in the northwest part of the Maysville quadrangle. The Xgp/Xhig unit is about 1.5 percent of the surface area of the quadrangle. The granite and pegmatite concordant sills (about 60 to 75 percent) are interlayered with septum and screens of hornblende intermediate gneiss (about 25 to 40 percent). The hornblende intermediate gneiss (Xig) is described separately.

The granite is white and ranges from very fine-grained to fine-grained aplite. It is composed of quartz, alkali feldspar, and plagioclase with minor (less than one percent) hornblende and/or biotite and trace fine disseminated magnetite. Slight variations in the distribution of hornblende and biotite locally produce a faint gneissic layering, and preferred alignment of mafic minerals creates a weak foliation. Pegmatites are white to slightly pinkish-white, simple, unzoned bodies consisting of quartz, alkali feldspar, plagioclase, biotite, and/or muscovite and local magnetite and red garnet. The pegmatites lack exotic minerals and evidence of prospects.

The granite and pegmatite sills form linear, resistant-rib outcrops and concentrated block float while the septum of hornblende intermediate gneiss is very

poorly exposed. Individual sills are up to hundreds of feet wide and form continuous outcrop-float zones that are thousands of feet long. On the north side of the North Fork the granite and pegmatite sills and hornblende intermediate gneiss are oriented about N30°W with moderate (30° to 55°) dips to the northeast and on the south side of the North Fork they are oriented about N35°E with moderate-steep (61 to 81°) dips to the southeast and northeast. Thus, the Xgp/Xhig zone appears to bend or warp as it crosses the North Fork.

The strongly concordant nature of granite and pegmatite (Xgp) sills and the fine-grain size and presence of weak penetrative metamorphic fabrics in the granite contrasts with the characteristics of the Berthoud-type granite and pegmatites (YXgp). The granite and pegmatite described here are interpreted to be older than the Berthoud Plutonic Suite and possibly related to, or older than, the Routt Plutonic Suite. The Xgp/Xhig unit is distinctive because of its bimodal mafic-felsic character. No relict textures that might provide indications of protoliths are preserved in these rocks.

Xmd Microdiorite dikes (Early to Middle Proterozoic?) – Two augite microdiorite dikes cut the Proterozoic rocks in the western half of the Maysville quadrangle. They are dark gray to dark greenish gray, very fine to fine grained, lack phenocrysts, and contain abundant, fine-grained, randomly-oriented, subhedral, elongated plagioclase laths. Abundant clinopyroxene with subophitic texture and minor brown hornblende are the main mafic constituents. Estimated modes are about 60 percent plagioclase, 30 percent augite, 5 percent skeletal magnetite, and less than 5 percent hornblende, quartz and biotite. Plagioclase is andesine (An 44), determined by the Michel-Levy method (15 grains). The rock is classified as a diorite (IUGS classification). Minor to trace blue-green actinolitic amphibole, quartz, and biotite are irregularly developed, appear secondary, and may be related to a very weak, metamorphic overprint. However, there are no preferred metamorphic fabrics. The dikes are weakly to moderately altered, including weak to moderate saussuritic (epidote-sericite) alteration of plagioclase, weak uralitic alteration of augite, and weak to moderate chloritization of hornblende. The southern dike contains trace disseminated pyrite and hematite and is cut by epidote and calcite veinlets. The longer western dike segment locally contains small, irregular pervasive epidote-garnet

endoskarn zones.

The two widely separated augite microdiorite dikes are very similar and are probably of similar age. The northern dike is present in the range front area on the north side of Squaw Creek near the northern boundary of the quadrangle. It occurs as a 1,500 ft long concentrated float zone. Float patterns and trends suggest the dike is less than 3 ft thick, is oriented roughly north-south, and has a steep to vertical dip. It cuts a large linear pendant of Proterozoic amphibolite gneiss (Xag) and cuts the foliated biotite granodiorite (Xgdf), indicating that the microdiorite dikes are younger than, or are a late part of, the Routt-type intrusions. The second dike is present as two northwest-trending segments on the north side of Willow Creek in the Proterozoic terrane in the southwest part of the quadrangle. The two segments are in different lithologic-structural domains. The western dike segment is 2,600 ft long, from 15 to 25 ft thick, and cuts muscovite-sillimanite gneiss (Xmsg) and amphibolite gneiss (Xag). The contacts are not exposed, but the dike trends about N40°W, paralleling the strike of the gneisses. The east segment of microdiorite dike is about 400 ft long, 25 ft thick, and cuts interlayered amphibolite gneiss (Xag), calc-silicate gneiss (Xcs), and biotite felsic gneiss (Xbfg). The dike strikes N63°W and has a vertical dip, which is slightly oblique to the gneisses. This dike has narrow chilled margins and crops out near a northeast-trending Tertiary (?) andesite dike (Ta). Cross cutting relations could not establish relative ages due to poor exposures.

ROUTT PLUTONIC SUITE- DENNY CREEK EQUIVALENT (~1.66 Ga) – The Routt-type coarsely porphyritic granodiorite (Xgd and Xgdf) is one of the most distinctive Proterozoic units in the region. The Routt-type intrusions in the Maysville quadrangle are interpreted to be satellite bodies of the largest Routt-type intrusion (about 25 miles long and 3 to 5 miles wide) that is present in the southern Mosquito Range. These Routt-type intrusions were previously referred to as the Trout Creek Augen Gneiss (Hutchinson and Hedge, 1967). Similar rocks in the central Sawatch Range were referred to as the Denny Creek Granodiorite Gneiss (Brock and Barker, 1972). Tweto (1987) recommended abandoning the term gneiss for these units and referred to them as Denny Creek granodiorite. Hutchinson and Hedge (1967) reported a 1,665 Ma Rb-Sr age for the

intrusion in the Trout Creek area and Bickford and Boardman (1984) reported a U-Pb zircon age determination of 1,672 +/- 5 Ma from the southern part of the intrusion in the Cameron Mountain quadrangle.

Two main areas of Proterozoic biotite granodiorite occur in the Maysville quadrangle: a large area of deformed, foliated biotite granodiorite (Xgdf) in the northwest quadrant and small, scattered intrusions of undeformed biotite granodiorite (Xgd) in the southwest quadrant. The foliated granodiorite is equivalent to Proterozoic foliated granodiorite (Xgdf) of Keller and others (2004) in the Buena Vista East quadrangle

Xgdf Foliated augen granodiorite (Early Proterozoic?) – Foliated augen granodiorite is present in an 18,000-ft long and 1,000- to 5,000-ft wide, east-northeast-trending zone crossing the southeast slopes of Mount Shavano (plate 1). It is medium to dark gray and medium to very coarse grained. It is composed of large (0.5 to 1.5 inch) microcline phenocrysts and augen in a medium-grained matrix of plagioclase, quartz and biotite, with accessory magnetite and sphene (fig. 27). The microcline crystals range from tabular, subhedral to euhedral, moderately aligned phenocrysts to more commonly highly stretched and flattened augen. Estimated modes include 20 to 25 percent quartz, 30 to 40 percent microcline, 30 to 35 percent plagioclase, and 8 to 12 percent biotite and magnetite. The foliated granodiorite is mineralogically variable and plots in the granite b field close to the quartz monzonite join (IUGS classification). Crawford (1913) provided a whole-rock chemical analysis of foliated granodiorite from Jennings Creek (Garfield quadrangle) that indicates a chemical classification (De la Roche and others, 1980) of granodiorite.

The foliated granodiorite displays variable textural development of moderate to strong penetrative mylonitic deformation fabrics. It displays a weak to strong foliation with the preferential alignment of biotite and remnant alkali-feldspar phenocrysts that are locally drawn out to a well-developed augen structure. Overall, the fabrics are protomylonitic to orthomylonitic. Discrete mappable zones of stronger mylonitic fabrics were not identified but they are preferentially developed along contacts with Early Proterozoic gneiss.

The foliated granodiorite intrudes older Early Proterozoic gneisses (Xag and

Xhig) along the southeastern contact and is intruded by the younger Tertiary Mount Princeton pluton (Tmpp) along the northwestern contact. The moderate to strong fabrics developed in the granodiorite are locally consistent but vary over larger areas of the body.



Figure 27. Outcrop of Proterozoic foliated granodiorite (Xgdf) exhibiting mylonitic, augen textures.

The foliation in the granodiorite is generally conformable with the Proterozoic gneiss along the southern contact and becomes more variable away from the contacts and in the central part of the body. The predominant orientations are northwest with moderate to steep northeast dips and east-west with moderate to steep north dips. Farther to the northeast near the northern border of the quadrangle, the Early Proterozoic granodiorite (Xgdf) contact with the Early Proterozoic gneiss is truncated by the range-front Shavano fault zone. Two northeast-trending, elongated pendants of amphibolite gneiss (Xag) are present in the granodiorite in this area. The pendants are about 1,200 to 2,400 ft long in the Maysville quadrangle and extend into the southern part of the Mount Antero quadrangle. Gneissic layering in the pendants and foliations in the granodiorite are oriented about N75° to 85°W with moderate to steep dips to the northeast and southwest. Folding of foliations in the granodiorite was not observed, but variations in strike and especially local dip reversals suggest that foliations in the granodiorite and the contact with the gneisses are probably warped and folded.

A large body of foliated granodiorite is present in the Mount Aetna cauldron collapse structure in the Garfield quadrangle. Crawford (1913) and Dings and Robinson (1957) interpreted it as a foliated Tertiary intrusion. However, strong similarities to Proterozoic foliated granodiorite (Xgdf) in the Maysville quadrangle led Shannon (1988) to suggest affinities with Routt-type Proterozoic intrusions. The foliated granodiorite at these localities is similar to Proterozoic foliated granodiorite in the Buena Vista West quadrangle (McCalpin and Shannon, 2005), Buena Vista East quadrangle (Keller and others, 2004), Castle Rock Gulch quadrangle (Wallace and Keller, 2003), and Mount Harvard quadrangle (Brock and Barker, 1972).

A hybrid border facies (Xgdh) with finer grain size and higher mafic mineral content is locally developed in the foliated granodiorite along the Proterozoic gneiss contact but the zones are too small and discontinuous to map. The hybrid border rocks are variable, ranging from chilled, fine to medium-grained, mafic-rich, non-foliated to weakly foliated granodiorite with or without small microcline phenocrysts to strongly foliated gneissic granodiorite to quartz monzonite.

Xgd Granodiorite (Early Proterozoic?) – Five intrusions of biotite granodiorite are present in the southwestern part of the Maysville quadrangle. The two larger bodies, on the west edge of the quadrangle, are apophyses connected to two of three irregular intrusions that were mapped as Pikes Peak Granite in the southeastern part of the Garfield 15' quadrangle by Dings and Robinson (1957). They were later interpreted to be Early Proterozoic Denny Creek Granodiorite (Tweto, 1987, p. A26 and A27). The granodiorite is light to medium gray to pinkish gray and medium to very coarse grained (fig. 28). It is characterized by large 0.5 to 1.0 inch, tabular, subhedral to euhedral microcline phenocrysts in a medium-grained matrix of plagioclase, quartz, and biotite, with accessory magnetite and sphene. Microcline phenocrysts are randomly oriented to rarely, very weakly flow aligned. The mineralogy of the granodiorite is variable and the composition changes with proximity to contacts and to a lesser extent with variations in the amount of microcline phenocrysts. Estimates of mineral modes indicate 15 to 30 percent quartz, 25 to 40 percent microcline, 25 to 35 percent plagioclase, and 5 to 10 percent biotite and magnetite. Most of the samples are granite b but are close to the granite b-granodiorite join (IUGS classification). Rocks from the borders of intrusions are typically more mafic and finer grained and are locally transitional with hybrid granodiorite (Xgdh) locally developed in the contact zone.

The largest body is a 2,500-ft by 3,000-ft by 4,000-ft triangular area across the mouth of Fooses Creek in the west edge of the Maysville quadrangle. The second apophysis is a 2,000 ft long, east-west oriented body that is about 6,000 ft north of the southwest corner of the quadrangle. Two smaller, isolated bodies of granodiorite, about 1,500 ft long are present in the area between and east of the two apophyses. The fifth intrusion of granodiorite (Xgd) is present in a 4,000-ft long east-west zone on the north side of the South Arkansas River between the North Fork and Lost Creek. Numerous small, dike-like bodies of granodiorite, too small to map, are present throughout the Proterozoic terrane in the southwest part of the quadrangle. The contacts of the granodiorite intrusions with the older Proterozoic gneisses are rarely exposed. However, float trends and most of the dikes are parallel, or subparallel and concordant to the gneissic layering.

Xgdh Hybrid granodiorite (Early Proterozoic?) – Minor, irregular zones of mafic-rich hybrid granodiorite are locally developed along intrusive contacts of the granodiorite and foliated granodiorite (Xgd and Xgdf) intrusions. Most of these zones are too small to map at 1:24,000 scale, but a mappable zone of hybrid granodiorite is present along the southern contact of the southern apophysis of granodiorite (Xgd) in the southwest corner of the quadrangle. The zone of hybrid granodiorite is about 100-feet wide on the Maysville quadrangle and expands to about 400-feet wide in the Garfield quadrangle. Hybrid granodiorite is dark gray, fine to medium grained, equigranular to porphyritic, and contains more biotite and magnetite (10 to 20 percent) and less quartz and microcline than the granodiorite (fig. 28). The texture is variable, mainly related to the presence and amount of alkali feldspar phenocrysts. Estimated mineral modes suggest a quartz monzodiorite composition (IUGS classification).



Figure 28. Subcropping contact zone between Proterozoic granodiorite (Xgd, boulder upper left) and amphibolite gneiss (Xag, dark gray). Gneiss clasts are in contact breccia with mafic hybrid granodiorite (Xgdh) matrix.

Hybrid granodiorite is locally developed along the foliated granodiorite (Xgdf) contact with Proterozoic gneiss in the northwest part of the Maysville quadrangle. It is more mineralogically and texturally variable than in the southwest part of the quadrangle. The hybrid granodiorite ranges from fine to medium grained and equigranular to strongly foliated and locally strongly mylonitic. The hybrid granodiorite is interpreted as irregular border zones developed on the granodiorite intrusions produced by interaction and contaminated mafic gneisses (Xag and Xig).

LAYERED BIOTITE AND FELSIC AND HORNBLENDIC GNEISS COMPLEX

(~1.74 Ga) – The layered biotite and felsic and hornblendic gneiss complex (Tweto, 1987) is the most abundant component (estimated 23 percent of surface area) of the Proterozoic basement terrane in the Maysville quadrangle. The rocks are part of the Early Proterozoic Gunnison-Salida metamorphic belt (Bickford and Boardman, 1984 and Bickford and others, 1989), are similar to those described by Boardman (1976 and 1986) and Boardman and Condie (1986) in the Salida area, and are probably equivalent to the younger (1,740 to 1,730 Ma) metavolcanic/metasedimentary sequence of Bickford and Boardman (1984).

The character of the Proterozoic rocks changes from north to south in the Maysville quadrangle. In the northwest quadrant the Proterozoic rocks are dominated by relatively mafic to intermediate composition, amphibolite gneiss (Xag) and hornblende intermediate gneiss (Xhig). The rocks are hornblende rich and generally lack biotite, muscovite, and sillimanite. Minor horizons of calc-silicate gneiss (Xcs) containing epidote and minor garnet and quartzite are interlayered with the amphibolite gneiss.

In contrast, the Proterozoic metamorphic rocks in the southwest part of the quadrangle exhibit much more lithologic diversity including the presence of abundant felsic gneiss units and muscovite- and sillimanite-bearing gneisses; presence of distinctive muscovite schist and amphibolite agglomerate units; abundance of calc-silicates, quartzites, and Berthoud-type pegmatites; and presence and abundance of a variety of mineralization styles. Some of the differences in the Proterozoic terranes are transitional (for example, abundance of quartzites, calc-silicates, Berthoud-type

pegmatites) and others appear to be abrupt (presence of felsic gneisses, muscovite- and sillimanite-bearing gneisses, muscovite schist and amphibolite agglomerate) and may be related to the Salida-Maysville fault.

The Proterozoic rocks are lithologically and structurally complex and poorly exposed in the Maysville quadrangle. Most outcrops and in-place float are along the crests of main ridges and spur ridges. Mapping on the tree-covered sides of ridges and valley floors is hampered by lack of outcrop and significant down slope mixing of Proterozoic units. Consequently, mapping of most of the southwest quadrant Proterozoic terrane was conducted by tracking the estimated float proportions of various Proterozoic units. The mapping of key metamorphic units (for example muscovite-bearing units like Xmsg and Xmc) showed that they are discontinuous and are locally abruptly truncated. The truncation of lithologic units occurs along linear zones that are interpreted to be faults (see Structural Geology section).

Some lithologic-structural domains are lithologically simple, consisting of predominantly one rock type. Other lithologic-structural domains are composed of two or more lithologic units that form a mappable coherent pattern. Most of the lithologic-structural domains are composed of multiple lithologic units that are mixed and display no coherent patterns. A system of fractional bedrock units is used to describe many of the lithologically complex domains in the Proterozoic terrane. The first lithology is the predominant lithologic unit in the domain and additional lithologies exceeding about 25 percent are successively listed in decreasing order of abundance.

Many of the lithologic-structural domains display coherent structural orientations that are truncated or change across the bounding faults. The Proterozoic terrane in the southwest part of the Maysville quadrangle was initially a complex sequence of various lithologic units that have been further complicated and disrupted by a complex pattern of one or more faulting, and possible folding, events. No younging direction criterion could be established during this study and the relative ages of the various Proterozoic units are not known. Following are descriptions of the Proterozoic units arranged according to two general criterion: from more felsic compositions to more mafic compositions and from probable sedimentary rock protoliths to probable igneous rock protoliths.

Xcs Calc-silicate gneiss (Early Proterozoic?) – Almost all of the calc-silicate gneiss zones are associated with amphibolite gneiss (Xag) and hornblende intermediate gneiss (Xhig). The main areas of calc-silicate gneiss are present in a 17,000-ft long and about 3,000-ft wide, N30°W-trending zone that extends from Green Creek, on the southern boundary of the quadrangle, to the South Arkansas River, opposite Lost Creek. Four of the larger mappable areas of calc-silicate gneiss (Xcs) are shown within this larger belt of amphibolite gneiss (fractional Xag/Xcs unit). Smaller calc-silicate gneiss zones, too small or discontinuous to map separately, are associated with the amphibolite gneiss (Xag) belt and with smaller amphibolite gneiss and amphibolite agglomerate (Xaa) zones in the southwest corner of the quadrangle and a few areas extending northward to upper Como Creek.

In most areas the calc-silicate rocks occur in narrow horizons (tens of feet thick) that are apparently controlled by stratigraphy. The amount of calc-silicates present in the horizons is variable and ranges from weak calc-silicates with epidote-dominant assemblages (fig. 29), through moderate calc-silicates with more classic epidote-garnet assemblages, to strong calc-silicates with clinopyroxene-amphibole-mica-garnet-epidote assemblages. Calc-silicate rocks are interlayered with amphibolite and hornblende gneisses in a few areas and individual calc-silicate horizons are broader, up to 2,000 ft long and a few hundred feet thick, in some zones. Some areas of calc-silicate rocks are associated with very fine-grained, hornfels-like hornblende felsic gneiss (Xhfg) with weak calc-silicate overprint. Thus, the calc-silicate gneisses (Xcs) exhibit a transitional character from weak epidote calc-silicates to moderate epidote-garnet calc-silicates to strong calc-silicates with complex assemblages. The distribution of these various zones does not show systematic patterns that support zonation about a center or to specific intrusions. Consequently, the calc-silicate zones are considered to be regional, rather than local features (related to contact metamorphism) and are generally interpreted to be related to high-grade regional metamorphism (see Economic Geology section).

The calc-silicate gneisses are varicolored including light gray to black, green, tan and pink with common light-orangeish to reddish oxide staining. They range from very



Figure 29. Outcrop of epidote calc-silicates overprinting the matrix of Proterozoic amphibolite agglomerate (Xaa). Epidote calc-silicate (green with white quartz vein gashes) largely replaces the breccia matrix in the upper half of image.

fine grained to coarse grained. There is a general tendency for grain size to increase with increasing complexity of the calc-silicate mineral assemblage. Epidote-rich calc-silicates tend to be fine grained, epidote-garnet calc-silicates tend to be medium grained, and clinopyroxene-amphibole-mica-garnet calc-silicates tend to be medium to coarse grained. Hand sample and thin section studies indicate the more complex calc-silicate assemblages include the presence of diopside-hedenbergite, black amphibole (hornblende?), green amphibole (tremolite-actinolite), black biotite, chlorite, muscovite, garnet, epidote, quartz, carbonate, and sphene. Calc-silicate gneisses exhibit some layering that is of similar scale (inch to feet) as the layering in the amphibolite gneiss. The amphibolite gneiss locally has disseminated garnet and retrograde biotite in the vicinity of calc-silicate zones. The calc-silicates are generally non-foliated, but mica-rich layers are locally strongly foliated and sheared.

Many of the calc-silicate gneiss zones have been prospected and most of the larger mines (for example the Bon Ton mine) in the southwest quadrant of the Maysville quadrangle are related to zinc, copper, and lead mineralization that is associated with strong calc-silicate zones. The origin of the calc-silicate zones and the associated mineralization is a complex issue and multiple hypotheses have been suggested (Heinrich, 1981 and Sheridan and Raymond, 1984) (see Economic Geology section).

Oxide and sulfide minerals can locally be important constituents of the calc-silicate assemblage. Oxides include magnetite, which most often occurs as concentrated, massive bands or horizons (up to 2-ft thick) interlayered with the calc-silicate and amphibolite layers or as disseminated grains in the calc-silicate layers. Oxides also include the unusual, locally abundant mineral gahnite (Zn-spinel), traces of specular hematite, and Cu-oxides. Some of the mineralized calc-silicate zones contain two spinel phases (gahnite and magnetite) that appear to be mutually stable. Sulfides include sphalerite, chalcopyrite, pyrite, galena, and covellite. Mineralized calc-silicates at the Bon Ton mine contain both gahnite and sphalerite. Reaction rims of muscovite occur on gahnite when in contact with sphalerite, suggesting disequilibrium relations.

Possible protoliths for calc-silicate gneiss include limey clastic sedimentary rocks, possibly siltstones and shales, and strong calc-silicate zones may be related to impure limestone or marble layers. The magnetite-rich and massive magnetite layers are possibly replacements of relatively pure limestone or marble layers. No Proterozoic limestone or marble horizons have been identified in the Maysville quadrangle. Olson (1983) described a 3- to 6-ft thick marble layer that is along a northeast-trending zone with calc-silicates on the west side of Fooses Creek in the Palone Peak quadrangle, which is just outside the southwest corner of the Maysville quadrangle.

Xhfg Hornblende felsic gneiss (Early Proterozoic?) – Minor hornblende felsic gneiss zones are associated with areas of weak to moderate calc-silicate development scattered in the Proterozoic terrane in the southwest part of the Maysville quadrangle. They are associated with hornblende intermediate gneiss (Xhig) and locally interlayered with amphibolite gneiss (Xag). The largest area of hornblende felsic gneiss and associated weak calc-silicate gneiss (Xhfg/Xcs fractional unit) is present between Willow and Green

Creeks about 6,000 ft west of the Bon Ton mine. Smaller areas of hornblende felsic gneiss and calc-silicate gneiss are present in the north-northwest-trending amphibolite gneiss and calc-silicate gneiss belt between Green Creek and the South Arkansas River.

Hornblende felsic gneisses (Xhfg) are light gray, tan or brown, commonly with weak orangeish to reddish Fe-oxide staining. They are very fine- to fine-grained, dense, hard rocks with a siliceous hornfels character. They are generally unfoliated and massive with faint, fine-scale (fractions of inch to inch) gneissic layering produced by minor variations in the distribution of hornblende, biotite, and magnetite. Hornblende felsic gneisses are distinctly more felsic than associated hornblende intermediate and amphibolite gneisses. They are composed of about 65 to 70 percent plagioclase, 20 percent quartz, less than 10 percent mafic minerals, including about 5 to 7 percent hornblende and 1 to 2 percent biotite, about 0.5 percent magnetite, and trace accessory apatite and allanite. On the basis of estimated mineral modes they have dacitic-granodioritic compositions.

A weak calc-silicate overprint is common and has a preferential development of fine-grained epidote in specific thin layers or irregular patches. Veins of fine-grained epidote are locally abundant. Minor very fine-grained, disseminated pyrite is related to calc-silicate areas. Weak calc-silicate zones associated with hornblende felsic gneiss form broad zones up to about 2,000 ft long and 300 ft thick that are not in a spatial zonal relationship to the areas of moderate to strong calc-silicates and mineralization. Possible protolith for hornblende felsic gneiss may be fine-grained, carbonate-bearing, siliceous sedimentary rocks.

Xq Quartzite-metachert (Early Proterozoic?) – Quartzite-metachert is a very distinctive but minor rock type in the Proterozoic terrane in the southwest part of the Maysville quadrangle. It is light to dark gray or rarely black, generally very fine- to fine-grained, quartz-magnetite-hematite rock. Individual beds of quartzite-metachert range from about 3 to 25 ft thick and hundreds of feet up to 1,000 ft long. They are usually massive but locally have fine-scale (fraction of inch) remnant bedding laminations produced by variations in iron oxides. The quartzite is completely recrystallized and contains a trace to about 3 percent magnetite or hematite. Quartzite-metachert beds are

typically expressed by intermittent small-knob and linear-rib outcrops and zones of concentrated float (fig. 30). White bull-quartz veins from 0.1 inch to about 1 ft thick are commonly associated with the quartzites and probably represent remobilized quartz. The quartzite beds are locally intensely fractured and have abundant irregular slickensided and striated hematite slip surfaces.

Proterozoic quartzite-metachert was found in six areas in the southwest part of the Maysville quadrangle and one area just outside the west boundary of the quadrangle on the north side of the North Fork. Three segments of quartzite are present in the southwest part of the quadrangle and form a 9,000 ft long, east-west-trending zone that is subparallel and about 1,500 to 2,500 ft north of the quadrangle boundary. Two of the occurrences (1,000 and 700 ft long segments) form a discontinuous bed that is stratigraphically above a continuous, layer of muscovite-cordierite schist (Xmc). The schist makes a strike ridge that is oriented about N75°E with moderate to steep dips to the southeast. The third quartzite segment is about 4,000 ft west of the above two occurrences and consists of a west-northwest-trending concentrated float zone that is about 1,700 ft long. This segment is in a different stratigraphic position (structurally below) relative to the muscovite-cordierite schist layer. This suggests there are multiple horizons of discontinuous beds or lenses of quartzite-metachert.

The other three Proterozoic quartzite occurrences are farther northeast and are between Willow Creek and the South Arkansas River. Two of the occurrences (1,000 and 400 ft long segments) are in amphibolite gneiss (Xag) and calc-silicate gneiss (Xcs) sequences. These two occurrences are separated by about 8,000 ft and occur on opposite sides of a major northwest trending fault zone (BR/Xag). There is a remote possibility that these two segments of quartzite could represent the same stratigraphic horizon, which would suggest about 8,000 ft of left lateral offset across the fault zone. The sixth quartzite occurrence is an about 1,000 ft long, north-northeast trending zone that is approximately 3,000 ft southwest of Maysville. It is associated with a muscovite gneiss (Xmfs) and Berthoud-type granite and pegmatite sequence. A lack of outcrop prevents determining the structural relationship of these quartzite beds with the surrounding gneisses.



Figure 30. Outcrop of Proterozoic quartzite (Xq) representing lenses of meta-chert(?). Note abundant hematitic slickensides related to deformation.

Quartzite-metachert is interlayered with amphibolite gneiss (Xag) at one locality about 300 ft west of the western quadrangle boundary, on the north side of the North Fork. The quartzite is interlayered with amphibolite gneiss in the northern part of a 2,500-ft long roof pendant preserved in the roof zone of the North Fork leucogranite intrusion. The southern part of the roof pendant consisting of Xgd/Xgdh and Xag extends into the Maysville quadrangle. The about 85-ft thick zone of interlayered amphibolite gneiss and quartzite includes at least three beds of quartzite up to about 7 ft thick. The amphibolite gneiss is oriented about N56° to 62°W with steep dips (85° to 90°) to the northeast. Faint bedding (?) laminations in the quartzite are oriented N58°W with an 87° southwest dip subparallel to the amphibolite gneiss. The distribution and association of the quartzite beds suggest that at least three and probably four or more different horizons of quartzites are present in the Proterozoic sequence. Some of the quartzite beds are associated with mafic-rich amphibolite gneiss (Xag) and calc-silicate gneiss (Xcs) and some are associated with muscovite-cordierite schist (Xmc) and muscovite felsic schist (Xmfs).

The field relations and characteristics of the Proterozoic quartzites in the Maysville quadrangle are supportive of a chert protolith for these rocks.

Xmc Muscovite-cordierite schist (Early Proterozoic?) – The muscovite-cordierite schist is one of the most distinctive Proterozoic lithologic units recognized in the Maysville quadrangle and is suggested to have the best potential for semi-regional, mappable, key-stratigraphic horizons. The muscovite-cordierite schist is present as a continuous, N70° W-trending layer for about 10,500 ft along the western part of the southern margin of the quadrangle. It occurs in one of the largest lithologic-structural domains that displays the most systematic and coherent stratigraphy. Three segments of the schist are interpreted to be the same stratigraphic horizon, which has been offset by three faults. The western segment is at least 2,400 ft long (about 500 ft in Maysville quadrangle) and is right-laterally offset about 1,600 ft along a northwest-trending fault. The middle segment is about 8,000 ft long and the eastern segment is about 1,700 ft long. The middle and eastern segments are left-laterally offset about 1,750 ft along a north-northwest-trending fault. The eastern segment is offset to the north side of Willow Creek and is truncated by a north-northwest-trending fault at its easternmost extent. In the Maysville quadrangle, the schist unit does not occur on the east side of the fault, suggesting that significant offset (greater than 5,000 ft if right-lateral offset or greater than 9,000 ft if left-lateral offset) exists across this fault zone.

The muscovite-cordierite schist is light gray, fine to medium grained, and is strongly foliated (figs. 31 and 32). It commonly contains cordierite porphyroblasts that gradationally vary in size (from $\frac{1}{16}$ to $\frac{3}{4}$ inches) along strike within the schist unit. The western and eastern schist segments tend to have no cordierite or small ($<\frac{1}{16}$ inch) porphyroblasts. The western part of the central segment has small ($\frac{1}{16}$ to $\frac{1}{8}$ inch) cordierite porphyroblasts and the eastern part has abundant, large ($\frac{1}{4}$ to $\frac{3}{4}$ inch) cordierite porphyroblasts. Most hand samples of muscovite schist are weakly magnetic due to the presence of finely disseminated magnetite. A thin-section study of one sample from the eastern part of the central segment has estimated mineral modes of 30 percent quartz, 25 to 30 percent muscovite, 15 percent cordierite, 10 percent biotite, 10 percent plagioclase, 1 to 2 percent sillimanite, 1 to 2 percent magnetite, and trace tourmaline. The



Figure 31. Subcropping zone of muscovite-cordierite schist (Xmc) with large porphyroblasts of cordierite (dark brown).

mineralogy (muscovite, sillimanite, cordierite, and tourmaline) suggests a high aluminum content and shale protolith.

The western muscovite-cordierite schist segment does not crop out, but the concentrated float pattern suggests it is about 200 to 300 ft thick with a roughly west-northwest trend. The eastern half of the central segment is well exposed along a strike ridge where it is about 500 to 700 ft thick and is oriented $N46^{\circ}$ to $66^{\circ}E$ with moderate (46° to 78°) to vertical dips to the southeast. The eastern segment has limited outcrop mostly at low elevation near Willow Creek. Concentrated float suggests it is about 1,100 ft thick. The schist has variable orientations the most reliable of which is $N88^{\circ}E$ with vertical dip. Other measured orientations are from outcrops adjacent to the fault zone and are $N6^{\circ}$ to $30^{\circ}E$ with variable dips (29° and $34^{\circ}NW$ and $62^{\circ}SE$).

The three segments of muscovite-cordierite schist get progressively thicker to the east. The stratigraphic relations with the surrounding gneisses are consistent to the north with muscovite gneiss (Xmfs) and Berthoud-type granite and pegmatite dikes (YXgp) on

the north side of all three segments. In contrast, the rocks on the south side of the schist changes from predominantly amphibolite and calc-silicate gneiss (Xag/Xcs) at the west segment to predominantly amphibolite gneiss and biotite felsic gneiss (Xag/Xbfg) at the central segment to predominantly biotite felsic gneiss (Xbfg) at the east segment. These relations suggest the presence of facies variations in metamorphic units that may reflect primary stratigraphic facies variations. The schist is intruded by YXgp dikes and sills that are progressively more abundant to the east. The eastern schist segment is also cut by a short segment of a northeast-trending Tertiary (?) andesite dike.

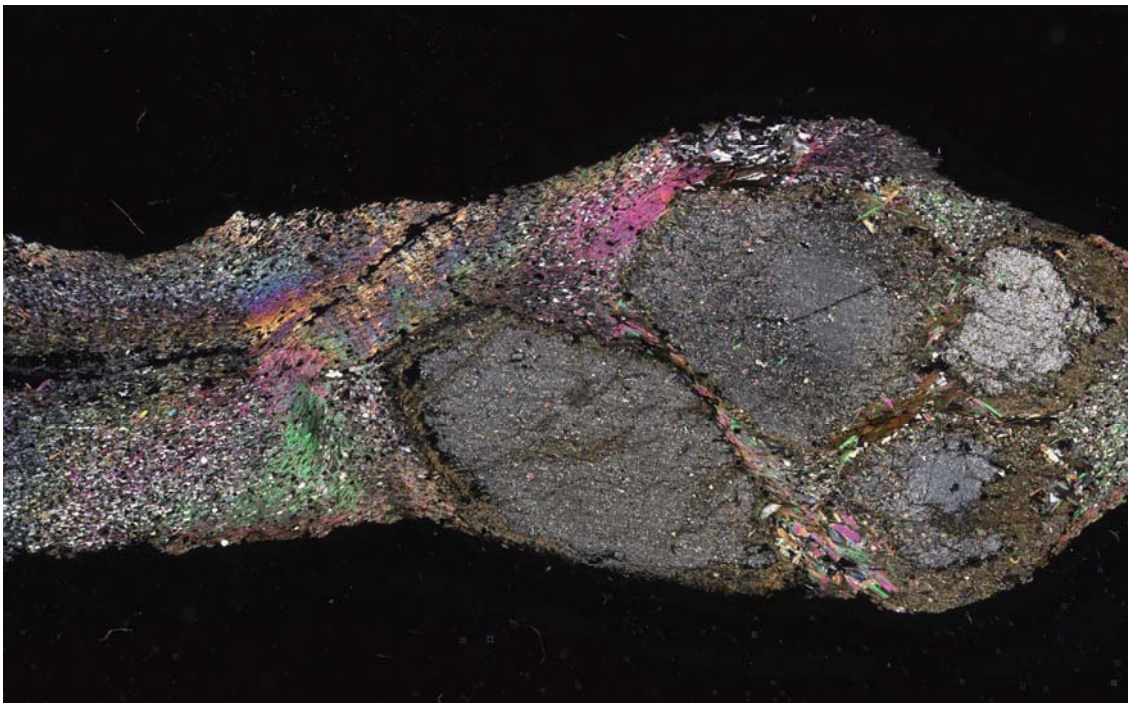


Figure 32. Photomicrograph of muscovite-cordierite schist showing cluster of cordierite porphyroblasts. Crossed nicols, approx. 1.4 inch across.

Xmsg Muscovite-sillimanite gneiss (Early Proterozoic?) – The muscovite-sillimanite gneiss is another distinctive Early Proterozoic metamorphic unit that occurs in a triangular-shaped, fault-bounded lithologic-structural domain in the southwest part of the Maysville quadrangle. The domain is about 7,000 ft by 10,000 ft by 13,000 ft and extends off the southern boundary of the quadrangle. It consists of muscovite-sillimanite gneiss

(Xmsg) with minor amphibolite gneiss in the western part and lineated amphibolite (Xal) in the eastern part. The two lithologies form a coherent structural block where the contacts between the units appear concordant and the foliations and lineations are similar and dip to the east and east-northeast. The muscovite-sillimanite gneiss forms a roughly north-south-trending, crescent-shaped zone that is about 11,000 ft long and up to 3,000 ft wide; this zone extends from Green Creek north-northwest across Willow Creek. It is poorly to moderately well exposed and locally makes good, continuous ledge outcrops.

The muscovite-sillimanite gneiss varies from a white to a mostly light- to medium-orangeish-brown color. The orangeish-brown color is related to a weak to moderate, pervasive limonite staining that generally increases to the south. Most of the muscovite-sillimanite gneiss is nonmagnetic and the limonite stain may be related to pervasive oxidation of disseminated magnetite. It is fine to medium grained (locally coarse grained) and moderately to strongly foliated. The muscovite-sillimanite gneiss generally lacks gneissic layering but is characterized by small (0.25 to 1.0 inch) eyes, lenses, or flattened nodules consisting of fine-grained sillimanite-quartz-muscovite (fig. 33). The amount, size, and composition of the eyes vary within the unit. Minor zones within the muscovite-sillimanite gneiss lack the eyes and other areas have small (0.25 to 0.5 inch) muscovite porphyroblasts. The eyes tend to be the same size in any given area and the size and abundance gradationally varies from place to place. Local gneissic structures are produced by discontinuous layers of medium- to coarse-grained microcline and quartz.

A study of two thin sections shows 35 to 40 percent quartz, 20 to 25 percent microcline, 5 to 15 percent plagioclase, 10 to 15 percent muscovite, 10 to 12 percent sillimanite, 3 to 10 percent biotite, with accessory zircon. On the basis of estimated modes the rock has a granitic composition that would plot near the join between the granite a and granite b fields (IUGS classification). The sillimanite tends to be concentrated in the eyes and occurs as very fine-grained bundles of needles that are locally intergrown with muscovite. The sillimanite and muscovite locally fringe each other, but textures usually suggest that sillimanite replaces the muscovite. Both thin sections show evidence of larger microcline grains with well-developed perthitic textures that appear to be pegmatitic segregations. The microcline grains are locally extensively

replaced by muscovite.

The western margin of the muscovite-sillimanite gneiss (Xmsg)/lineated amphibolite (Xal) domain is bounded by a north-northwest-trending fault that separates it from the domain to the west that contains the muscovite-cordierite schist (Xmc) unit. The eastern margin of the domain is bounded by a northwest-trending fault. The two faults that bound the domain are major faults with suspected thousands of feet of offset. The southern part of the domain is open and the muscovite-sillimanite gneiss and amphibolite extend beyond the south margin of the Maysville quadrangle.



Figure 33. Hand sample, billet and slab of muscovite-sillimanite gneiss (Xmsg). Eyes are composed of sillimanite-quartz-muscovite. Billet is stained showing irregular distribution of alkali feldspar (upper right).

The muscovite-sillimanite gneiss and lineated amphibolite have highly contrasting compositions that are suggestive of a mafic-felsic bimodal relationship. Further support for a conformable structural relationship is indicated by a long, narrow (about 100 ft thick) amphibolite gneiss body that is interlayered with the muscovite-sillimanite gneiss

forming an arcuate layer about 6,500 ft long. The layer of amphibolite gneiss forms a concentrated float zone about 600 to 1,000 ft east of, and subparallel to, the main muscovite-sillimanite gneiss and amphibolite contact. On the basis of the orientation of foliations and the contact patterns this lithologic-structural domain consists of a structurally lower felsic gneiss sequence to the west and a structurally higher mafic amphibolite sequence to the east.

The muscovite-sillimanite gneiss is cut by abundant, undeformed pegmatite dikes (YXp) and some white bull quartz (+/- muscovite) bodies. Some of the pegmatite bodies are moderately foliated, suggesting they are related to the Routt Plutonic Suite, and some pegmatites appear to be segregations within the muscovite-sillimanite gneiss. The muscovite-sillimanite gneiss is cut by a possibly Proterozoic microdiorite dike (Xmd) in the north part of the lithologic-structural domain and by a possibly Tertiary andesite dike on the south side of Willow Creek. The protolith of the muscovite-sillimanite gneiss is problematic. Previous workers have interpreted it as a metarhyolite lapilli-crystal tuff (Alers and Shallow, 1996). This interpretation is supported by the local interlayering and the conformable relationship to the amphibolite gneiss. However, the overall lack of remnant textures and layering and the relative uniformity and coarse-grain size of this unit may suggest a metamorphosed and deformed granitic intrusion as the protolith.

Xmfs Muscovite felsic schist (Early Proterozoic?) – The Early Proterozoic muscovite felsic schist (Xmfs) is present in a large lithologic-structural domain in the southwest quadrant of the Maysville quadrangle. It also occurs in a separate, smaller domain about 4,000 feet southwest of Maysville. The larger area of muscovite felsic schist is about 2,500 ft by 11,000 ft and forms an east-northeast-trending zone in the lithologic-structural domain that contains the muscovite-cordierite schist (Xmc).

The muscovite felsic schist is light tanish white to medium gray, fine to predominantly medium grained, and moderately to strongly foliated (fig. 34). It is a muscovite-rich, quartzo-feldspathic-rich rock that has the general appearance of a uniform metagranitic rock. It does not exhibit gneissic layering or significant variations in grain size. Muscovite is locally present as porphyroblasts to about ½ inch in size. It lacks visible sillimanite in hand sample and does not contain the eyes or nodules of

sillimanite-quartz-muscovite that are characteristic of the muscovite-sillimanite gneiss (Xmsg). It has some intergrown biotite, and localized textures suggest it was the original phyllosilicate in the rock that has been variably replaced by muscovite.

The distribution of units suggests that the muscovite felsic schist occurs in a stratigraphic position that is in between the muscovite-cordierite schist (Xmc) on the south and a sequence of amphibolite gneiss (Xag) and biotite felsic gneiss (Xbfg) on the north. The muscovite felsic schist forms a fairly large lithologically coherent area and it is not interlayered with other Proterozoic units. Some float is mixed with amphibolite gneiss and biotite felsic gneiss in contact zones, suggesting the possibility of transitional or interlayered contacts.

The muscovite felsic schist is cut by abundant Middle Proterozoic granite and pegmatite bodies (YXgp) and some bull-quartz veins related to the Berthoud Plutonic Suite. It generally does not make good outcrop and in float areas the small pieces of muscovite felsic schist are typically overwhelmed by the Berthoud-Type granite and pegmatite float. The granite and pegmatite bodies appear to be predominantly concordant with the foliation in the felsic gneiss. The best area of muscovite felsic schist outcrop is about 6,000 ft along a strike-ridge that runs parallel to and north of Willow Creek. The gneiss is generally oriented about N75°E with a shallow to moderate (27° to 60°) dip to the south. This orientation is similar to the muscovite-cordierite schist (Xmc) on the ridge south of Willow Creek and suggests that the two units are part of the same structural domain.

The muscovite felsic schist has some characteristics similar to the muscovite-sillimanite gneiss (Xmsg) and the two units are juxtaposed for a short distance across one of the lithologic-structural domain-bounding faults on the north side of Willow Creek. However, they are treated as separate mappable units, although they could represent transitional units of the same or similar stratigraphic horizon or rock type. The felsic composition, lack of gneissic layering, and the relative homogeneity over large areas suggest that the protolith of the muscovite felsic schist was probably a medium-grained granitic intrusion.

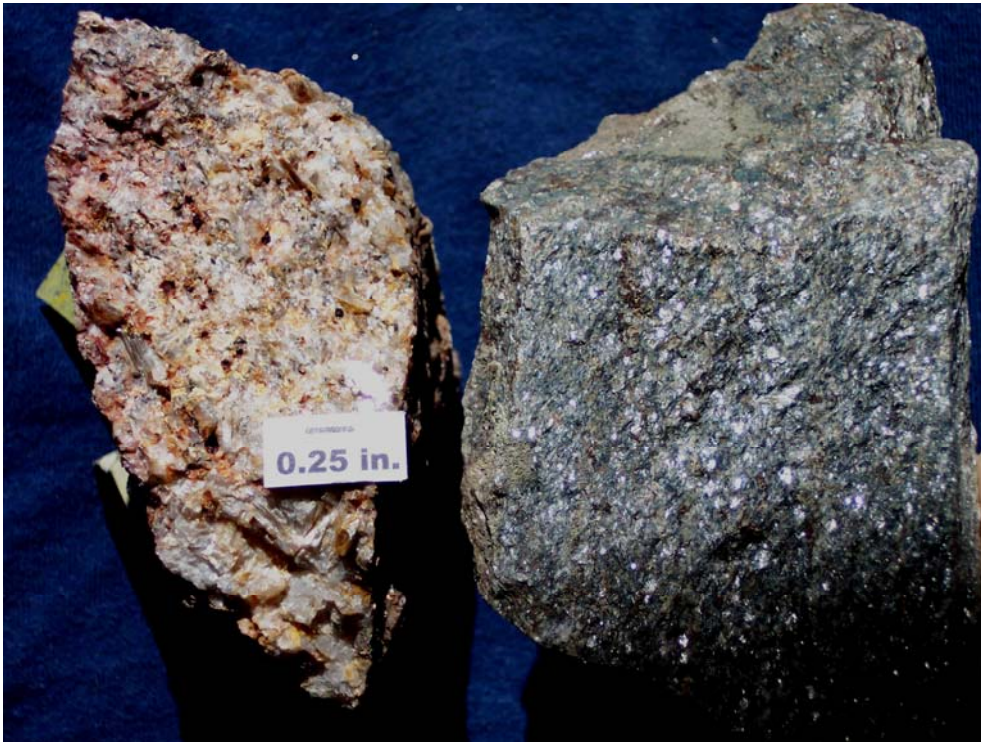


Figure 34. Hand samples of Proterozoic muscovite felsic schist (Xmfs) showing medium- to coarse-grained, quartz-rich variety (left) and fine- to medium-grained muscovite porphyroblastic variety (right) .

Xbfg Biotite felsic gneiss (Early Proterozoic?) – Biotite felsic gneiss is relatively common in the large lithologic-structural domain that occurs in the southwestern part of the Maysville quadrangle. It occurs as the primary lithology in four domains, including three domains where it is associated with abundant amphibolite gneiss (Xag) and one domain where it is associated with Berthoud-type granite and pegmatites (YXgp). It is also present in two domains where amphibolite gneiss is the dominant unit. The biotite felsic gneiss is commonly mixed with, and locally interlayered with, amphibolite gneiss (Xag) and hornblende intermediate gneiss (Xhig) and may be transitional with these units.

Biotite felsic gneiss is light to medium gray, mostly fine grained, and weakly to moderately foliated. It is a quartzo-feldspathic-rich rock with well-developed, regular gneissic layering. The biotite felsic gneiss is distinctly finer grained than the muscovite-

sillimanite gneiss (Xmsg) and the muscovite felsic schist (Xmfs). The foliations are always parallel to the gneissic layering. Gneissic layering is fine-scale on the order of fractions of an inch to tens of inches. Layering typically involves variations in biotite and magnetite content. The mineralogy is variable with biotite as the predominant mafic mineral, but some muscovite-rich layers or zones with both biotite and muscovite occur locally. Minor sillimanite is locally visible in hand sample. Biotite felsic gneiss lacks garnet porphyroblasts that are characteristic of the biotite felsic gneiss further north in the Buena Vista West quadrangle (McCalpin and Shannon, 2005). Some samples have larger crystals (to about $\frac{1}{8}$ inch) of plagioclase and amphibole that may be remnant phenocrysts or crystal fragments.

Two thin sections of biotite felsic gneiss were examined; these sections contain variable quartz from about 30 to 60 percent, plagioclase from 20 to 25 percent, and biotite from 10 to 25 percent, minor microcline from about 2 to 5 percent, and muscovite from 0 to 8 percent. The suite of accessory minerals includes magnetite, apatite, sphene, and zircon. Aside from rare remnant possible phenocrysts, the biotite felsic gneisses were completely recrystallized during regional metamorphism. The quartz-plagioclase-rich mineralogy and especially high quartz content suggests a siliceous protolith. The regular fine-scale gneissic layering and fine-grained textures suggest probable sedimentary or volcanoclastic protoliths.

The largest biotite felsic gneiss domain is in the southwestern part of the quadrangle and forms a roughly 6,000 ft by 6,000 ft trapezoidal area that extends from nearly the top of the ridge north of Willow Creek to the South Arkansas River. Overall, the biotite felsic gneiss is poorly exposed and predominantly occurs as small fragment float. The domain has abundant Berthoud-type granite and pegmatite (YXgp) bodies that locally make up 50 percent of the area. The southern margin of the domain is transitional with the northern part of the muscovite felsic schist domain to the south. The biotite felsic gneiss (Xbfg) and muscovite felsic schist (Xmfs) domains contain the main locus of Berthoud-type granite and pegmatite intrusions.

Biotite felsic gneiss is less abundant in the eastern part of the Proterozoic terrane south of the South Arkansas River where there are small domains and thin horizons that are interlayered with amphibolite gneiss (Xag). Similar narrow horizons of biotite felsic

gneiss that are too small to map are interlayered with the amphibolite gneiss and hornblende intermediate gneiss in the Proterozoic rocks in the northwest part of the Maysville quadrangle.

Xhig Hornblende intermediate gneiss (Early Proterozoic?) – The hornblende intermediate gneiss is the predominant lithology in two large (about 17,000 ft long and 7,000 ft wide) lithologic-structural domains in the northwestern quadrant of the Maysville quadrangle. It is also present as a smaller 2,000 ft by 4,000 ft domain about 6,000 ft west of Maysville and smaller unmappable zones in the southwest part of the quadrangle. The hornblende intermediate gneiss (Xhig) is locally interlayered with amphibolite gneiss (Xag) and the two rocks commonly have similar appearances. The main distinction between them is that the hornblende intermediate gneiss contains quartz and some biotite, is more quartzo-feldspathic (in leucocratic gneiss layers), and overall has a less mafic composition.

The hornblende intermediate gneiss is medium to dark gray and fine to medium grained, with generally weak foliation and well-developed gneissic layering (fig. 35). The foliation parallels the gneissic layering and is produced by the alignment of elongated hornblende and micas. The gneissic layering is fine scale, on the order of fractions of an inch to inches. Locally the hornblende gneiss contains minor biotite and/or muscovite that sometimes occur concentrated in more deformed and moderately foliated layers. Textural relations suggest that they are probably retrograde metamorphic minerals that preferentially formed along late shear bands that generally parallel the gneissic layering.

Two thin sections of hornblende gneiss were examined and show highly variable mineralogy (related to gneiss layering) with 15 to 70 percent plagioclase, 7 to 60 percent hornblende, 10 to 20 percent quartz, 1-2 percent biotite, 0 to 0.5 percent muscovite, 0.5 to 7 percent magnetite-ilmenite, and trace accessory apatite and allanite. Some hornblende gneiss is interlayered with amphibolite gneiss in areas of calc-silicate gneiss. Calc-silicates are more commonly associated with the amphibolite gneiss, but the hornblende gneiss locally contains minor red garnet and is cut by weak, irregular epidote calc-silicate bands and veinlets.



Figure 35. Outcrop of Proterozoic hornblende intermediate gneiss (Xhig) with localized mylonitic fabrics.

The largest area of hornblende intermediate gneiss is a 19,000 ft long semi-circular area that extends from the south shoulder of Mount Shavano to the South Arkansas River. The eastern part of this area is an 18,000 ft long, crescent-shaped zone of predominantly Routt-type (?) granite and pegmatite sills interlayered with narrow septa or screens of hornblende intermediate gneiss (Xgp/Xhig). The presence of weak foliations and gneissic layering in some of the granites associated with the pegmatites provides the main support that they are Routt-type or Pre-Routt-type intrusions. The western part of the large area of hornblende intermediate gneiss has less than 50 percent granite and pegmatite intrusions. Some interlayered amphibolite gneisses generally become more abundant toward the northeast. The large area of hornblende intermediate gneiss is cut by the northeast-trending Tertiary quartz monzodiorite (Tqm) intrusion on the south side of the North Fork and is cut by the Tertiary North Fork leucogranite (Tnfg) on the north side of the North Fork.

The hornblende intermediate gneiss was completely recrystallized during

metamorphism and is locally migmatitic. The regular fine-scale gneissic layering suggests a possible layered protolith and the mineralogy suggests an intermediate composition.

Xaa Amphibolite agglomerate (Early Proterozoic?) – The amphibolite agglomerate is a minor and localized, but very distinctive, unit that was found in three zones in the southwest corner of the Maysville quadrangle. A fourth zone is present about 1,000 ft southeast of the southwest corner of the quadrangle. The zones consist of interlayered amphibolite agglomerate and predominantly amphibolite gneiss with minor biotite felsic gneiss (Xbfg) and muscovite felsic schist (Xmfs). The zones range from about 100 to 2,000 ft long and 100 to 600 ft thick. Individual layers of amphibolite agglomerate are up to 25 to 30 ft thick and can be traced for up to 300 ft along strike. The amphibolite agglomerate generally makes good outcrop with small knobs and ledges.

The amphibolite agglomerate is a dark-gray to black, fine- to medium-grained peculiar rock exhibiting a well-preserved remnant agglomerate or breccia structure (figs. 29 and 36). The term agglomerate is used because of the typical subrounded clast shapes and a suspected volcanic protolith. They are essentially metavolcanic breccias with predominantly subrounded clast shapes. The remnant textures suggest poor to locally moderate sorting of clasts and a high proportion of clasts to matrix. Clasts range from ½ inch to 2.0 ft in size and from rounded to angular in shape. Most clasts are 2 to 6 inches in size and are subrounded. Clast compositions are variable, ranging from monolithic agglomerate with just amphibolite and amphibolite gneiss clasts to heterolithic breccias with mixed clasts of amphibolite, felsic metavolcanic (?), biotite felsic gneiss, microdiorite, medium-grained gabbro, and quartzite-metachert (?). The gneissic layering in amphibolite gneiss clasts is randomly oriented from clast to clast, suggesting that the gneissic structure is a primary layering feature in the clasts. The breccia is generally matrix supported and the matrix is usually recrystallized, fine-grained amphibolite. The breccias generally lack foliations, but large areas up to hundreds of feet long display evidence of plastic deformation where the clasts have been stretched and drawn out parallel with the breccia layer contacts (fig. 36).

Estimated modes of amphibolite agglomerate (from one thin section and hand

samples) indicates they are composed of amphibole (50 percent) and plagioclase (25 to 35 percent), with variable, irregularly distributed quartz (0 to 10 percent and up to 20 percent in some clasts), microcline (0 to 1 percent), biotite (0 to 5 percent in specific clasts), with accessory sphene, magnetite and apatite, and calc-silicate related epidote that replaces plagioclase and amphibole. The amphibolite agglomerate tends to have a weak to moderate, epidote-rich calc-silicate overprint that preferentially replaces the amphibolite matrix or occurs as irregular veins, bands, and patches. Minor Cu-oxide associated with epidote calc-silicate suggests the meta-agglomerate locally has weak copper mineralization (probably disseminated chalcopyrite).

Field relations suggest at least two probable stratigraphic zones of amphibolite agglomerate, although unrecognized structural complexities could have produced duplication by isoclinal-like folding. Two east-northeast-trending zones cross the west edge of the quadrangle on the ridge on the north side of Willow Creek. The south zone is discontinuous for about 2,000 ft and is about 100 ft to 200 ft thick. Just off the west edge of the map area the zone is oriented east-west and dips 51° south. To the east the zone is oriented about $N18^{\circ}W$ with $20^{\circ}SW$ dip, suggesting that the layer is folded. The north zone is continuous for at least 1,500 ft and ranges from about 200 ft thick on the east (where truncated by the Proterozoic granodiorite Xgd intrusion) to 600 ft thick off of the west boundary of the map area. The third continuous zone of amphibolite agglomerate occurs as a 2,000 ft long and about 200 ft thick, northwest-trending zone about 7,500 ft north-northeast of the southwest corner of the quadrangle. The amphibolite agglomerate is cut by Routt-type granodiorite (Xgd) sills and small irregular dikes of Berthoud-type granite and pegmatite (YXgp) dikes. On the basis of field observations the amphibolite agglomerates are pre-metamorphic intraformational breccias that were formed as part of the protolith stratigraphy. The breccias form continuous, mappable horizons associated with some amphibolite sequences. The amphibolite agglomerates are potentially good key marker horizons but they form discontinuous zones in the Maysville quadrangle.



Figure 36. Outcrop of Proterozoic amphibolite agglomerate (Xaa) with mixed mafic and felsic metavolcanic clasts. Note stretched, elongated clasts.

Xal Lineated amphibolite (Early Proterozoic?) – Lineated amphibolite is present in one main area associated with the triangular-shaped lithologic-structural domain with the muscovite-sillimanite gneiss (Xmsg) in the eastern part of the Proterozoic terrane south of the South Arkansas River. The lineated amphibolite makes up a 4,000 ft by 4,000 ft by 5,000 ft triangular area in the eastern part of this domain that extends across Green Creek and beyond the southern edge of the quadrangle. It is poorly exposed with minor small outcrops and commonly found as concentrated float.

The lineated amphibolite is dark gray to black and generally fine grained. The mineralogy is dominated by amphibole and plagioclase; the rocks lack quartz and micas and are generally nonmagnetic. Estimated modes are 50 to 70 percent hornblende and 30 to 50 percent plagioclase. In contrast to the well-layered amphibolite gneiss, the lineated amphibolite occurs as thick massive zones suggesting a more homogeneous protolith. The amphibolite is characterized by a moderate to strong penetrative lineation where the amphiboles are aligned, discontinuous rods (fig. 37). When viewed normal to the lineation the rock appears to have a strong foliation and when viewed parallel with the lineation the rock appears to be equigranular and non-foliated. The orientation of the lineation is consistently to the north-northeast (N10° to 35°E) with generally moderate, but locally shallow plunges (20° to 64°) to the northeast.

Along the western contact with the muscovite-sillimanite gneiss a transitional zone of amphibolite gneiss (with minor interlayered hornblende intermediate gneiss and biotite-muscovite felsic gneiss) with gneissic layering is concordant to the contact and to the moderate to strong foliation in the muscovite-sillimanite gneiss (Xmsg). The gneisses in the transitional zone are generally oriented north-south with moderate dips (54° to 70°) to the east.

In the central part of the lineated amphibolite sub-domain minor areas of the amphibolite are interlayered with hornblende intermediate gneiss (Xhig), biotite felsic gneiss (Xbfg), and calc-silicate gneiss (Xcs); these interlayers become more abundant and in larger sized areas to the southeast. The eastern boundary of the lineated amphibolite sub-domain is a major northwest trending fault zone that merges with or is truncated by the Willow Creek fault bounding the western edge of the South Arkansas graben. The distribution of Berthoud-type granite and pegmatite intrusions also changes across the

western sub-domain boundary with the muscovite-sillimanite gneiss. The granite and pegmatite intrusions are fairly abundant in the muscovite-sillimanite gneiss, decrease in abundance in the amphibolite gneiss transition zone, and are rare to absent in the lineated amphibolite sub-domain.



Figure 37. Outcrop of Proterozoic lineated amphibolite (Xal). Strong amphibole lineation plunges steeply to left, parallel to yellow pencil magnet.

The characteristics of the lineated amphibolite suggest a fine-grained, non-layered, massive protolith with mafic composition, possibly basalt flows. Associated sequences of well-layered gneisses may represent interlayered mafic, intermediate and felsic metavolcanic and metasedimentary rocks.

Xag Amphibolite gneiss (Early Proterozoic?) – The amphibolite gneiss is a significant lithology covering about 7 to 10 percent of the surface area of the Maysville quadrangle. It makes up about 20 to 25 percent of the crystalline bedrock area and about 25 to 30 percent of the Proterozoic terrane. Thus, it is one of the dominant lithologic units

of the Proterozoic metamorphic rock sequence. The amphibolite gneiss is commonly interlayered and transitional with hornblende intermediate gneiss (Xhig) and calc-silicate gneiss (Xcs) and is locally interlayered and transitional with biotite felsic gneiss (Xbfg) and muscovite felsic schist (Xmfs). In areas where the interlayered gneisses crop out, the orientation of gneissic layering is usually conformable, suggesting that the gneisses represent sequences of layered lithologies of contrasting composition. The orientation of the amphibolite gneiss layering is usually parallel or subparallel to the boundaries of the lithologic-structural domains. Amphibolite gneiss is generally poorly exposed and occurs as zones of fine rock float with limited, small outcrops.

Amphibolite gneiss is dark gray to black and predominantly fine grained with well-developed, fine- to medium-scale (fraction of inches to feet) gneissic layering. The gneiss has simple mineralogy consisting predominantly of hornblende and plagioclase. Estimated modes show 60 to 80 percent amphibole, 20 to 40 percent plagioclase, 0 to 2 percent biotite, and trace to 3 percent sphene. Abundant epidote and minor quartz and magnetite are present in areas with calc-silicate overprint. Localized zones of amphibolite gneiss have minor biotite that usually occurs in localized weak to moderate foliated bands paralleling the gneissic layering. This biotite is interpreted to be related to a weak retrograde metamorphic overprint. Amphibolite gneiss has variably developed metamorphic foliation that parallels the gneissic layering. Most of the amphibolite gneiss is non-foliated and local areas have weak foliation produced by alignment of elongated amphibolites and minor retrograde biotite. Localized, discontinuous zones of mylonitic amphibolite have strong foliation.

The amphibolite gneiss is present in a couple of small lithologic-structural domains in the Proterozoic terrane south of the South Arkansas River where it is the overwhelming lithology (less than ten percent mixed lithologies, generally Berthoud-type granite and pegmatite intrusions). Many areas mapped as predominantly amphibolite gneiss also include small irregular and discontinuous layers of massive amphibolite, mylonitic amphibolite, and calc-silicate-bearing amphibolite that are too small to map at 1:24,000 scale. Discontinuous layers of massive amphibolite (about 20 to 50 ft thick) are interlayered with amphibolite gneiss in the lithologic-structural domains in the southwest corner of the quadrangle. The massive amphibolites are generally more mafic rich with a

higher proportion of hornblende than amphibolite gneiss and are locally riddled with fine net veinlets of white plagioclase. Minor small zones of moderate to strong mylonitic amphibolite gneiss are present in the southwest part of the quadrangle but no continuity was established.

Amphibolite gneiss is commonly intimately associated with areas of calc-silicate gneiss (Xcs) or has a weak to moderate calc-silicate overprint. The calc-silicate assemblage is dominated by epidote and, locally, actinolite. In areas of well-developed calc-silicate gneiss the adjacent amphibolite gneiss typically has a weak to moderate calc-silicate overprint characterized by garnet-magnetite-epidote-actinolite +/- clinopyroxene and biotite-chlorite assemblages. Four of the larger, continuous areas of calc-silicate gneiss (Xcs) are shown on the map.

The amphibolite gneisses are locally cut by abundant sills and dikes of Berthoud-type granite and pegmatite (YXgp) and possibly older Routt-type granite and pegmatite (Xgp). They are also cut by Middle Proterozoic (?) microdiorite dikes and Tertiary (?) andesite dikes. The rocks were completely recrystallized during amphibolite-grade metamorphism. Rare relict textures include small plagioclase eyes that may represent remnant plagioclase phenocrysts or crystal fragments. The regular gneissic layering is generally interpreted to represent remnant, primary layering (stratification) in the protolith. This is supported by the presence of interlayered amphibolite agglomerate (Xaa) with well-preserved remnant breccia structures, the presence of randomly oriented amphibolite gneiss clasts in the amphibolite agglomerate, and the presence of massive amphibolite layers. The composition of the amphibolite gneiss suggests a mafic, basaltic protolith and remnant textures support an interlayered sequence of basaltic volcanoclastics, flows, and minor breccias.

STRUCTURAL GEOLOGY

The Maysville quadrangle is located in a tectonically complex region that is dominated by the Late Paleogene-Neogene Rio Grande rift (figs. 4 and 5). The structural interpretations presented here strongly corroborate the views of many earlier workers,

that the present structural configuration of the main rift components (axial basins, rift shoulder uplifts and accommodation zones) are largely influenced and controlled by pre-existing structure (Taylor, 1975; Tweto, 1977, 1979a, and 1980a; Chapin, 1979 and 1988; Lindsey and others, 1983; Chapin and Cather, 1994). The strongest support for this interpretation comes from the similarity in the orientation of the main rift components and their bounding structures and regional structural trends produced by Proterozoic, Late Paleozoic, and Laramide tectonic events. Evidence of control of specific rift-related faults by reactivation of older structures is rare and difficult to prove.

PROTEROZOIC DEFORMATION

The Proterozoic terrane exposed in the western half of the Maysville quadrangle is lithologically and structurally complex. Most of this terrane, especially in the southwest quadrant, can be viewed as a complex arrangement of lithologic-structural domains that are bounded by faults. Most of the domain boundaries in the southwest part of the quadrangle have northwest to north-northwest orientations and a few have northeast orientations. Less evidence of multiple lithologic-structural domains is found in the Proterozoic terrane in the northwest part of the quadrangle, but the faults show the same two predominant north-northwest and northeast orientations. In general, the faults are poorly exposed and it is difficult to prove that any of them have Precambrian ancestry.

No evidence for through-going, major Proterozoic shear zones analogous to the mylonitic-ductile shear zones common in the Front Range (Idaho Springs-Ralston Creek and Loveland Pass-Berthoud Pass shear zones) and in the northern Sawatch Range (Homestake shear zone) was found during this study. Minor zones of strong mylonitic fabrics were found in the southwest part of the Maysville quadrangle, but no continuity could be demonstrated for these zones and no indication that they are associated with the domain boundaries was found. The mylonite zones are interpreted to be the remnants of narrow Proterozoic shear zones that have been highly disrupted by subsequent deformation events.

The Early Proterozoic foliated granodiorite (Xgdf) in the northwest part of the quadrangle exhibits a moderate to strong, penetrative deformation fabric (foliation, alignment of alkali-feldspar augen, and mylonitic fabrics) that is variable in orientation. In the central part of the body the foliation is roughly east-west with moderate to steep dips, mostly to the north. Along the southern contact with amphibolite and hornblende gneisses the foliations are typically concordant with the contacts and the gneissic layering. These moderate to strong penetrative deformation fabrics are not present in the small intrusions of Proterozoic granodiorite (Xgd) in the southwestern part of the quadrangle. Keller and others (2004) showed a roughly north-south oriented zone of Proterozoic foliated granodiorite (Xgdf) that is about 32,000 ft long and 2,500 to 7,000 ft wide within the large Denny Creek granodiorite (Xgd) body in the Southern Mosquito Range on the east side of the rift in the Buena Vista East quadrangle. These observations suggest that the Proterozoic foliated granodiorite (Xgdf) probably represents localized, but broad zones of Early Proterozoic shearing that may have developed just after emplacement of the Routt-type granodiorite intrusions and during the regional metamorphic event. The zone of Proterozoic foliated granodiorite in the Maysville quadrangle together with a zone preserved in the Mount Aetna cauldron in the Garfield quadrangle (Shannon, 1988) suggest they may be remnants of a major Proterozoic shear zone trending roughly N75°E. The shear zone is 42,000 ft long and at least 6,000 ft wide.

In the southwest quadrant of the quadrangle, the metamorphic foliations developed in the various Proterozoic lithologic units always parallel the gneissic layering. In some of the lithologic-structural domains the foliations and gneissic layering are parallel to the orientation of the key lithologic units (Xmc, Xag, and Xq), suggesting that most or all of the gneissic layering is a remnant of original bedding and stratigraphy. The main trend of this stratigraphy and parallel metamorphic fabric is about N70°E. However, a number of smaller domains suggest a subsidiary N35°W orientation. Only minor evidence of small-scale folding of the gneisses was found during this study. The presence of some small-scale folding, the local warping of the orientation of the gneisses and the sharp change in foliations and gneiss orientations in some domains suggest that the Proterozoic sequence may have been significantly folded prior to being disrupted by younger faulting. Major changes in domain internal structural orientation may also be

related to rotation of domain blocks during faulting.

One key element of a number of the major fault zones in the Proterozoic rocks is the presence of linear, mappable zones where the rocks are finely broken. These zones are referred to and mapped as “broken rock zones” and will be described in the Laramide deformation section.

LATE PALEOZOIC DEFORMATION

No evidence for Late Paleozoic structures related to the Ancestral Rocky Mountains orogeny was found in the Maysville quadrangle. The closest major Late Paleozoic faults are the Pleasant Valley fault and the Kerber-Crestone fault, about 20 mi east and 25 mi south-southeast, respectively, of Maysville (De Voto, 1972, and De Voto and Peel, 1972). De Voto (1972, figs. 11 and 12) showed an unnamed northwest-trending fault splaying off the Pleasant Valley fault and ending just south of Salida. Knepper (1974 and 1976) referred to this Late Paleozoic fault as the Salida-Coaldale fault. De Voto (1972) also showed an inferred, north-northwest-trending fault along the east side of the proposed Ancestral Sawatch uplift that is in the general area of the present Upper Arkansas graben.

LARAMIDE DEFORMATION

Evidence for Laramide deformation in the Maysville quadrangle is difficult to prove due to the lack of geologic datum horizons in the period of about 72 to 42 m.y. Further, the distinction between Laramide faulting and Neogene faulting related to the Rio Grande rift is hampered by the lack of adequate reference datum that can be used to bracket the age of offsets on most of the faults in the quadrangle. This is the case for all of the faults in the structurally complex, southwest part of the quadrangle. No Mesozoic or Early Cenozoic sedimentary rocks are found in the region and no Laramide-aged intrusive rocks have been identified in the Maysville quadrangle. However, it is possible

that Tertiary (?) andesite dikes (Ta) mapped in the Proterozoic terrane in the southwest quadrant of the quadrangle could be that old. No volcanic rocks related to the Middle Tertiary or Late Tertiary magmatic pulses are exposed in the quadrangle, although it is possible that some Middle Tertiary volcanic rocks could be preserved on the floor of the Upper Arkansas and South Arkansas grabens below the base of the Tertiary Dry Union Formation.

Some of the faults mapped in the Proterozoic terrane in the western half of the Maysville quadrangle are interpreted to be Laramide faults or at least have Laramide heritage. Laramide folds and faults with clear evidence of pre-Mount Princeton pluton ages (about 36.6 Ma) are closely associated with the N40°W-trending belt of Paleozoic sedimentary rock outliers that extends from Aspen to the Kerber Creek area (fig. 5). The north-northwest-trending folds and north-northwest- and north-trending reverse and thrust faults responsible for preservation of the Paleozoic rock outliers described by Dings and Robinson (1957) in the nearby Monarch area were interpreted to be related to the Laramide orogeny. A number of these faults and associated Paleozoic sedimentary rocks are present about 6,000 feet west of the Maysville quadrangle boundary. The small Paleozoic sedimentary rock outliers in the southwest part of the Maysville quadrangle are interpreted to be the erosional remnants of a larger outlier that was disrupted by younger faulting related to the Rio Grande rift. It is suggested that this large Paleozoic rock outlier was originally down faulted into the Proterozoic basement during the Laramide. Thus, some of the faults in the area of the Paleozoic rock outliers probably have Laramide offsets.

The lithologic-structural domains in the southwest quadrant of the quadrangle are bounded by northwest-, north-northwest-, and northeast-trending faults and broken rock (BR) zones. Some of the bounding faults are expressed by a combination of linear broken rock zones and linear lithologic-structural discontinuities that correlate with topographic features including saddles and swales on ridges and small gulches on the sides of the ridges. Other bounding faults are inferred, with no surface expression, and are placed at locations of lithologic and/or structural discontinuity. A number of these bounding faults are shown with limited strike extent because the evidence for a lithologic-structural discontinuity could not be demonstrated on the strike projection. These inferred faults

sometimes terminate at a cross structure, but some are shown to terminate with unclear structural relationship. Some of the north-northwest- and northwest-trending faults that have no topographic expression and no supporting evidence other than a lithologic-structural discontinuity may be healed faults as old as Proterozoic.

BROKEN ROCK (BR) ZONES – Discrete zones of finely broken rock (BR) occur as linear, mappable zones with northwest, northeast and north-south trends in the Maysville quadrangle (plate 1). These only occur in the Proterozoic terrane and only affect various Proterozoic lithologies. The zones are characterized by the almost complete lack of outcrop and the rock occurs as a float concentration of finely comminuted chips generally smaller than ½ inch and commonly less than ¼ inch. The other important characteristics of BR zones are the presence of a weak, orangish to reddish-brown limonite staining on the rock chips and the presence of slickenside surfaces on some of the chips. The slickensided material coating the surfaces of the rock chips is variable and ranges from limonite and/or hematite to less common phyllosilicates including chlorite and sericite. The linear BR zones are best observed where they cross ridges and are topographically expressed as flats, swales, or saddles. The relatively straight trend pattern of the northwest-trending BR zones relative to topography suggests they have steep to vertical orientations.

The overall character and float pattern of BR zones suggest they are brittle fault zones that were broken or shattered and represent fluid circulation zones that deposited light Fe-oxide and locally phyllosilicate coatings on fracture surfaces. The slickensided surfaces on the chips suggest recurrent movement on the fault zones. The BR zones are finely brecciated rocks; however, they are not true breccias because they never have evidence of a matrix or cement that binds the fragments.

The BR zones are similar to the reactivated broken zones that are associated with Precambrian shear zones in the Front Range (Shannon, 1983, unpub. mapping). However, the BR zones in the Maysville quadrangle are not cored with mylonitic, ductile shears and the broken rock is much more finely comminuted. The size of the broken rock fragments may be related to the rock type. Berthoud-type granite and pegmatite dikes

(YXgp) typically make coarser rock float and small knobby outcrops in contrast to the gneissic rocks, which are present as fine (less than ½ inch) chips. The field relations suggest that the fine-grained gneisses behaved more brittlely and were preferentially shattered in comparison to the medium to very coarse-grained Berthoud-type intrusive bodies (YXgp).

The field relations and distribution of the BR zones are complex and unclear. In the Maysville quadrangle, four mappable main BR zones range from about 100 ft to 1,200 ft wide (plate 1). Three of the mappable BR zones are present in the southwest quadrant, and numerous smaller zones range from tens of feet up to about 100 ft wide but are too narrow or discontinuous to show at 1:24,000 scale. These smaller zones occur along many of the lithologic-structural domain boundary faults and support that these zones are a common feature of the major fault zones in the Proterozoic rocks. Two of the mappable BR zones are oriented northwest, a similar orientation to many of the domain boundaries. The westernmost BR zone is about 7,000-ft long, extends off the west edge of the map, and pinches out near the fault terminus in Willow Creek. The second northwest-trending BR zone is about 8,500 ft long and extends from the South Arkansas River to north of Willow Creek where it intersects the third main BR zone. This northwest-trending BR zone skirts by the southwest edge of a large Paleozoic outlier of Ordovician Manitou limestone, about 7,000 ft west-southwest of Maysville. The limestone/dolomite is not broken and shattered along this contact.

The third main BR zone is a north-south-trending, irregular zone along the western bounding structural zone of the South Arkansas graben, the Willow Creek fault. This zone is the longest and most irregular, extending from near the South Arkansas River southward about 14,000 ft across Green Creek and beyond the south edge of the quadrangle. The relationship of the BR zone to the four Ordovician limestone/dolomite occurrences along the west edge of the South Arkansas graben is problematic. The Ordovician limestone/dolomite bodies are interpreted to be structural-erosional remnants of Paleozoic sedimentary rock and thus are considered to be part of the basement rocks making up the west edge of the South Arkansas graben. The limestone/dolomite bodies are localized in highly irregular jogs in the BR zone and adjacent Willow Creek fault. The northernmost Paleozoic body consists of locally brecciated and shattered Manitou

limestone that is exposed in a window through Quaternary gravel (Qbo) on the west edge of Maysville. This limestone body is interpreted to be a slice of Paleozoic carbonate rock that was caught up in, brecciated, and down dragged along the Willow Creek fault.

To the south along the Willow Creek fault, the contact of the second Paleozoic outlier with the BR zone is concealed by a concentrated zone of colluvial boulders derived from the Dry Union Formation (Td2) that is uphill to the southwest. No indication was found that this Paleozoic outlier is shattered or significantly brecciated. Further south, the BR zone skirts around the west side of the third large, well-exposed, thick-bedded dolomite outlier north of Willow Creek. Again, no brecciation or shattering of the dolomite is evidenced in the contact zone with the gneiss. The BR zone to the west of the dolomite does contain some outcrops of the gneissic rocks that may indicate the nature of the parent material for BR zones. The amphibolite gneiss (Xag) has moderate to strong chlorite alteration with abundant irregular chloritic and hematitic slip surfaces. The rocks are so altered and deformed that no consistent gneiss layering is apparent. Abundant chips of hematitic quartzite derived from a layer of Proterozoic quartzite (Xq) on the ridge to the north are mixed with gneiss chips in the BR zone. The southernmost Paleozoic outlier occurrence on the south side of Green Creek is small and very poorly exposed. Most of the limestone occurs as small float chips. In summary, BR zones in the southwest quadrant of the Maysville quadrangle are mappable structural zones of fine shattering that are preferentially developed in the Proterozoic gneisses and do not affect adjacent Paleozoic rock outliers.

The fourth BR zone, in the northwest quadrant of the Maysville quadrangle, occurs as a continuous 4,500-foot long, northeast-trending zone along the range front Shavano fault zone. The BR zone is between the north fork of Squaw Creek and the north edge of the quadrangle and continues for at least another 3,500 ft into the southern part of the Mount Antero quadrangle. In the Maysville quadrangle, the BR zone is 1,000 to 1,200 ft wide and in its southwestern part consists of concentrated, fine, float chips of Proterozoic foliated granodiorite (Xgdf). To the northeast the amounts of amphibolite gneiss chips in the BR zone increases, and in the southern part of the Mount Antero quadrangle segments of the BR zone are dominated by amphibolite gneiss chips. The amphibolite gneiss is derived from sheet-like pendants of gneiss in the Proterozoic

granodiorite.

The outer part of the range front structural zone consists of a continuous zone of silicified Proterozoic fault breccia with much coarser clasts than the BR zone rock chips. The fault breccia occurs as an at least 150-foot wide, concentrated float zone and as small blocks on a mine dump at a caved shaft. The breccia has angular clasts of Proterozoic foliated granodiorite (Xgdf) up to a couple of inches in size, in a silicified matrix. Outboard of the Proterozoic fault breccia to the southeast, a zone of Tertiary rhyolite porphyry (Trp) and aphyric rhyolite (Tr) dikes occurs as discontinuous outcrop, subcrop, and float along the range front. The rhyolite dikes are from 20 to 30 ft thick and are locally brecciated and silicified. The rhyolite dikes and silicified breccias do not occur as a component of the BR zone, nor are Dry Union Formation conglomerate clasts indicated.

The continuity of the BR zone and rhyolite dikes to the southwest is uncertain due to lack of exposure. The range front fault zone is concealed for 6,000 ft by the Quaternary tills that came out of the north and south forks of Squaw Creek. Farther southwest the range front structural zone is very poorly exposed and much of it is covered with coarse Proterozoic rock colluvium. Some rhyolite porphyry on the lower adit dump of the Blank mine suggests that rhyolite dikes exist along the range front structure in this area. Further southwest in the steep gulch north-northeast of the Angle of Shavano Campground, a subcropping BR zone with finely comminuted Proterozoic gneiss is exposed in a small erosional window in Quaternary till. Between the North Fork and the Cree Creek area the continuity and width of the BR zones is uncertain due to abundant colluvial float. A large irregular BR zone wraps around the small hill between Lost Creek and Cree Creek near the southernmost part of the Shavano fault. These observations suggest there may be a northeast-trending continuous BR zone associated with the Shavano fault zone, which extends for over 30,000 ft. across the northwest part of the quadrangle.

The age of the BR zones in the Maysville quadrangle is not well understood and the brecciation and shattering of the rocks could range from the Proterozoic to recent. However, the brittle nature of the deformation does not support an Early or Middle Proterozoic age for the faulting. This leaves a potential age ranging from the Late Paleozoic to the Neogene. As described above, the BR zones in the southwest part of the

quadrangle are intimately associated with some of the northwest- to north-northwest-trending faults that may have Laramide heritage. However, the strong association of BR zones with the two structures that bound the western margin of the Upper Arkansas graben and South Arkansas graben (Shavano fault zone and Willow Creek fault, respectively) suggests that the BR zones may be related to Neogene faulting associated with the rift. If the BR zone shattering was produced during repeated Neogene faulting that juxtaposed Proterozoic rocks on the west with the Tertiary Dry Union gravels on the east then some mixing of the Tertiary gravel clasts with the BR zones might be expected. However, there is a complete lack of a rounded pebble component and a lack of the lithologic diversity that typifies the Dry Union conglomerate clasts in the BR zones, especially those segments that are directly adjacent to the Dry Union Formation.

It is possible that the BR zones represent remnants of the earliest rift fault breaks that are preserved in the stranded walls of the fault zones and that the Dry Union gravels have been juxtaposed during younger faulting events that have stepped inward (with respect to South Arkansas graben) and away from the earlier faults. Another possibility is that the spatial arrangement of BR zones with the west edge of the grabens may be fortuitous and could be explained by marginal rift bounding faults using and reactivating older planes of weakness related to Laramide faults. Another less likely interpretation is that the BR zones are somehow related to the emplacement of the detached Paleozoic blocks/sheets (Td2ls) that were incorporated in the lower part of the South Arkansas graben Dry Union Formation (Td2) section. However, the lack of shattering in the Paleozoic outliers and the linear distribution of the BR zones and the indication they are localized along steeply dipping fault zones does not support this interpretation.

BR zones are relatively subtle features and can easily be overlooked. Some of the more important aspects of the zones that could be used to help constrain their origin are the distribution pattern and timing. So far they have only been found cutting Proterozoic rocks. It would be very important to determine if BR zones have a broad regional distribution pattern in the Proterozoic terrane or if they are spatially related to the rift. They also might be localized in the structurally complex area of intersecting faults, horsts, and grabens at the south end of the Upper Arkansas graben. The preliminary observations presented here suggest they are at least locally intimately associated with

major fault structures that bound the western side of the Rio Grande rift grabens.

The timing of formation is also critical to the interpretation of BR zones. Do they cut any of the Tertiary intrusions including the Mount Princeton pluton, Mount Aetna cauldron-related rocks or the younger Mount Antero leucogranites? It may be possible with detailed studies to date the age of slickensided phyllosilicate coatings in the broken rocks. The reason that they do not cut and affect the Paleozoic rock outliers (for a Laramide origin or post-Laramide origin) and the Oligocene rhyolite dikes (for a Neogene origin) is still a problem. The overall relationships support a two-stage structural process for formation of BR zones involving early Laramide faulting and reactivated Neogene faulting.

POST-MIDDLE TERTIARY AND RIO GRANDE RIFT **DEFORMATION**

The most obvious major faults on the Maysville quadrangle are the bounding faults that frame the western side of the Upper Arkansas graben (Shavano fault zone) and South Arkansas graben (Willow Creek fault) and the concealed fault (Salida-Maysville fault) that separates the Upper Arkansas graben from the South Arkansas graben. These faults clearly have major Neogene offsets related to formation of the rift grabens and juxtapose rift fill against Proterozoic and Tertiary rocks.

In the northwest quadrant of the quadrangle the presence of the late Eocene-early Oligocene intrusions related to the Mount Princeton pluton and the Mount Aetna cauldron, and late Oligocene intrusions related to the Mount Antero leucogranites, provides a datum to evaluate the ages of faulting (fig. 38). The faults in this area include three subparallel north-northwest-trending faults, one north-south-trending fault, one west-northwest-trending fault, and two parallel, major northeast-trending faults. The north-northwest- and north-south-trending faults cut Proterozoic rocks and at least two of them appear to be truncated where they obliquely intersect the northeast-trending-range front Shavano fault zone. The north-northwest-trending faults continue northward where they cut the late Eocene-early Oligocene Mount Princeton pluton in the northwest corner

of the quadrangle. The north-northwest- and northeast-trending faults cutting the Mount Princeton pluton continue northward into the Mount Antero quadrangle where they cut the early Oligocene Mount Aetna ring dikes and the Oligocene Mount Antero leucogranite intrusions (Shannon, 1988). Thus, some of the faults have significant offsets that are younger than about 29.8 Ma (average age of leucogranites).

The north-northwest-trending faults are the southern end of a zone of similar north-northwest-trending faults that define the western margin of a long, rift-shoulder horst block that is informally referred to as the Collegiate Peaks horst (figs. 4 and 5; Shannon and others, 1987c; Shannon, 1988). The down-to-the-west sense of offset across the western margin of the horst block was estimated to be about 2,600 ft on the basis of offset of internal textural igneous-stratigraphic horizons in the Mount Princeton pluton and other lithologic discontinuities. Additional support for differential uplift of the horst block is indicated by the distribution of peaks higher than 14,000 feet and the resetting of apatite fission-track ages. The down-to-the-west sense of apparent offset on the north-northwest-trending fault (which offsets the Proterozoic Xag/Xhig-Xgdf contact in the northwest quadrant of the Maysville quadrangle) is compatible with it being related to the western margin of the Collegiate Peaks horst. The north-northwest-trending faults in the northwest quadrant of the quadrangle are of similar orientation to faults in the southwest quadrant, some of which are interpreted to be Laramide faults. It is suggested that the north-northwest trend of the Collegiate Peaks horst may be influenced by Laramide basement structures (and possibly even earlier Late Paleozoic and Proterozoic structures) that have been superimposed on the Oligocene intrusions.

The northeast-trending faults in the northwest part of the Maysville quadrangle also fit into a larger regional picture of complex faulting in the Sawatch Range rift-shoulder uplift. The northeast-trending fault crossing the very northwest corner of the Maysville quadrangle, herein informally referred to as the McCoy Creek fault, is situated between Mount Shavano and Tabeguache Peak and extends into the southwest corner of the Mount Antero quadrangle. This fault is oblique to the southeast margin of the Mount Aetna cauldron ring zone defined by various ring zone features including Mount Aetna



Figure 38. Steep rift-related fault cutting California leucogranite (Tcm) in upper Squaw Creek. The fault trends N22 E 79 NW and is subsidiary to major N-NW trending fault related to Collegiate Peaks horst. Fault contains brecciated leucogranite and silicified material.

quartz monzonite ring dikes (Tma). The fault crosses Browns Creek and continues northeastward where it intersects the range-front Sawatch fault zone at Raspberry Gulch. On the north side of Browns Creek, geological relations between the Mount Antero leucogranite and the California leucogranite intrusions indicate that the McCoy Creek fault has significant down-to-the-northwest sense of offset (Shannon, 1986 and 1988). The northeast-trending fault extends to the southwest along McCoy Creek into the Garfield quadrangle. In the area of the North Fork, the fault has significant down-to-the-northwest offset indicated by the offset of the North Fork leucogranite intrusion (Shannon, 1988).

The second major northeast-trending fault in the northwest part of the quadrangle is the range-front Shavano fault zone (figs. 4 and 5). This fault zone has an overall trend of N35°E and defines the main break in slope at the range front. The strong structural and spatial relationship between the northeast-trending faults and the set of northeast-trending rhyolite dikes suggest these fractures were controlling the emplacement of the Oligocene dikes. The group of rhyolite dikes (Trp and Tr) that occur in the Proterozoic rocks have an overall orientation of N25°E with 50°NW dip. Two of the dikes were intruded along the Shavano fault zone and local brecciation indicates continued movement of the fault zone after they were emplaced.

The relations described here indicate the presence of a major northeast-trending horst block, herein informally referred to as the Jones Peak horst, which makes up the exposed bedrock area in the northwest part of the Maysville quadrangle (fig. 5). The Jones Peak horst block is about 48,000 ft long and about 13,000 ft wide. It appears to be terminated on the northeast at the north-northwest-trending range-front Sawatch fault zone. The Jones Peak horst extends southwest into the Garfield quadrangle where the continuation of the McCoy Creek fault south of the North fork is uncertain. Estimated offset on the northeast margin of the Jones Peak horst is a minimum of about 600 ft in the North Fork in the Garfield quadrangle, and possibly up to 2,300 ft on Mount White in the Mount Antero quadrangle. No datum allows the determination of offset on the southeast margin of the Jones Peak horst, but a minimum of 4,000 ft of offset on the basement rocks is suggested by the elevation difference from the top of Mount Shavano to the Tertiary and Quaternary sedimentary rocks southeast of the Shavano fault zone. The

southwestern continuation of the Shavano fault is also uncertain. It has been traced to a cluster of mines on the east side of Cree Creek where it is concealed by Quaternary till.

The west margin of the Collegiate Peaks horst and the northeast margin of the Jones Peak horst intersect about 4,000 feet north of Mount Shavano in the southwest corner of the Mount Antero quadrangle (figs. 4 and 5). This area is extremely structurally complex and the relative ages of uplift of the two horst blocks is not clear cut. However, the overall pattern of faulting and the cross-cutting relationships with the Oligocene leucogranite intrusions suggests that the northeast-trending Jones Peak horst is probably slightly younger than the north-northwest-trending Collegiate Peaks horst.

A west-northwest-trending, mostly inferred fault, herein informally referred to as the Squaw Creek fault extends along Squaw Creek in the northwest quadrant of the Maysville quadrangle (fig. 5). At the very north edge of the quadrangle a zone of small faults on the south side of Squaw Creek cuts the Mount Pomeroy subunit (Tmpp) and controls numerous associated springs. This fault does not appear to cut the north-northwest-trending fault contact between the Mount Pomeroy subunit (Tmpp) and the California leucogranite (Tcm) at the head of Squaw Creek (in the Mount Antero quadrangle), suggesting that it is older than the north-northwest-trending faults. The west-northwest-trending fault is mostly inferred because it is concealed by glacial gravels (Qpt) in Squaw Creek. However, it may explain apparent offsets (right lateral) in the Mount Princeton (Tmpp)-Proterozoic granodiorite (Xgdf) contact and the Proterozoic granodiorite (Xgdf)-Proterozoic amphibolite gneiss (Xag) contact across Squaw Creek. East of the range front the inferred Squaw Creek fault is associated with a lineament shown on satellite and DEM images that follows the approximate trend of Squaw Creek and is interpreted to be concealed by Quaternary gravels. However, Denesha (2003) found evidence for a west-northwest-trending, north (48° to 82°)-dipping fault cutting the Dry Union Formation on the eastward strike projection of the Squaw Creek fault in the Salida West quadrangle. In addition, an apparent lithologic discontinuity in the character of the Dry Union Formation across this inferred structure is suggested by a distinct change in the assemblage of clast/boulder lithologies. The inferred Squaw Creek fault is parallel to the Salida-Maysville fault; both faults show up as lineaments on DEM images.

The Salida-Maysville fault is a major west-northwest-trending transverse fault

that truncates the Upper Arkansas graben and separates it from the South Arkansas graben (fig. 5). To the east, it is part of a zone of faults that truncates the northern part of the Sangre de Cristo Range and separates it from the Salida graben (Perry, 1971; Scott and others, 1975; Knepper, 1976). In the Maysville quadrangle, the fault defines a major lithologic discontinuity--on the east, between the two different sequences of the Dry Union Formation (Td on the north and Td2 on the south); on the west, between the Proterozoic terrane (on the south) and the thick sequence of Quaternary gravels and Tertiary Dry Union Formation (Td on the north). The Salida-Maysville fault is mostly inferred where it is concealed by gravels along the South Arkansas River. About 7,000 feet west-northwest of Maysville the location of the fault is more certain and is related to outcrops of faulted, brecciated, and altered Proterozoic granodiorite (Xgd) and intermediate gneiss (Xhig) and a small window of Dry Union Formation exposed in a short unnamed gulch on the north side of the highway. South of the Dry Union Formation exposures, a cut across the Proterozoic rocks exposed a fault with N83°E strike and 63°NW dip, suggesting an orientation or sub-orientation for the Salida-Maysville fault in this area.

To the west, the Salida-Maysville fault position is inferred to run on the north side of Cree Creek. Once the Salida-Maysville fault reaches the projected intersection area with the Shavano fault zone at the western boundary of the quadrangle, the evidence for the fault is less certain. Evidence is not compelling to continue the major lithologic discontinuity along the projection of this fault westward into the Garfield quadrangle. If it continued west-northwest, the Salida-Maysville fault would be concealed by Pinedale till (Qpt) in upper Cree Creek and eventually transect the southern part of the Mount Aetna cauldron. Although there are suggestions of a continued west-northwest lineament on satellite and DEM images, there is no evidence for an associated lithologic discontinuity across the Mount Aetna cauldron (Shannon, 1988).

In the area of projected intersection of the Shavano fault and the Salida-Maysville fault previous workers (Scott and others, 1975; Tweto and others, 1976) have mapped an irregular north-south fault that truncates the Shavano fault and would also truncate the strike projection of the Salida-Maysville fault. Some evidence for this fault was found in this study, indicated by a broad BR zone extending to the ridge crest on the north side of

Cree Creek. The map pattern of the BR zone suggests a north-south oriented fault that merges with the BR zone along the southwesternmost part of the Shavano fault (plate 1). However, the north and south extension of the north-south fault is concealed by Quaternary till/gravel. No evidence exists that this fault extends north to the North Fork or south across the South Arkansas River. Thus, the continuation of the Shavano fault and the Salida-Maysville fault beyond the west edge of the quadrangle is uncertain. The field relations suggest these two faults may have moved nearly simultaneously and neither one continue on the strike projection with significant offset.

Another major question involves the relationship and relative ages of the Shavano and Willow Creek faults bounding the western margins of the Upper Arkansas graben and South Arkansas graben, respectively. The Willow Creek fault has a northeast-trending bend at its north end. The BR zone and the contact with the Dry Union Formation along this segment of the Willow Creek fault are parallel to the Shavano fault. The Willow Creek fault appears truncated by the Salida–Maysville fault. If the Shavano fault and the Salida-Maysville fault moved at the same time, it would suggest that the Willow Creek fault is older. The interrelationships of the rift-bounding faults, the grabens, and the rift-shoulder uplift horst blocks are extremely complicated and the interpretation will require additional detailed studies in the surrounding areas, including the Mount Antero, Garfield, Mount Ouray, and Poncha Pass quadrangles.

QUATERNARY DEFORMATION

Geologic evidence suggests that some faults in the quadrangle have been active in Quaternary time. The most active fault is the Shavano fault zone, which lies at the base of the Sawatch Range and Mount Shavano in the northwest quarter of the map area (plate 1). Fault scarps (thick lines with hachures on the map) in the Shavano fault zone define a broad fault zone composed of 3 to 4 parallel, southeast-dipping normal faults in a zone 0.5-1.1 mi wide that displace Quaternary glacial and alluvial deposits. An additional step-fault crosses the range-front piedmont 2.2-2.5 mi from the range front. The best-preserved faults scarps are generally on those fault strands closest to the range front, such

as at the mouth of Squaw Creek. However, it is difficult to measure the tectonic offset of Quaternary deposits across these fault traces, for three reasons.

First, many of the faults coincide with the fronts of terminal moraines (for example, Squaw Creek), so the vertical relief from recent faulting cannot be distinguished from the primary vertical relief formed during moraine deposition. Second, across most fault scarps different-age deposits are on the upthrown and downthrown sides, complicating displacement estimates. Third, fault scarps are obscured in places by landslides. These landslides may be earthquake-induced landslides and flowslides that formed during the violent ground shaking and surface rupturing on the Shavano fault zone, but the height of the present landslide headscarp almost certainly exaggerates the amount of vertical fault surface displacement during each faulting event. Altogether, the surface expression of Quaternary faulting on the Shavano fault zone is less well preserved and less impressive than at range-front locations farther north, such as along the Sawatch fault zone in the Buena Vista West quadrangle (McCalpin and Shannon, 2005).

Evidence for additional Quaternary faulting exists in the far northeastern corner of the quadrangle (Sections 1, 2, 11, 12; T50N, R7E; and Sections 35, 36; T51N, R7E), where a group of four suspected Quaternary faults cuts Tertiary Dry Union Formation. These faults were identified from aligned, down-to-the-east steps in the Quaternary pediment surfaces. These steps tend to be rather broad and 12 to 30 ft high, so if they are fault scarps, they are more subdued (and presumably older) than fault scarps of the Shavano fault zone. The faults appear to continue between several pediment surfaces and are inferred to connect via prominent gullies on valley sidewalls. The overall strike of these faults ranges from N15°W to N30°W. In addition, there is a parallel N30°W-trending lineament to the southwest of this fault swarm.

None of these faults were exposed in outcrop, so the latest period of movement is unknown. They appear to dismember the east-sloping Nebraskan pediment surface (map unit Qna), so some of the movement must predate the early Pleistocene.

If these faults are projected about 3 mi northward into the Mount Antero quadrangle, they would intersect the southern end of the range-front Sawatch fault zone, which north of Brown's Creek trends about N20°W. South of that point, the range front

gradually bends about 70° to become the Shavano fault zone, which trends $N50^\circ E$. Thus, this swarm of four faults appears to represent a southward continuation of the Sawatch fault zone, composed of distributed down-to-the-east step faulting. This fault geometry implies that the down-to-the-east Quaternary displacement on the western side of the Upper Arkansas graben is partitioned between components, a larger one at the range front (Shavano fault zone), and a smaller one that trends south-southeast into the valley fill (southward continuation of the Sawatch fault zone).

DISCUSSION

The tectonic-structural setting of the Maysville quadrangle is complicated by its location along the northern part of the complex transfer or accommodation zone that separates the Upper Arkansas axial basin from the San Luis axial basin (fig. 5). Chapin and Cather (1994) suggested a model that relates northeast-trending accommodation zones that segment the Rio Grande rift to pre-existing transverse structural lineaments related to Late Cenozoic clockwise rotation of the Colorado Plateau. They suggested the poorly exposed and less constrained accommodation zone associated with the Upper Arkansas and San Luis grabens is the northeast-trending Villa Grove accommodation zone.

Additional complications are suggested by the developing picture of rift shoulder uplifts, extra- and intra-graben horst blocks, and complex compartmentalization of the main axial grabens (fig. 39). Two previously recognized subparallel horst blocks that impinge on the east side of the Upper Arkansas graben are the Browns Canyon horst and the large Sangre de Cristo horst (Knepper, 1974 and Taylor, 1975).

The Browns Canyon horst (informal name used herein) occurs in the southern Mosquito Range on the east edge of the Upper Arkansas graben about 6 mi north-northwest of Salida. It is about 6 mi long, 1.5 mi wide and trends about $N40^\circ W$. The main Sangre de Cristo Range trends about $N28^\circ W$ along the western side of the San Luis Valley and bends to about $N45^\circ W$ in the Villa Grove area. The very northern end of the range is oriented about $N67^\circ W$ and is an intragaben horst (or tilted block?) where it is

adjacent to the southwestern edge of the Salida graben. The Salida-Maysville fault is the structural boundary between the Sangre de Cristo horst and the Salida graben in the east and the structural boundary between the South Arkansas graben and the Upper Arkansas graben in the west. The fault continues westward across the southwestern part of the Maysville quadrangle and defines the structural boundary between the Proterozoic terrane outside the west margin of the South Arkansas graben and the Tertiary Dry Union Formation in the southwestern part of the Upper Arkansas graben. Thus, the Salida-Maysville fault, which trends about N70°W across the quadrangle, is a major west-northwest-trending transverse structure associated with the Sangre de Cristo horst and defines the southern margin of the Upper Arkansas graben.

Two horst blocks have been recognized on the west side of the rift: the N15°- to 35°W-trending Collegiate Peaks horst (Shannon, 1988) and the about N35°E-trending Jones Peak horst informally defined in this report (fig. 39). The southern part of the Collegiate Peaks horst is oriented about N15 W and is about 10 mi long and 12,000 ft wide from Browns Creek to Sheep Mountain. It bends to a N35°W trend in the area southwest of Mount Yale where it is less defined but may be over 15,000 ft wide. The Jones Peak horst trends N35° to 40°E and is about 40,000 ft long and 13,000 ft wide.

Evidence also exists that the axial grabens are subdivided and compartmentalized into sub-grabens and/or broken up by smaller intragaben horsts. McCalpin and Shannon (2005) showed preliminary evidence for the presence of a N40°W-trending intragaben graben in the Maxwell Park area in the Buena Vista West quadrangle. The postulated Salida graben in the eastern part of the southern Upper Arkansas graben (Knepper, 1976) may extend west and include the area between the Squaw Creek fault and the Salida-Maysville fault as suggested in this report (fig. 39). If so, the Salida graben trends about N70°W and is about 17 mi long and 4 mi wide. Additional evidence for the westward continuation of the Salida graben is the major change in the composition of the Dry Union conglomerate clasts across the Squaw Creek fault. Detailed studies of Dry Union clast compositions may provide important clues about the location of sub-grabens and the bounding faults. Deep drilling for water wells or exploratory geothermal wells, and the ability to log those wells, would also help delineate these boundaries.

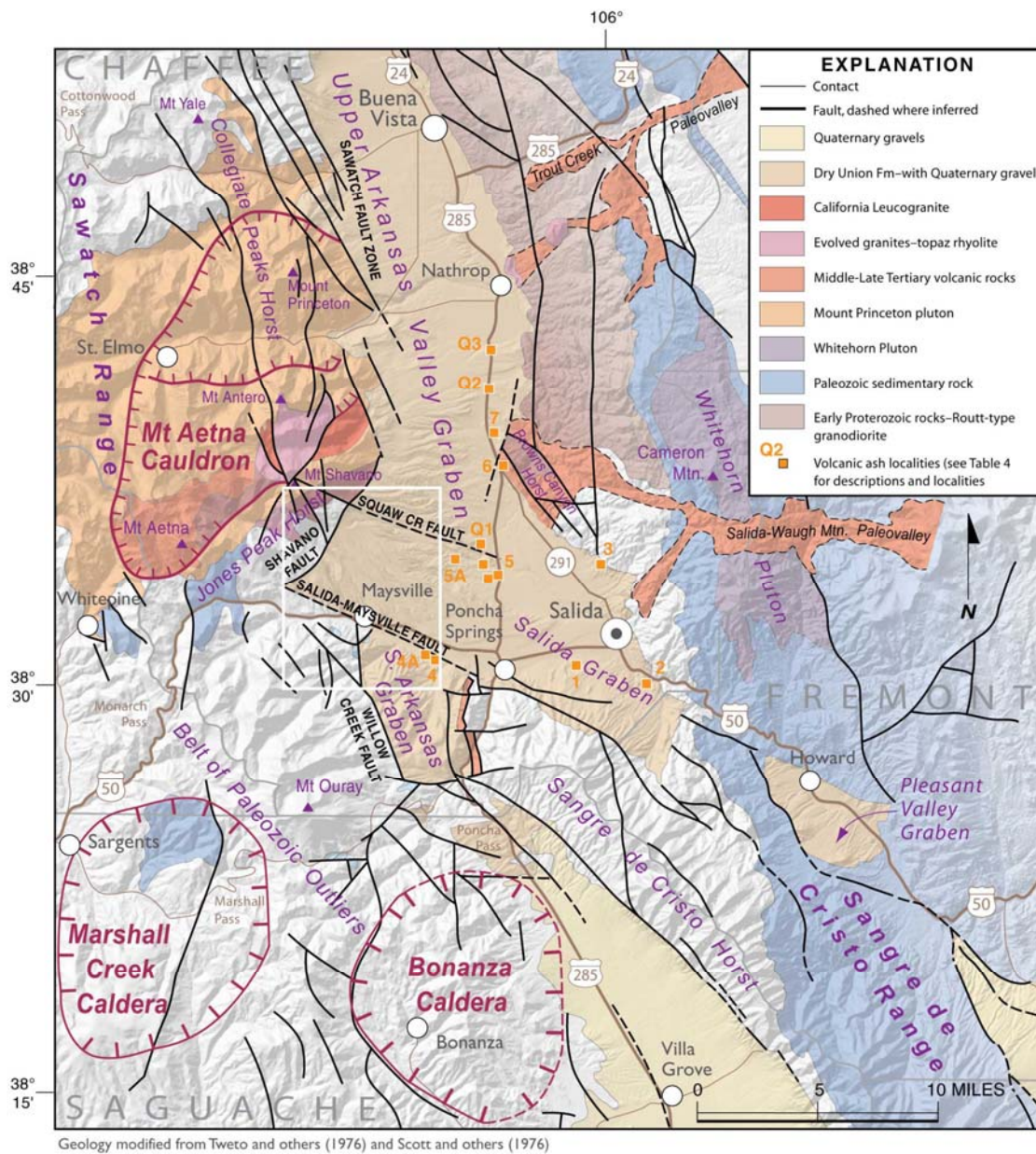


Figure 39. Summary of Rio Grande rift architecture and location of Tertiary and Quaternary volcanic ash localities. Maysville quadrangle location shown with white rectangle. See text for sources of map information.

The complex structural relations in the Maysville quadrangle indicate the presence of a major N70°W-trending, transverse fault, the Salida-Maysville fault. We suggest in this report that the Villa Grove accommodation zone of Chapin and Cather (1994) is the southern end of a broad, transverse boundary zone between the San Luis

graben and the Upper Arkansas Valley graben. It extends from Villa Grove in the upper San Luis Valley to the Salida area and is bounded on the north by the west-northwest-trending Salida-Maysville fault (fig. 39). Such an interpretation is favored because the symmetry of the rift shoulder uplifts does not abruptly change but is more of a transition across this broad 20 mi wide area. On the west side of the rift, the Proterozoic rocks in the core of the Sawatch Range extend southward (partially under Tertiary volcanic rock cover) to Mineral Hot Springs where these rocks terminate at the north end of the San Luis Valley. On the east side of the rift, the Proterozoic rocks in the core of the Sangre de Cristo Range continue northward to Poncha Springs, where they terminate at the south end of the Upper Arkansas Valley. Thus the asymmetric rift shoulder uplifts overlap for about a 20 mile wide area. Therefore a more inclusive name for this complex zone is the Poncha Springs-Villa Grove accommodation zone (see fig. 5).

Observations presented in this report suggest two and possibly four or more volcanic ash beds are present in the South Arkansas graben sequence (Td2). Additional volcanic ash beds have been reported in the Upper Arkansas graben sequence (Td). Table 4 provides a compilation of all Miocene and Pliocene volcanic ash localities that have been identified in the southern part of the Upper Arkansas graben and the South Arkansas graben. Nine localities of volcanic ash are identified in the Dry Union Formation (Td and Td2) and three localities of volcanic ash are in Quaternary deposits (fig. 39). Multiple ash beds are reported at four of the Dry Union Formation ash localities. Basic characteristics of the ashes including thickness, presence and character of glass, mineralogy of primary crystal fragments, and degree of contamination may provide information that could be used to correlate the different localities. More advanced techniques including tephrochronology and glass and mineral chemistry may help to confirm correlations and ultimately provide absolute ages on specific volcanic ashes. Consequently, the volcanic ash beds in the Dry Union Formation are suggested to be important time-stratigraphic markers that will be useful in recognizing and separating the different stratigraphic sequences in the different Dry Union Formation structural domains and providing absolute age constraints on inception of rift-related faulting and sedimentation.

Table 4. Compilation of Miocene-Pliocene and Quaternary volcanic ash localities in the southern part of the Upper Arkansas graben and South Arkansas graben. Locations are shown on figure 39.

DRY UNION FORMATION: VOLCANIC ASH LOCALITIES

<u>No.</u>	<u>LOCALITY</u>	<u>LOCATION</u>	<u>ASHES</u>	<u>THICKNESS</u>	<u>USGS#</u>	<u>AGE</u>	<u>REFERENCE</u>
1	Salida Southwest	Sec 7, T49N, R9E; Salida West quad	4	?		Plio.	Van Alstine, 1969
2	Salida Southeast	Sec 16, T49N, R9E; Wellsville quad	1	6" to 2'		L. Mio.	Van Alstine, 1969
3	Dead Goat Gulch	Sec 20, T50N, R9E; Salida West quad	1	6" to 2'		Plio.	Van Alstine, 1969
4	Little Cochetopa Cr. E.	Sec 7, T49N, R8E; Maysville quad	2(?)	3'		Mio.	Van Alstine, 1969
4A	Little Cochetopa Cr. W.	Sec 12, T49N, R7E; Maysville quad	2	6" and 1'		Mio.	This Study
5	Droney Gulch	Sec 21, T50N, R7E; Salida West quad	2+			Plio.(?)	Denesha, 2003
5A	Droney Gulch West	Sec 20, T50N, R7E; Salida West quad	1			Plio.(?)	Denesha, 2003
6	Hecla Junction South	Sec 34, T51N, R8E; Nathrop quad	1	?	USGS D296?	E. Plio.	Van Alstine, 1969
7	Section 16	Sec 16, T51N, R8E; Nathrop quad	1	?	USGS D-298	Plio.	Van Alstine, 1969

QUATERNARY GRAVEL: VOLCANIC ASH LOCALITIES

<u>No.</u>	<u>LOCALITY</u>	<u>LOCATION</u>	<u>ASHES</u>	<u>THICKNESS</u>	<u>USGS#</u>	<u>REFERENCE</u>
Q1	Squaw Creek	Sec 17, T50N, R8E; Salida West quad	1	?	USGS V-775	Scott and others, 1975
Q2	Browns Creek	Sec 9, T51N, R8E; Nathrop quad	1	?	USGS V-767	Scott and others, 1975
Q3	Centerville	Sec 35, T15S, R78W; Nathrop quad	1	?	USGS V-774	Scott and others, 1975

GEOLOGIC HAZARDS

Potential geologic hazards in the Maysville quadrangle fall into four categories: (1) landslides, (2) floods and debris flows, (3) seismicity and active faulting, and (4) abandoned mined lands.

LANDSLIDES

We mapped 12 landslide deposits, and 2 large inferred slide blocks of relatively intact Proterozoic rock (table 5). The mean area of all landslide deposits (excluding the inferred slide blocks) is 19 acres, with a range from 1 acre to 45 acres. These areas do not include the source area from which the landslide slid, which lies between the slide headscarp and the upslope margin of the landslide deposit.

Table 5. Summary of landslide deposit areas, by map unit in the Maysville quadrangle.

Map Unit	Number of Deposits/ Description/Lithologies	Range of Areas (acres)	Mean Area (acres)
Qlsy	1 area; young landslide deposits, uneroded; failure of residuum at head of 1 st -order drainage	1.1	1.1
Qlso	3 areas; older landslide deposits (eroded, dissected); 2 small wedge failures in Proterozoic rock; 1 slump in Td	18-45	35
Qls	7 areas; undivided landslide deposits; 2 slumps off the Pinedale terminal moraine of Squaw Creek; 2 slumps in residuum (?) flanking Qlsy; small slide in Tqm in North Fork; slide off range front fault zone between North Fork and Lost Creek; slide at N map boundary	2-33	15
Inferred slide blocks	2 very large wedge failures of Proterozoic rock	385-830	608
TOTALS	12		

Landslide deposits are relatively rare in the Maysville quadrangle, for several reasons. First, more than half the quadrangle is composed of a low-gradient range-front piedmont underlain by Tertiary Dry Union Formation. Streams have incised valleys up to 220 ft deep into the piedmont, but no landslides are mapped on the valley walls. This lack of mappable failures can probably be explained by the general aridity of the piedmont, and by the strength of the sandy to gravelly textured Dry Union Formation. Second, the Proterozoic and Tertiary intrusive rocks that underlie the steeper slopes of the Sawatch Range are generally too competent for slope failure except where weakened by faulting.

Landslides elsewhere in the Upper Arkansas Valley are strongly controlled by geology and nearly always occur in proximity to rift-related normal faults (Keller and others, 2004; McCalpin and Shannon, 2005). Presumably, the rock mass strength in the faulted rock is low enough to permit slope failure of fractured and/or altered rock on steep slopes during times of either elevated water table, strong shaking from earthquakes on the Shavano fault zone, or both.

In the Maysville quadrangle, however, only 4 of the 12 mapped landslides are associated with the Shavano fault. The two largest landslides at the range front are contiguous failures of till at the front of the Pinedale terminal moraine of Squaw Creek. These two landslides overlie, and the eastern one is cut by, strands of the Shavano fault zone. The landslides are complex slumps containing linear grabens subparallel to the Shavano fault zone. Downslope from the slumps we map an anomalous fan-shaped deposit (Qfol) that has the morphologic characteristics of both an alluvial fan and a flow-type landslide. Scott (1975) classified this deposit as landside deposits (undivided), but we map it as a separate mixed landslide/alluvial fan deposit due to its odd morphology. This odd deposit appears to bury the Bull Lake terminal moraine.

From the relative locations of the Qls and Qfol deposits, we infer that the distal part of the failed Pinedale terminal moraine slumped in its upper parts but liquefied and flowed downslope in its lower parts, forming the Qfol deposit. This inference suggests that the till mass was quite wet at the time of failure. Accordingly, we infer that the Qls deposits were formed during a surface-rupturing ($M > 7$) earthquake on the Shavano fault zone while the Pinedale terminal moraine was still being deposited, about 25,000 to 15,000 years ago.

In addition, older landslides may have also occurred in this same area but may have been obscured by the Pinedale-age landsliding. For example, the Bull Lake terminal moraine would have been equally susceptible to failure while it was being deposited (about 130,000-150,000 years ago) if a large earthquake had occurred during that time period.

The other range-front landslide lies between the North Fork and Lost Creek and is a failure of Proterozoic rock on the range-front faceted spur. This landslide deposit is quite long in relation to its width, indicating that the landslide had enhanced mobility, perhaps also an indicator of high water content.

The largest area of landsliding lies in Proterozoic rock on the south side of the South Arkansas River, west of Maysville. The reach of the river valley west of Maysville is by far the narrowest part of the valley, with the narrowest constriction between Maysville and Lost Creek. Here, several segments of the southern valley wall appear to have moved northward and nearly pinched off the valley. The youngest, lowest, and smallest slide block is mapped as a landslide deposit (Qlso), is labeled Slide Block III, and has a recognizable headscarp and somewhat hummocky topography. Roadcuts on the north side of US 50 opposite Qlso expose extremely shattered and brecciated Proterozoic rock that may represent a correlative part of Qlso now stranded on the opposite side of the river. The landslide deposit is shaped like a triangle, bounded by linear flanks trending northwest and northeast. These flanks parallel the trends of the two main fault sets mapped south of the South Arkansas River. On the basis of this coincidence, we believe that Qlso is a wedge failure of quasi-intact Proterozoic rock that is sliding northward on the north-plunging intersection of NW- and NE-dipping normal faults.

Upslope from Slide Block III are two progressively larger areas interpreted as older slide blocks (Slide Blocks I, II). Slide Block II is the lower and smaller block and coincides with the narrowest, most constricted reach of the South Arkansas River. Like Slide Block III, Slide Block II is bounded by linear northwest- and northeast-trending gullies that parallel the two regional fault sets. Slide Block I is an even larger but less well-defined block bounded by similar faults. Field checking revealed that the Proterozoic rocks within Slide Blocks I and II are not generally any more fractured or shattered than Proterozoic rocks beyond the blocks. This suggests that the slide blocks

have moved as large, intact gravity slide blocks in which all the deformation was concentrated on the basal failure plane rather than being distributed throughout the sliding mass.

Neither the exact age nor the triggering mechanism of these slide blocks is known. In a general sense, downcutting by the South Arkansas River through the Pliocene and Pleistocene probably progressively “daylighted” the intersection lines of various pairs of normal faults, permitting a series of wedge failures over time. If valley aggradation in glacial periods alternates with valley incision in interglacial periods, then these failures probably occurred during the interglacial periods. The wedge failures could also have been triggered by large earthquakes in the Shavano fault zone.

Reactivation of these large bedrock wedge failures could pose problems if they moved far enough to block the South Arkansas River and impinge on US 50. Because of their large size, amount of vertical relief, and bedrock content, it does not appear economically feasible to stabilize these bedrock wedge failures with any engineering measures. Therefore, this landslide area constitutes a potentially unmitigatable (earthquake-related?) geologic hazard that must be seriously considered by planners and highway engineers.

FLOODS AND DEBRIS FLOWS

Intense summer rainstorms or rapid melting of deep snowpack during unusually warm spring thaws may cause localized flooding and debris-flow activity. For example, most of the area mapped as Holocene alluvium (Qal) in the quadrangle lies on modern flood plains and is potentially subject to flooding. A related hazard is that of sheetwash and sheetfloods at the heads of small drainages, debris flows in ephemeral and intermittent streams, and resulting deposition on alluvial fans. Such areas are generally mapped herein as alluvium/colluvium (Qac).

All undissected Holocene alluvial fans (Qf, Qfy) are potentially subject to debris-flow deposition over most of their surfaces. Fans with the highest hazard are those for which drainage basins contain large areas of exposed Tertiary Dry Union Formation with

sparse vegetation. One such area is the steep slopes along lower Green Creek. Other fans vulnerable to debris flows are the fans along the south side of the South Arkansas River, both west of Maysville (draining Proterozoic rock) and east of Maysville (draining Dry Union Formation).

SEISMICITY

The Maysville quadrangle lies in the Rio Grande rift, an active zone of crustal extension. The level of historic seismicity is low in the Colorado portion of this rift. A search of the USGS/NEIC Internet catalog of earthquakes "Preliminary Determination of Epicenters" (1973-2003 A.D.) reveals only one measured earthquake within a 6 mi radius of the center of the quadrangle (table 6).

Table 6. Summary of measured earthquakes within a 6-mi radius of the center of the Maysville quadrangle. Source: USGS website,

http://neic.usgs.gov/neis/epic/epic_circ.html

Catalog= PDE

Circle Search, centered on UTM-E 407472, UTM-N 4268501

Radius: 6.0 mi

Data Selection: Historical & Preliminary Data

<u>YEAR</u>	<u>MO</u>	<u>DA</u>	<u>ORIG TIME</u>	<u>UTM-E</u>	<u>UTM-N</u>	<u>DEP(mi)</u>	<u>MAG</u>	<u>DIST(mi)</u>
1994	08	04	164941.35	412932	4273767	3.1	2.50 ML	4.3

However, in 1921 a swarm of earthquakes occurred a short distance west of the Maysville quadrangle, at roughly 386800E and 4273000N (near the ghost town of Shavano in the North Fork). This swarm was felt at St. Elmo (northwest of the Maysville quadrangle) and Garfield (west of the Maysville quadrangle) and included 14 small events ranging from intensity II to IV from February and July of 1921 (table 7; Humphreys, 1921). These are the only historic earthquakes known to have occurred near the southern end of the Sawatch Range. Unfortunately, very little is known about this

earthquake swarm (Kirkham and Rogers, 2000), so the causative fault(s) are unknown.

Despite the relative scarcity of historic seismicity, geologic evidence suggests that some faults in the quadrangle have been active in Quaternary time (see previous section on Structural Geology, Quaternary Deformation). For purposes of estimating earthquake hazards, we assume that the Shavano fault will rupture along with the southern Sawatch fault, as the latter is defined by the U.S. Geological Survey. According to the US Geological Survey's National Seismic Hazard Map (http://earthquake.usgs.gov/research/hazmaps/products_data/2002/faults2002.php), the southern Sawatch fault can generate earthquakes up to (moment) Magnitude 7.0. This magnitude estimate is based primarily on the fault length (28 mi), a length which includes the Shavano fault zone.

In the event of an M 7.0 earthquake on the Sawatch fault zone, hazards would be related to strong ground shaking, shaking-induced ground failure such as liquefaction and landslides, and fault surface rupture. For the town of Maysville (zip code 81211), in any 50 year-long period, a 10 percent chance exists that peak horizontal ground shaking will be stronger than 0.06g (1g= gravitational acceleration), a 5 percent chance it will be stronger than 0.9g, and a 2 percent chance it will be stronger than 0.20g (U.S. Geological Survey 2002 National Seismic Hazard Maps).

The latter estimate (2 percent chance in 50 years) is statistically equivalent to the largest earthquake expected in about 2,500 years. However, the recurrence interval of surface-rupturing earthquakes on the Sawatch fault zone is much longer than 2,500 years (estimated as 10,000 to 40,000 years farther north in the Buena Vista West quadrangle; see McCalpin and Shannon, 2005), so the actual shaking that might occur during a surface-rupturing earthquake will be greater than 0.20g at Maysville and much greater closer to the Sawatch fault zone. More precise estimates for any specific site would require a site-specific ground-motion study.

The strong shaking may induce landslides and rockfalls in the Sawatch Range and liquefaction of areas containing high water tables (less than 30 ft deep) where the aquifer is mainly sand. The latter condition may exist in parts of the broad flood plain of the South Arkansas River (map unit Qal) downstream from Maysville, where water levels in wells stand only 4-20 ft below the surface.

Table 7. Historical (pre-instrumental) earthquakes in or near the Maysville quadrangle, according to Kirkham and Rogers (2000). All these events occurred a few miles west of the Maysville 7.5' quadrangle, in the adjacent Garfield 7.5' quadrangle.

<u>ID</u>	<u>DATE ORIGIN TIME</u>				<u>EPICENTRAL LOCATION</u>	<u>UTM (E)</u>	<u>UTM (N)</u>	<u>INTENSITY (MM)</u>	<u>REFERENCES</u>
	<u>YEAR</u>	<u>MONTH</u>	<u>DAY</u>	<u>(UTC)</u>					
34	1921	FEB.	6	06:15	ST. ELMO	386794	4272984	IV	52,112
35	1921	FEB.	6	06:25	GARFIELD	386794	4272984	IV	52,112
36	1921	FEB.	6	06:30	ST. ELMO	386794	4272984	IV	52,112
37	1921	FEB.	17	01:45	GARFIELD	386794	4272984	III	52
38	1921	FEB.	17	13:05	GARFIELD	386794	4272984	III	52
39	1921	FEB.	26	15:55	GARFIELD	386794	4272984	III	52
40	1921	FEB.	7	17:00	GARFIELD	386794	4272984	III	52
41	1921	MAR.	4	06:00	GARFIELD	386794	4272984	II	52
42	1921	MAR.	8	19:15	GARFIELD	386794	4272984	IV	52
43	1921	MAR.	9	01:25	GARFIELD	386794	4272984	III	52
44	1921	MAR.	12	07:00	GARFIELD	386794	4272984	II	52
45	1921	MAR.	22	21:45	GARFIELD	386794	4272984	III	52
46	1921	JUL.	27	21:30	GARFIELD	386794	4272984	III	52,112
47	1921	JUL.	29	02:55	GARFIELD	386794	4272984	III	52,112

References: 52= Humphreys, 1914-1924; 112= Stover and others, 1984.

Fault surface rupture during a large earthquake might instantaneously rupture the ground surface and uplift the upthrown side of the fault by 5-8 ft. This movement might displace any structures or facilities sited across the fault trace (typically located beneath the center of the mapped fault scarps), such as roads, canals, pipelines, buried utilities, or houses or barns. Fortunately, the Shavano fault traces lie in a remote and undeveloped area with difficult access. Only in the North Fork do traces of the Shavano fault cross any infrastructure, such as the Angel of Shavano Campground.

ABANDONED MINED LANDS

Collapse of abandoned mine shafts and adits, many of which may be covered by thin surficial material, pose a potential hazard. A number of abandoned mines are present in the Maysville quadrangle and are mostly clustered in the Proterozoic terrane in the southwest quadrant. In addition, some abandoned mines are located along the Shavano fault zone along the range front in the northwest quadrant; a cluster of seven placer mine cuts is present in Droney Gulch at the east edge of the quadrangle. A total of 44 mine adits, 12 mine shafts, and 14 cat cuts/trenches were located during this study. In addition, about 100 prospect pits were found and they are commonly clustered in the same areas as the significant mines. Mine and prospect locations are shown on plate 1 and UTM coordinates are given in appendix 1. Prospect pits are generally from about 1 to 6 ft deep with small waste piles; pits over about 10 ft deep with moderate to large waste dumps are considered to be caved shafts.

None of the abandoned mines have been officially sealed, and most have collapsed or caved by themselves over the years. A few of the larger mines have adits and shafts that are open or partly caved and represent potential hazards to humans and animals. The most dangerous hazards are two open shafts located at 396300E, 4265404N and 392536E, 4265221N. In addition, caved or slumped shafts that may still present hazards are located at 394411E, 4272693N; 392133E, 4274205N; 395635E, 4263036N; 393899E, 4265778N; and 394692E, 4265610N. Open adits or partly caved adits were found at 395684E, 4262799N; 391634E, 4263994N; 391299E, 4263069N; and 395540E,

ECONOMIC GEOLOGY

Currently no mining operations are active in the Maysville quadrangle. Minor historic production of base and precious metals is reported from small- to medium-sized mines mostly in the Proterozoic terrane in the southwest part of the quadrangle. Potential mineral resources in the Maysville quadrangle primarily include construction sand and gravel with less potential for metallic minerals including copper, zinc, lead, silver, and gold.

Although the region is known for numerous hot and warm thermal springs, no geothermal activity is indicated in the Maysville quadrangle. The Cottonwood and Mount Princeton hot springs (Sharp, 1970; Olson and Dellechaie, 1976; and Pearl and Barrett, 1976) are in the Buena Vista West and Mount Antero quadrangles, respectively. Both of these thermal areas are located along the Sawatch fault zone on the west side of the Upper Arkansas Valley. The Browns Canyon warm springs (Russell, 1945; Sharp, 1970) are located in the Browns Canyon area on the east side of the Upper Arkansas Valley. The Poncha hot springs (Russell, 1945 and 1950) are located about 5,000 ft south of Poncha Springs and about 7 mi east-southeast of Maysville.

INDUSTRIAL MINERALS

Future industrial mineral potential mainly includes sand and gravel deposits. Some potential for pegmatite minerals, mainly potassium feldspar and possibly beryllium and rare-earth element minerals, also exists.

SAND AND GRAVEL – As of 2002, commercial sand and gravel mines were not active in the quadrangle (Guilinger and Keller, 2002). However, many of the Quaternary

alluvial deposits appear to contain sand and gravel of commercial quality, on the basis of natural and artificial exposures. The best potential resources are contained in the alluvial terraces and flood plain of the South Arkansas River downstream from Maysville. Within these terraces, the younger alluvial deposits are less weathered and constitute the better resource (map units Qal, Qpo, Qbo, Qboy, Qboo, Qi). Additional gravel resources exist in the older terraces (in order of increasing age, map units Qk3, Qk2, Qk1, Qn2, Qna1, Qna, Qn), but the gravels are progressively more decomposed with age and contain progressively more soil formation products (calcium carbonate and red clay), so are less suited for most commercial uses.

PEGMATITE DEPOSITS – Abundant pegmatite (YXp) and granite and pegmatite (YXgp and Xgp) dikes and sills invade the Proterozoic gneisses in the western half of the Maysville quadrangle. Some relatively large pegmatite bodies (both Xgp and YXp) are associated with the hornblende intermediate gneiss and amphibolite gneiss in the steep cliffs on the north and south sides of the North Fork. Some of the pegmatites are associated with fine-grained granite gneiss with weak foliation and faint gneiss layering. Because of the metamorphic fabrics in the associated granite they are considered to be related to the Routt Plutonic Suite. Other large pegmatite bodies are considered to be related to the Berthoud Plutonic Suite although the distinctions are commonly ambiguous. The pegmatites are simple and unzoned, consisting predominantly of quartz and alkali feldspar with minor biotite, muscovite, garnet, and magnetite. The remote location prohibits future exploitation.

The Proterozoic gneisses in the southwest part of the Maysville quadrangle are intruded by swarms of Berthoud-type granite and pegmatite dikes and sills. The pegmatites tend to be elongated bodies that are both concordant and discordant to the enclosing gneisses. They are commonly up to 800 to 1,200 ft long and range from tens of feet to 200 feet wide. They are simple, unzoned pegmatites consisting predominantly of quartz, alkali feldspar, and plagioclase. Minor minerals include biotite, muscovite, garnet, epidote, magnetite, zoisite, thulite (mangian zoisite), rhodochrosite, and tourmaline. Kouter (1969) noted the presence of beryl and trace scheelite in pegmatites in the adjacent Mount Quray quadrangle.

A number of the larger pegmatite bodies in the area of the Bon Ton mine and on the ridge between Willow Creek and Green Creek were prospected by cat cuts and trenches. It is estimated that this exploration probably occurred during the 1960's and 1970's as the ground disturbance was not reclaimed. Additional pegmatite exploration activities may have occurred during 1985 to 1989 (Molycorp, Inc. Willow and WG unpatented claims) on the ridge between Willow and Green Creeks. Examination of the pegmatite exposures failed to show any exotic minerals other than mica and trace tourmaline. The unzoned character and lack of abundant exotic minerals indicates little potential for Be, W, REE, and U-Th in the pegmatites. The relatively large size of the pegmatites and easier access in the southwest part of the quadrangle are positive aspects, but it is unlikely that they would be attractive for future development.

METALLIC MINERALS

The Maysville quadrangle has experienced minor historic metallic mineral production. The most significant mines occur in two principal areas: the Proterozoic terrane in the southwest quadrant; and along the northeast-trending Shavano fault in the northwest quadrant. In addition, a few areas with minor placer mine workings are present in the east-central part of the quadrangle. The small- to medium-sized mines in the Maysville quadrangle are not part of any official mining districts. However, the Maysville area is surrounded by a number of significant mining districts. The Monarch and Chalk Creek mining districts are the two largest gold producing districts in Chaffee County (Dunn, 2003). The Monarch (or Garfield-Monarch) mining district is located about 6.5 miles west of Maysville and covers approximately 94 sq miles. It includes the principal mines on Monarch Ridge from which significant production of silver, lead, zinc, and gold occurred mostly from 1883 to 1893 and continued until around 1915. Most of the mineralization occurs as replacement deposits and fault-fissure fillings in Paleozoic carbonate rocks and is interpreted to be genetically related to the Mount Princeton pluton (Crawford, 1913; and Dings and Robinson, 1957).

The Chalk Creek mining district, located about 13 miles northwest of Maysville,

includes the Mary Murphy mine, which may have been in continuous production from its discovery in 1870 to 1925 (Dunn, 2003). Most of the district's ore reserves were exhausted by 1918, but intermittent production of gold, silver, copper, lead, and zinc continued until 1944. The Cottonwood mining district is located about 20 miles north-northwest of Maysville and has minor veins with silver, lead, and gold but had only minimal production (Dunn, 2003).

The Browns Canyon and Poncha mining districts are located about 9 miles northeast and 7 miles east-southeast of Maysville, respectively. Fluorspar was discovered in the Browns Canyon area in about 1923 and significant production is reported from 1927 to the late 1950's (Van Alstine, 1969; Dunn, 2003). Minor fluorspar production is recorded for the Poncha mining district from 1933 to 1944 (Russell, 1950).

The Turret and Calumet mining districts are overlapping and are located about 7 mi north and north-northeast, respectively, of Salida and about 14 mi northeast of Maysville. The Turret district was established by 1897 and was in decline by 1904, with intermittent production until about 1941 (Dunn, 2003). Significant iron and some copper, gold and silver were produced. The Calumet mine was located in 1880 and was worked for iron from 1881 to 1889 (Dunn, 2003). Some gold, silver, and copper production continued from about 1904 until the 1920's. The Cleora mining district is located about 2 miles east and southeast of Salida and includes calc-silicate-related copper and tungsten mineralization (Heinrich, 1981). Production was insignificant from this district.

The Sedalia mining district is located about 4 mi north-northeast of Salida and about 10 mi east-northeast of Maysville. The stratabound copper-zinc-calc-silicate deposit was located in 1881 and operated intermittently until 1923 (Heinrich, 1981). The Sedalia mine was once the largest copper mine in the state (Heinrich, 1981; and Dunn, 2003). Most of the ore produced was mainly oxidized, secondarily enriched ore with about 5 percent Cu and 10 percent Zn, with minor Ag and Au.

A number of areas in the southern part of the Upper Arkansas Valley were worked for placer gold. The Arkansas River gold placers include a number of placer areas along the Arkansas River between Granite and the Salida area (Vanderwilt, 1947; and Parker, 1974). The gold placers were discovered in 1897 and small operations have been intermittent up to the present. The Buena Vista gold placers refer to the Arkansas

River placers near Buena Vista (Vanderwilt, 1947). The name Browns Creek gold placers refers to placers along Browns Creek where minor production has been intermittent from the early 1900's to about 1939 (Vanderwilt, 1947; and Dunn, 2003). The name Salida gold placers refers to the Arkansas River placers around the town of Salida (Vanderwilt, 1947).

The Mount Antero pegmatite mining district is located about 9 mi north-northwest of Maysville and includes minor quartz-molybdenite mineralization at the California mine and world-famous aquamarine-bearing pegmatites associated with the Mount Antero Granite (Sharp, 1976) and the California leucogranite intrusion (Shannon, 1986 and 1988). The Monarch Pass pegmatite district is located on the Continental Divide in the Monarch Pass area but does not have associated development or economic pegmatite minerals (Dunn, 2003).

The Marshall Pass uranium mining district is located about 11 mi south-southwest of Maysville. Uranium was discovered in 1955 and small scale mining operations continued from 1958 to 1968 (Dunn, 2003). In 1968, larger open-pit mining and leaching techniques were attempted.

A regional evaluation of the mineral resource potential of the San Isabel National Forest, south-central Colorado was conducted by Taylor and others (1984). They reviewed deposit models for various types and ages of ore deposits and specifically evaluated areas with indicated potential. Descriptions of Proterozoic stratabound deposits of copper-zinc and tungsten-copper, skarn deposits with iron, copper, gold, and tungsten, and epithermal vein deposits with gold, silver, base metals, and uranium are of specific interest in evaluating mineralization and alteration in the Maysville quadrangle.

MINING HISTORY – Detailed coverage of the Maysville quadrangle during the field work for this study indicates no current or recent mining activities in the quadrangle. Most of the significant mines in the Maysville quadrangle were worked around the late 1800's and the early 1900's. Significant mines include a number of medium-sized, underground mines associated with adits and/or shafts with associated medium-sized waste dumps. Two of the mine areas are associated with patented mining claims and the rest are associated with unpatented mining claims.

Patented Lode Mining Claims – There are two groups of patented lode mining claims in the Maysville quadrangle. The oldest patented claim includes the Copper King claim (Mineral Survey 1165) which was patented by Monarch Mining Co in December 1880 and is located southwest of the Maysville town site, in NW¹/₄, Section 3, T49N, R7E. This claim still has an open shaft (+40 feet) with a moderate-sized waste dump, with abundant Cu-oxide stained quartz-magnetite veins in hornblende intermediate gneiss.

The largest patent group includes the Alaska group located at 13,400 to 14,000 feet elevation just south of the summit of Mount Shavano (Sections 6 and 7, T50N, R7E). The Alaska group includes eleven claims that were patented (Mineral Surveys 15899 and 15901) in November 1904 by the Mt. Shavano Mining and Milling Company. Crawford (1913) mentioned that a tunnel (adit on west side of ridge) was being driven around 1910 and that a shipment from the surface workings ran about \$40.00 gold per ton. Minor Cu-oxides and quartz veins are associated with garnet-epidote calc-silicate hosted in amphibolite gneiss. On the basis of the visible ground disturbance that can be seen today, there does not appear to have been any significant work on these patented claims after about 1910. Information from the Bureau of Land Management LR2000 Data Base indicates that there have not been any unpatented lode mining claims in this area since the mid-1960's.

Unpatented Lode Mining Claims – Most of the larger mines in the Maysville quadrangle are associated with unpatented lode mining claims on federal lands that pre-date the Bureau of Land Management claim record data base. An historical review of the old unpatented mining claims requires a detailed analysis of the Chaffee County courthouse records that was beyond the scope of this study. However, descriptions by Crawford (1913, plate 1 and pages 279-281) indicate that many of the mines were active around 1910 and that the bulk of the mining activity was in progress at that time. Practically all of the significant mines that were identified during this study are shown on Crawford's (1913) map. Notable exceptions include the Blank mine (SE¹/₄, Section 8, T50N, R7E) and mines on the ridge between upper Willow Creek and Como Creek (SE¹/₄, Section 12, T49N, R6E).

The small mines and prospects along the Shavano fault zone north of Squaw Creek (NE¹/₄, Section 4, T50N, R7E) and between Cree Creek and Lost Creek (NW¹/₄, Section 30, T50N, R7E) were active around 1910. These mines were primarily associated with silicified fault breccias and quartz veins. The mines between Cree and Lost Creeks have high silver associated with copper, lead and zinc mineralization and anomalous gold (sample 05-854/855/857 with 82 ppm Ag, 1.02 percent Cu, 0.90 percent Pb, 0.48 percent Zn and 0.257 ppm Au). The Bureau of Land Management LR2000 unpatented claim records (BLM LR2000) indicated minor unpatented lode claims associated with these mines and prospects from around 1959 to 1984.

The Blank mine is located along the Shavano fault zone in the range front area between Squaw Creek and the North Fork. It includes a lower caved adit and upper caved shaft, both with moderate-large sized waste dumps. There are also six caved adits with small waste dumps along a northeast-trending 1,000 ft long zone, along the range front and to the north of the main Blank mine workings. In addition, there is evidence on the ground of a limited exploration drilling program in the Blank mine area. It includes five short drill access roads and at least four drill pads that occur along a N35°E trend extending for about 1,250 feet between the lower adit and upper shaft. A lack of unpatented mining claims in Bureau of Land Management records in the Blank Mine area indicate that the mining activity and exploration drilling predate the 1960's and 1970's.

Additional large mines in the northwest part of the Maysville quadrangle include a cluster of mines and prospects in upper Lost Creek (SE¹/₄, Section 13 and NE¹/₄, Section 24, T50N, R6E and SW¹/₄, Section 18 and NW¹/₄, Section 19, T50N, R7E). Crawford (1913, p. 280) mentioned the Lost Basin Group of 13 unpatented claims and the Series Junction Group of 3 unpatented claims in upper Lost Creek. The Lost Basin Group included the Lost Basin mine, which was a 600 ft long adit in 1910, on a quartz-sulfide vein hosted in the gneiss.

Crawford (1913) showed the locations of most of the main mines in the southwest quadrant of the Maysville quadrangle. They include the cluster of mines (five adits) in upper Como Creek (NW¹/₄, Section 7, T49N, R7E) with copper and zinc mineralization (sample 05-106A/106B with 0.94 percent Cu and 1.69 percent Zn) associated with calc-silicates and minor quartz veining. A group of mines (two adits and one shaft) and

numerous prospects on the ridge between Como and McClure Creeks (NE¹/₄, Section 6, T49N, R7E) includes the Highland claim where a shaft intersected a 3 to 18 inch thick vein with good galena (Crawford, 1913). Samples from the three main mines indicate some silver is associated with copper, lead, and zinc mineralization associated with vuggy quartz veins (sample 05-237/237A/238 with 27 ppm Ag, 0.38 percent Cu, 1.96 percent Pb and 0.96 percent Zn).

Crawford (1913) showed a cluster of mines associated with the Paymaster group of unpatented claims about a mile west of Maysville (SE¹/₄, Section 32, T50N, R7E). Several small shipments of silver-lead ore with gold were made from five 125 to 300 ft long adits. Samples from two of the mines indicate significant silver and some gold associated with copper, lead, and zinc mineralization (sample 05-648/649 with 152 ppm Ag, 2.12 ppm Au, 1.09 percent Cu, 3.88 percent Pb, and 0.45 percent Zn). Crawford (1913) showed another cluster of mines and prospects about 0.5 mile southwest of Maysville. These mines and prospects are located in NE¹/₄, Section 4, T49N, R7E and include three caved adits. Cu-oxide and clotty to disseminated sulfides occur in both hornblende intermediate gneiss (Xhig) and pegmatite (YXp). Mineralization from a mine and prospect pit indicate significant gold and silver associated with copper mineralization (sample 05-631/632 with 6.66 ppm Au, 112 ppm Ag and 7.65 percent Cu). The mineralization is unusual because of very low lead (70 ppm) and zinc (110 ppm) contents.

Crawford (1913, p.280) described mining activity at the Bon Ton mine on the ridge between Willow Creek and Green Creek, in the south-central part of the Maysville quadrangle (SE¹/₄, Section 9, T49N, R7E). The property in 1909 consisted of a shaft and two or more adits on an 8 inch wide vein of sphalerite-pyrite in garnetiferous gneiss. Activity at the Cinderella mine, about a mile south of the Bon Ton mine (in the Mount Ouray quadrangle), included a few shallow prospects with galena, Zn-oxides, and Cu-oxides associated with amphibole and garnet (Crawford, 1913, p. 281). Samples from the main Bon Ton mine adits show some silver and gold associated with copper and zinc mineralization (samples 05-4 and 05-32 with 0.14 to 1.22 ppm Au, 22 to 41 ppm Ag, 1.36 to 1.61 percent Cu and 0.54 to 12.1 percent Zn).

Observations in the southwestern quadrant of the quadrangle indicate evidence of

relatively recent (post-1970?) exploration activities including access roads and cat cuts and trenches on Proterozoic pegmatites (Xgp and/or YXgp) on the ridge between Willow Creek and Green Creek, in the SE¹/₄ and NE¹/₄, Section 9, T49N, R7E. This pegmatite exploration may have been related to an unpatented claim block (Willow and WG claims) held by Molycorp, Inc and located in 1985 and 1987 in Sections 9, 10 and 16, and expanded in 1988 to Sections 3 and 4 (BLM LR2000). All of the Willow claims were abandoned in 1989.

Evidence of a ground exploration survey grid was noted in the area around the Bon Ton mine in the SE¹/₄, Section 9, T49N, R7E. The grid was apparently used for control on a soil sample survey and possible geophysical surveys. Examination of Bureau of Land Management LR2000 unpatented claim records indicates additional exploration activities in the area of the Bon Ton and Cinderella mines. American Selco, Inc. located the Carol and Redman unpatented claims (NE¹/₄ and SE¹/₄, Section 9 and NE¹/₄, NW¹/₄ and SW¹/₄ Section 16) in 1977 and 1978. This exploration was related to metamorphosed Proterozoic massive sulfides (Knight, 1981) and the claims were abandoned in 1979. Brancote, U.S., Inc. located the Redman unpatented claim block in 1989 in the Cinderella Mine area (SW¹/₄ and NE¹/₄, Section 16). These claims were successively abandoned in 1998, 2000, and 2001. American Copper and Nickel located the Cindy unpatented claims (Sections 9, 10 and 16) in 1994. These claims were successively abandoned in 1995, 1998, 2000, and 2001. The Brancote, U.S., Inc. and American Copper and Nickel exploration programs were also probably investigating the potential for metamorphosed volcanogenic massive sulfides. No evidence was noted for systematic exploration drill testing in the Bon Ton mine area, although limited drill testing could have been conducted and reclaimed on existing roads. Knight (1981) showed the location of 5 exploration drill holes in the Cinderella mine area that were completed in 1978.

Placer Mining Claims – Most of the significant placer mining activity in the Maysville quadrangle was focused in three areas in the northeast quadrant of the quadrangle. Early placer mining activities were noted by Crawford (1913) to have occurred in one or two localities “in the ravines and gulches on the slopes of Shavano Mountain.” He showed one mine/prospect area that roughly corresponds with the area northwest of the Blank

cabin in the NE¹/₄ of Section 9. This area consists of Quaternary alluvial fan (Qfy) and landslide (Qfol) deposits derived from Bull Lake and Pinedale tills. Consequently, Crawford's (1913) placer locality may be a misplotted location of the upper Placer Creek workings.

Examination of the Bureau of Land Management LR2000 unpatented mining claim records indicate the presence of recent extensive placer mining claims that covered the northeast part of the Maysville quadrangle. The Valley View placer claim block was located in 1965 and covered the area from the range front on the west and extending east of the eastern quadrangle boundary, and from the South Arkansas River in the south and extending north of the northern quadrangle boundary. Many of the Valley View placer claims were abandoned in 1992 and 1994. A smaller placer claim block was maintained in the area of Sections 13, 14, 15, 21, 22, 23, 24, 25, 26 and 27 (T49N, R7E) and was finally abandoned in 2002. Another large block of placer claims (ALKE claims) were located and abandoned in 1996 in the same area as the Valley View claims. A new Valley View claim block was located in 2006 in Sections 23, 24, 25 and 26 indicating continued interest in the placer potential of this area. One placer claim (Early Fall claim) was located in 1979 in Willow Creek near the Bon Ton mine area but was abandoned in 1991.

Parker (1974) briefly described two placer mining areas along Placer Creek (Sections 14 and 15, T50N, R7E) and at the intersection of Placer Creek and Blank Gulch (Section 26). He stated that little is known of the history of these placers but mentioned that William Blank was reported to have produced \$30,000 in gold from the "upper placers." He also mentioned that Golden Fleece Placer Company operated a small mechanized plant in 1946 and Geo-Resources Exploration, Inc. was conducting placer exploration in 1959 and 1960.

PLACER DEPOSITS – Two areas of minor placer workings have been previously identified on the piedmont surface in the central part of the Maysville quadrangle (Parker, 1974; and Scott and others, 1975). They were described by Parker (1974) but little is known about their history. The largest placer workings are up to 80 ft wide for 870 ft along Placer Creek in NE¹/₄ and SE¹/₄, Section 15, T50N, R7E. This area is near the

contact of two Quaternary gravels (Qn and Qna) according to Scott and others (1975) and is interpreted to be near the contact between Quaternary gravel (Qna) and the Tertiary Dry Union Formation (Td) in this study. Smaller placer workings are present at the junction of Placer Creek with Blank Gulch in the NE¹/₄ of the NE¹/₄, Section 26 (Parker, 1974; and Scott and others, 1975).

A third area of placer workings was found during this study in the SE1/4, NW14, Section 18, T50N, R8E. Abundant placer cuts explore the basal contact of the Quaternary gravel (Qna) capping the Dry Union Formation (Td). Scott and others (1975) interpreted the Quaternary gravel cap as Pleistocene Kansan (?) alluvium (Qk), whereas it is interpreted to be Pleistocene Nebraskan alluvium (Qna) in this study. The placer workings occur for a distance of 600 to 700 ft on the north and south sides of Droney Gulch. The gravel cap consists of matrix supported boulder conglomerate with subangular to rounded blocks to 5 ft in size. The gravel is bedded with sandy to gritty layers and local imbrication of elongated conglomerate clasts. The gravel is distinctly orange stained and locally the sand and conglomerate beds are irregularly impregnated with weak Fe and Mn oxides. A small outcrop at creek level, interpreted to be in the underlying Dry Union Formation, has bedded siltstone with a gritty, pebble conglomerate layer containing moderate Fe and Mn oxides with a trace of Cu oxides on Proterozoic pebble clasts. The placer workings are along the basal contact of the gravel cap with the underlying Dry Union Formation. Parker (1974) indicated that about \$30,000 in gold was produced from the Section 15 placer area and that the gold is reported to have been heavy and rough and was associated with abundant black sand in the gravel.

Parker (1974) concluded that most of the important placer deposits in Colorado were formed during the Bull Lake or Pinedale stadials of the Wisconsin stage. Many of the alluvial placers have been modified by glacial action. Glacial modification of preexisting placers resulted in the formation of distinctive deposits that are localized in the end and lower lateral moraines and in the outwash trains. He suggested that the source of the placers in the Maysville quadrangle is the mineralized area high on the southeast face of Mount Shavano where there was some eluvial placers.

LODE DEPOSITS – The distribution of small- to medium-sized, historic mines and numerous small prospects are shown on the geologic map (plate 1). A total of 44 mine adits, 12 mine shafts, 14 cat cuts/trenches, and about 100 prospect pits were located during this study (appendix 1). The distribution of these mines and prospects indicates the most likely areas of potential exploration and development in the Maysville quadrangle. Most of the significant mines and potential areas for mineral exploration are located in the Proterozoic terrane in the southwest quadrant of the quadrangle. In addition, three areas have small- to medium-sized historic mines in the northwest quadrant of the quadrangle.

The majority of mineralization in the Maysville quadrangle consists of base metals and precious metals associated with calc-silicate zones (Xcs) in sequences of amphibolite and hornblende gneiss (Xag and Xhig). On the basis of limited studies of deposits in the Maysville quadrangle and similar deposits in the region, the deposits have been previously interpreted as Proterozoic skarn deposits (Heinrich, 1981) or metamorphosed Proterozoic massive-sulfide deposits (Knight, 1981; Sheridan and Raymond, 1984; Alers and Shallow, 1996; and Heimann and others, 2005). Since most of the deposits exhibit features that are associated with both of these deposit types, the distinction between them is not clear cut and classification of the deposits is controversial. The interpretation of the deposit types is further complicated by the common association of younger Proterozoic intrusions, specifically abundant pegmatites related to the Berthoud Plutonic Suite, and locally Tertiary andesite dikes (Ta) and epithermal-style veins with the mineralization.

Twelve samples of representative mineralization from mine waste dumps were selected for commercial multi-element geochemical analyses (table 8; UTM coordinates for samples are given in appendix 1). Some of the samples are composites from groups and clusters of mines and prospects. The geochemistry shows the overall copper-lead-zinc-silver character of the mineralization hosted in the Proterozoic rocks in the Maysville quadrangle. Some samples have anomalous to sub-ore grade gold and anomalous bismuth. Also of note are the very low values (below detection) of arsenic and antimony.

Two principal mining areas are present in the northwest part of the Maysville

quadrangle. The first area is a cluster of caved shafts and an adit located about 3,000 ft south of the summit of Mount Shavano in the SW¹/₄, Section 6, T50N, R7E. The caved shafts are on a flat saddle at about 13,400 ft elevation and the caved adit is located at about 12,880 ft on the west side of the ridge. The mines are associated with the Alaska group of patented claims that include 11 claims patented in 1904. The mineralization is associated with a sliver of amphibolite gneiss that is localized along a north-northwest-trending fault. The fault sliver of amphibolite gneiss is hosted in the Proterozoic foliated granodiorite (Xgdf). Mineralization includes minor Cu-oxides associated with epidote-actinolite-garnet calc-silicates, Fe- and Mn-oxides and gossan, and minor vuggy quartz veins. A grab sample of mineralized material, oxides and calc-silicates (sample 05-265, table 8) indicates anomalous silver (21 ppm) and gold (0.889 ppm), weakly anomalous copper (950 ppm), and slightly anomalous zinc and lead. The style of mineralization is the same as the mineralization in the southwest quadrant of the quadrangle. It is not clear why these claims made it to patent. The extremely remote location, the limited size of the mineralized area (that is, hosted in narrow fault slice of amphibolite gneiss), and relatively weak copper and precious-metal signature make it highly unlikely that future exploration and development activities would be conducted on these claims.

The other principal area of mining and exploration activity in the northwest part of the quadrangle is associated with the northeast-trending Shavano fault zone along the range-front area. The most significant mine is the Blank mine, located in the SE¹/₄, Section 8, T50N, R7E. The main workings include an upper caved shaft with a large waste dump and a lower caved adit with a large waste dump that has been spread out over a large area. The lower adit has a significant spring issuing from it, indicating that the adit probably undercuts the surface shaft and intersected the main Shavano fault zone. Relatively abundant rhyolite porphyry and fault-brecciated Proterozoic rock on the adit dump suggests that the adit intersected a rhyolite dike and the Shavano fault. There are no outcrops in the mine workings or in the area. The upper shaft dump has mostly Proterozoic rocks and abundant fault-brecciated gneisses with a small component of light-gray limestone and brecciated limestone. The limestone was previously interpreted

Table 8. Geochemistry of select mineralized rocks from mines and prospects in the Maysville quadrangle, Colorado. Sample locations are given in appendix 1.

SAMPLE	Wt. kg	Au ppm	Au ppm	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %
05-4	1.73	0.138		41	4.32	<50	300	<10	<20	<0.05
05-32	1.75	1.215		22	4.65	<50	<100	<10	140	3.36
05-78	1.28	0.043		12	7.24	<50	200	<10	30	12.05
05-106A/106B	1.28	0.022		2	2.6	<50	300	10	<20	8.08
05-183A	1.01	0.081		4	0.6	<50	100	<10	<20	0.73
05-237/238	2.02	0.081		27	2.27	<50	500	<10	20	0.08
05-265	1.4	0.889		21	5.06	<50	100	<10	30	6.34
05-280	1.1	0.011		3	2.03	<50	100	<10	<20	18.75
05-335	0.95	0.015		1	5.36	<50	700	<10	<20	0.43
05-631/632	1.63	6.7	6.66	112	5.7	<50	3500	<10	50	0.53
05-648/649	2.66	2.12		152	1.3	<50	1500	<10	110	0.36
05-854/855/857	2.3	0.257		82	5.56	<50	600	10	200	2.34

SAMPLE	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	K %	Mg %	Mn ppm	Mo ppm
05-4	500	20	60	13550	6.17	1.4	1.46	1890	30
05-32	20	20	20	16050	27.5	0.2	1.78	7150	20
05-78	<10	30	320	14450	8.38	0.3	2.72	2070	<10
05-106A/106B	30	10	30	9360	5.04	0.7	6.67	2570	<10
05-183A	<10	10	130	3700	1.83	0.1	0.36	490	<10
05-237/238	20	10	80	3800	9.87	0.9	0.13	10600	20
05-265	<10	30	100	950	13.95	0.4	0.64	2000	<10
05-280	40	10	20	220	2.78	0.5	0.7	9800	<10
05-335	<10	<10	20	10	1.5	3.2	0.19	220	<10
05-631/632	<10	<10	40	76500	2.85	2.6	0.32	1310	<10
05-648/649	20	10	80	10850	13.15	0.5	0.09	27100	100
05-854/855/857	20	20	70	10150	2.84	3.3	0.29	2090	30

SAMPLE	Na %	Ni ppm	Pb ppm	S %	Sb ppm	Sr ppm	Ti %	V ppm	Zn ppm	Zn %
05-4	<0.05	10	1150	5.9	<50	10	0.11	<10	>100000	12.1
05-32	0.31	10	200	1.1	<50	30	0.17	30	5440	
05-78	0.43	70	50	0.3	<50	430	0.47	200	300	
05-106A/106B	0.3	10	80	0.1	<50	60	0.1	40	16850	
05-183A	0.25	10	<20	0.3	<50	20	<0.05	20	90	
05-237/238	0.1	10	19600	0.1	<50	40	0.25	60	9570	
05-265	0.14	20	150	0.1	<50	180	0.24	80	290	
05-280	0.44	<10	3960	1.1	<50	190	0.08	30	8340	
05-335	1.42	<10	140	<0.1	<50	90	0.19	20	200	
05-631/632	1.99	<10	70	1	<50	200	0.16	10	110	
05-648/649	<0.05	30	38800	0.2	60	140	<0.05	10	4450	
05-854/855/857	0.6	10	8990	0.1	<50	120	0.1	30	4810	

Commercial analyses by ALS Chemex, Sparks, Nevada (Certificate RE05113617). ICP-AES (ME-ICP61a) with four-acid digestion. Gold by fire assay with AA finish (sample 05-631/632 checked with gravimetric finish).

05-4	Bon Ton mine- SW adit	05-280	Blank mine-upper shaft
05-32	Bon Ton mine- NE adit	05-335	Range Front shaft fault breccia
05-78	N. Metamorphic adit	05-601	S. Maysville shaft
05-106A/106B	Upper Como Creek adits	05-631/632	W-SW Maysville group
05-183A	Greens Creek adit	05-648/648A/649	Paymaster mine adits
05-237/237A/238	Como-McClure Highland mine	05-854/855/857	Cree-Lost Cr. adits
05-265	Alaska Patented Claims		

by Sharp (1976) to be a fault slice of Paleozoic carbonate. The limestone is locally silicified and contains minor disseminated to clotty pyrite and a trace of galena and sphalerite. A select sample of mineralized limestone, silicified limestone, and silicified fault-brecciated amphibolite gneiss (sample 05-280, table 8) from the shaft dump show anomalous zinc (8,340 ppm) and lead (3,960 ppm), and weakly anomalous copper (220 ppm). Gold (0.011 ppm) and silver (3 ppm) are extremely low. A number of small mines (caved adits) also are present in this area, most with silicified, fault-brecciated Proterozoic rocks on the waste dumps.

Another area of very small mines and prospects is along the Shavano fault zone north of Squaw Creek (Sections 3 and 4, T50N, R7E) and extends northeast across the northern quadrangle boundary (Section 34, T51N, R7E). All of these mines and prospects are all on silicified, fault-breccias along the Shavano fault. Some of the prospects occur in the broken rock zone (BR/Xgdf) inboard of the main Shavano fault zone. Small mines are on silicified, fault-brecciated Proterozoic foliated granodiorite (Xgdf) and prospects are on silicified, fault-brecciated rhyolite porphyry (Trp) and aphyric rhyolite (Tr) dikes. Minor quartz veins are locally associated with the silicified breccias. No sulfides were observed. A sample of silicified, fault-brecciated Proterozoic granodiorite (05-335, table 8) was submitted for geochemistry and shows no anomalous values. The silicification and quartz veins in the Tertiary rhyolite dikes indicate that some of the silicification in the Shavano fault zone is younger than about 29 Ma.

A cluster of small mines occurs along the Shavano fault zone on the ridge between Cree Creek and Lost Creek in the NW¹/₄, Section 30, T50N, R7E. The main rock type is Berthoud-type granite and pegmatite dikes (YXgp) and minor hornblende intermediated gneiss (Xhig). Silicified, fault-brecciated Proterozoic pegmatite is abundant and some chalcedonic to vuggy quartz veins are present. One mine dump has minor epidote-actinolite-chlorite calc-silicates. Minor Cu-oxides occur in the calc-silicates but mostly occur in silicified pegmatite and gneiss. Some disseminated pyrite, chalcopyrite, and galena occur in silicified rock and quartz veins. A select sample of mineralized material from three caved adits (sample 05-854/855/857, table 8) has highly anomalous copper (1.02 percent), lead (8,990 ppm), zinc (4,810 ppm), and silver (82 ppm). The

localization of silicification and quartz veining in fault breccias associated with Tertiary rhyolite dikes in the Shavano fault zone is interpreted to support a relatively young age (post-29 Ma) for the silicification. The chalcedonic and locally vuggy, open-space textures of the silicification and quartz veins, suggest a shallow-level epithermal character to the mineralization.

The mines and prospects in the Proterozoic terrane in the southwest quadrant of the quadrangle are commonly (but not exclusively) associated with calc-silicate zones that are interlayered with amphibolite gneiss (Xag). Some small mines and numerous prospects are located on Berthoud-type granite and pegmatite dikes and sills (YXgp) or quartz veins. Many mines and prospects have all three of these features (calc-silicates, pegmatites, and quartz veins) and it is not always clear what the target of mining and prospecting was.

Three types of igneous rocks are locally associated with the calc-silicate zones: (1) most common are Berthoud-type granite and pegmatite dikes; (2) a Proterozoic (?) microdiorite dike (Xmd); and (3) Tertiary (?) andesite (Ta) dikes. Calc-silicate minerals do not occur in (that is endoskarn) the Berthoud-type granite and pegmatite dikes or the Tertiary (?) andesite dikes. Further, the calc-silicate zones are not spatially associated with the granite and pegmatite and andesite dikes, nor are there indications of zonation of calc-silicate assemblages about these intrusions. The calc-silicate zones are not spatially associated with the Routt-type granodiorite (Xgd) intrusions and dikes. These relationships suggest that the calc-silicate zones (Xcs) do not have the characteristics of contact skarns associated with intrusions.

A Proterozoic (?) microdiorite dike (Xmd) located about 10,000 ft southwest of Maysville has local epidote endoskarn and weak sulfide mineralization. In addition, some amphibolite zones have irregular development of patches and veins of endoskarn-like epidote-actinolite. These relationships suggest that the microdiorite dikes and metamorphic recrystallization of the amphibolites may have been contemporaneous with the formation of the calc-silicate zones.

The distribution of four of the larger calc-silicate gneiss (Xcs) zones is shown on plate 1. Additional areas of smaller calc-silicate gneiss mixed with amphibolite gneiss are shown with fractional units (Xag/Xcs). The largest group of mines in the southwest

quadrant of the Maysville quadrangle is associated with an amphibolite gneiss (Xag) and calc-silicate gneiss (Xcs) zone on the ridge between Willow Creek and Green Creek. This area includes the Bon Ton mine in the SE¹/₄, Section 9, T49N, R7E. A second group of mines is present about 1,500 to 4,000 ft south of the Maysville quadrangle boundary, on the ridge between Green and Redman Creeks, in Sections 16 and 21, T49N, R7E. This group of mines includes the Cinderella mine shown on the U.S. Geological Survey 71/2-minute Mount Ouray quadrangle base map. Historically the locations of the Bon Ton and Cinderella mines have been uncertain. Sheridan and Raymond (1984) and Heimann and others (2005) reverse the locations of these mines with the Cinderella mine shown north of the Bon Ton mine.

The calc-silicate zones exhibit a transitional character from hornfels gneiss to weak epidote calc-silicate to moderate epidote-garnet calc-silicate to strong, complex calc-silicate assemblages. The distribution of these zones of variable calc-silicate mineral development do not show systematic patterns that support zonation about a specific center or to specific intrusions. Therefore, the calc-silicate zones are considered to be regional, rather than local features and are generally interpreted to be related to high-grade (amphibolite), regional metamorphism. The areas of calc-silicate development are suspected of having a relatively lime-rich protolith, possibly including carbonate-bearing fine-grained sediments. Areas of strong calc-silicate development may represent horizons of impure to pure limestone/marble.

The mineralization is spatially associated with strong calc-silicate zones characterized by more complex calc-silicate assemblages that include diopside-hedenbergite, black amphibole (hornblende?), green amphibole (actinolite-tremolite), magnetite, hematite, pink and reddish-brown garnet, black biotite, muscovite, chlorite, epidote, quartz, carbonate, and sphene. Knight (1981) identified an anthophyllite gneiss unit that is spatially associated with the Zn-Cu mineralization. Mineralization includes disseminated to semi-massive sulfides that are generally intimately associated and intergrown with calc-silicate gangue. The mineralization includes sphalerite, chalcopyrite, and locally abundant gahnite (Zn-spinel), with minor chalcopyrite, galena, and covellite. The size of the sulfide-rich zones was not determined in this study, but the distribution of mine workings suggests the sulfides are concentrated in relatively narrow

stratigraphic horizons (1 to 5 ft thick) that are probably discontinuous lenses. Polished thin sections of sulfide-oxide ore from the Bon Ton mine show the presence of both sphalerite and gahnite in the same samples (fig. 40). The gahnite locally occurs as inclusions in the sphalerite and has reaction rims of fine muscovite. Sphalerite, gahnite and chalcopyrite occur as inclusions in garnet. The two spinel group minerals gahnite and magnetite also occur together and locally have common grain boundaries.

Magnetite and hematite are locally abundant. The mineralized calc-silicate zones also tend to be spatially associated with magnetite-rich layers (up to about 1.5 ft thick) in the amphibolite gneiss. The magnetite is commonly massive and fine to medium grained, with local disseminated chalcopyrite. Some workers (Knight, 1981; Sheridan and Raymond, 1984; and Heimann and others, 2005) have suggested that the magnetite-rich horizons may represent banded iron formation. All of the magnetite-rich layers associated with the mineralized calc-silicate zones in the southwest quadrant of the Maysville quadrangle are massive layers interlayered with amphibolite and lack an associated siliceous component. An alternate origin involving selective replacement of carbonate-rich or pure limestone layers by massive magnetite is suggested here.

A number of geochemical samples were collected from mines in the southwest quadrant of the Maysville quadrangle. Most are from the major mines associated with the mineralized calc-silicate zones. Two samples (05-04 West Adit and 05-32 East Adit, table 8) from the Bon Ton mines both contain gahnite and sphalerite, and have highly anomalous zinc (12.1 and 0.5 percent, respectively), copper (1.4 and 1.6 percent, respectively), and silver (41 and 22 ppm, respectively). Gold is moderately anomalous (0.138 and 1.215 ppm, respectively) and lead is weakly anomalous (1,150 and 200 ppm, respectively).

Another group of small mines are associated with narrow, moderate to strong calc-silicate gneiss horizons near the southwest corner of the quadrangle, in SE¹/₄, Section 12, T49N, R6E and NW¹/₄, Section 7, T49N, R7E. A sample (05-78, table 8) from Section 12 has highly anomalous copper (1.4 percent) and moderately anomalous silver (12 ppm). A composite sample (05-106A/106B, table 8) of selected mineralized material from two caved adits in Section 7 show highly anomalous zinc (1.7 percent) and copper (0.9 percent). A cluster of small mines in SE¹/₄ Section 32, T50N, R7E (north of

the large Paleozoic rock outlier) is intimately associated with a narrow, strong calc-silicate gneiss layer. A composite sample (05-648/648A/649) from three caved adits has highly anomalous lead (3.9 percent), copper (1.1 percent), zinc 0.4 percent), gold (2.12 ppm) and silver (152 ppm; highest silver value from quadrangle).

A small cluster of mines and prospects, about 2,000 ft west-southwest of Maysville (NE1/4, Section 4, T49N, R7E), exhibits different characteristics. The mines and prospects are predominantly in hornblende intermediate gneiss (Xhig) and muscovite felsic schist (Xmfs) with abundant Berthoud-type pegmatites (YXp). There is

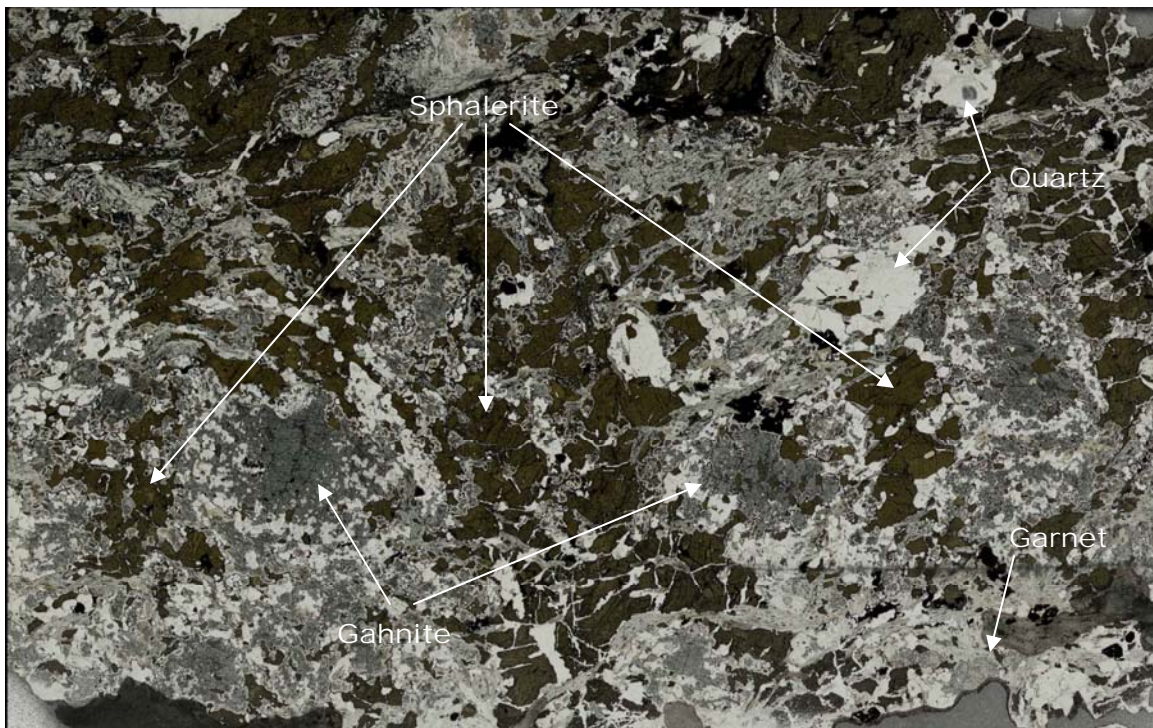


Figure 40. Photomicrograph of mineralized calc-silicate gneiss (Xcs) from the Bon Ton mine- SW adit. With gahnite and sphalerite associated with biotite-quartz-muscovite-garnet assemblage. Plane light, approx. 1.4 inch across.

amphibolite on one of the mine dumps, but there is little or no calc-silicate alteration. Many of the prospects are on pegmatite bodies with weak to moderate Cu-oxides. A composite sample (05-631/632, table 8) consisting of select Cu-oxides in pegmatite and hornblende gneiss was collected from two mines. Minor remnant disseminated to clotty chalcopyrite is present in the pegmatite. The sample has highly anomalous copper (7.7

percent; highest copper value from quadrangle), gold (6.7 ppm; highest gold value from quadrangle), and silver (112 ppm; second highest silver value from quadrangle). This sample is has very low zinc (110 ppm) and lead (70 ppm). The sample suggests that the pegmatites locally have disseminated chalcopyrite with relatively high gold and silver values and explains the high interest in prospecting the pegmatites.

Another cluster of small to medium mines and prospects is present about 13,000 ft west-southwest of Maysville, on the ridge between Como and McClure Creeks. The mines and prospects are in biotite felsic gneiss (Xbfg) and muscovite felsic schist (Xmfs) with abundant Berthoud-type pegmatites. The pegmatites have coarse magnetite crystals and some muscovite. The main mines have sorted “ore” piles of quartz veins, vuggy quartz veins and gossan material with some remnant chalcopyrite and galena. A composite sample (05-237/237A/238, table 8) was collected from sorted piles from three of the larger mines. The sample shows highly anomalous lead (1.96 percent), zinc (0.96 percent), copper (0.38 percent), and silver (27 ppm). The open-space, locally vuggy character of the veins suggests they may be epithermal veins. A polished thin section shows about 15 percent barite gangue and 5 percent carbonate gangue in the quartz veins. Sulfides include chalcopyrite and galena, with much of the chalcopyrite replaced by hematite.

The origin of the sulfide (-oxide) Zn-Cu-Pb-Ag mineralization is problematic. The stratabound character and the meta-volcanic/metasedimentary protoliths are supportive of a Proterozoic, stratabound and strataform massive sulfide origin. Although the mineralized zones are relatively small in the Maysville quadrangle, the potential for larger mineralized zones is suggested by nearby deposits like the Sedalia mine, where grades were significantly improved by supergene enrichment. Overall, there is low to moderate potential for the discovery of additional small, Cu-Zn-Pb-Ag-Au orebodies in the Maysville quadrangle.

WATER RESOURCES

Water resources on the Maysville quadrangle include surface and subsurface ground water.

SURFACE WATER

The largest stream in the quadrangle is the South Arkansas River, which flows from west to east across the southern part of the quadrangle. It is the major drainage in the southern part of the Upper Arkansas Valley and forms the local base level for all tributary streams, such as those that drain the range-front piedmont. The only stream gage on the South Arkansas River was located 7.5 mi downstream from the Maysville quadrangle and has records only from 1922-1940. Upstream of this stream gage (elevation 7,040 ft), the South Arkansas River has a drainage area of 208 sq. mi. In the period 1922-1940 the annual mean streamflow at the gage ranged from a low of 13.1 cfs (cubic ft per second) in 1940 to a high of 72.6 cfs in 1923 (U.S. Geological Survey, 2006 NWIS Web Data). Mean monthly flow reaches a maximum in May (average 70 cfs) and June (average 86 cfs), due to snowmelt in the upper drainage basin. Lowest monthly flows occur in July (average 11 cfs) and October (average 19 cfs). The highest (peak) flow recorded between 1922 and 1940 was 1,220 cfs on June 17, 1923. By comparison, the peak flow in other years between 1922-1940 ranged from about 100 to 500 cfs.

The largest tributary to the South Arkansas River is the North Fork, which enters the South Arkansas River at Maysville. The North Fork is not gaged and no published streamflow data are available.

Several irrigation ditches carry water from the South Arkansas River, eastward across the terraces (Qbo, Qk) in the far eastern part of the quadrangle. These ditches are all on the northern side of the South Arkansas River and include (from west to east) the North Fork Ditch, which originates at Maysville, the Cameron Ditch, and the Missouri Park Ditch.

The only spring shown on the Maysville 7.5' topographic base map lies on the range-front piedmont, where the head of Blank Gulch is crossed by a fault trace

(395795E, 4272725N). The fault trace has probably uplifted a lens of alluvium along Blank Gulch, such that the base of the perched water table in the alluvium daylights on the scarp face. There are probably additional, smaller, unmapped seasonal springs along the other traces of the Shavano fault zone at the head of the piedmont, particularly downslope of the major canyons.

GROUND WATER

Ground water is an important resource in the Maysville quadrangle, as indicated by the 109 registered water wells recorded by the Colorado Division of Water Resources. The wells are concentrated in the south-central part of the quadrangle in the town of Maysville and upstream in the North Fork, with a smaller number of wells along the South Arkansas River east of Maysville. Most of the wells are shallow (73 are less than 100 ft deep), and only 10 are deeper than 200 feet; the deepest well is 450 feet deep. 79 of 88 wells (90 percent) have a static water level less than 100 ft below the surface and 60 of the wells (68 percent) have a static water level of 50 ft below the surface, or less.

Depth to water and well yield correlate with both geologic map unit and with topographic position. In the town of Maysville, wells in the low flood plain (map unit Qal) have water levels from 0-30 ft below the surface (average 14 ft) with yields of 3-20 gallons per minute (gpm) and an average yield of 11 gpm. However, wells in map unit Qal in progressively smaller tributary drainages tend to have deeper water levels and lower yields. As a whole, wells in map unit Qal have water levels ranging from 5-105 ft (average 33 ft).

Wells in the valley of the South Arkansas produce water from coarse-grained, well-sorted, permeable outwash gravels in terraces of Pinedale (Qpo), Bull Lake (Qbo), and Kansan (Qk2, Qk3) age. Wells in the Qpo terrace in Maysville have water levels of about 15 ft (similar to wells in map unit Qal there) and yields of 12-15 gpm. Wells in map unit Qbo directly east of Maysville have water levels of 12-70 ft and yields of 15-30 gpm. [There are no wells on terraces Qboy and Qboo farther downstream, due to the availability of ditch irrigation]. These relatively consistent and high yields indicate that

water near Maysville is being produced from coarse, permeable outwash gravels, and the rather shallow water depths suggest that water is perched in these deposits atop older, less permeable deposits.

The seven wells drilled into the Qbo terrace northwest of Maysville (the “cemetery terrace”) illustrate the difference in water depth and yield between the presumed perched aquifer in coarse Bull Lake outwash and the deeper aquifer in finer grained Dry Union (?) Formation. The three shallow wells (30, 35, and 60 ft deep) on the cemetery terrace have water levels from 0-20 ft below surface and yields of 9-15 gpm. In contrast, three deep wells on the same terrace (180, 230, and 300 ft deep) have much deeper water levels (60-81 ft below surface) and much smaller yields (0.1-1 gpm), representing production from a much tighter underlying aquifer.

Few wells exist on the range-front piedmont that makes up about half the area of the Maysville quadrangle, due to the lack of private land and development on the piedmont. A group of seven wells on the distal piedmont in the northeast part of the quadrangle (between Squaw Creek and Cedar Gulch) in Dry Union Formation may be representative of the remainder of the piedmont. These wells range from 130-450 ft deep and have water levels of 69-319 ft below surface. The yields are relatively small (0.5-6 gpm) and variable. The three shallower wells (130, 183, 284 ft) tend to have lower yields (2.5, 1, 0.5 gpm) than the deeper wells (285, 300, 450 ft; 6, 3, and 5 gpm, respectively), suggesting that in this area, the permeability of the Dry Union Formation increases with depth.

Scattered wells do exist in Proterozoic rock south of the South Arkansas River, in the area of the mapped slide blocks. Depth to static water and yield vary erratically in this area, with wells in “intact” crystalline rock having water levels of 150-190 ft and yields of 0.5-1 gpm. In contrast, a well in the same area and rock type on the margin of a slide block has a depth of 151 ft, water level of 18 ft, and yield of 450 gpm. This high yield suggests the well is tapping a very permeable zone of crushed rock on the landslide margin.

REFERENCES

- Alers, B.K., and Shallow, J.M., 1996, Semiconformable Cu-Zn, Zn-Pb-Ag, synvolcanic mineralization and rhyolitic volcanic successions in polydeformed terranes of the Proterozoic Colorado province [abstr.]: Geological Society of America Abstracts With Programs, v. 28, no. 7, A-155.
- Best, M.G., 1982, Igneous and metamorphic petrology: New York, W.H. Freeman and Company, 630 p.
- Bickford, M.E., and Boardman, S.J., 1984, A Proterozoic volcano-plutonic terrane, Gunnison and Salida area, Colorado: *Journal of Geology*, v. 92, p. 657-666.
- Bickford, M.E., Schuster, R.D., and Boardman, S.J., 1989, U-Pb geochronology of the Proterozoic volcano-plutonic terrane in the Gunnison and Salida areas, Colorado, *in* Grambling, J.A. and Tewksbury, B. J., eds., Proterozoic geology of the southern Rocky Mountains: Geological Society of America Special Paper 235, p. 33-48.
- BLM LR2000, Bureau of Land Management Land & Mineral Legacy Rehost 2000 System (www.blm.gov/lr2000/).
- Boardman, S.J., 1976, Geology of the Precambrian metamorphic rocks of the Salida area, Chaffee County, Colorado: *The Mountain Geologist*, v. 13, no. 3, p. 89-100.
- Boardman, S.J., 1986, Early Proterozoic bimodal volcanic rocks in central Colorado, U.S.A., Part 1; Petrography, stratigraphy and depositional history: *Precambrian Research*, v. 34, p. 1-36.
- Boardman, S.J., and Condie, K.C., 1986, Early Proterozoic bimodal volcanic rocks in central Colorado, U.S.A., Part II; Geochemistry, petrogenesis and tectonic setting: *Precambrian Research*, v. 34, p. 37-68.
- Bookstrom, A.A., 1981, Tectonic setting and generation of Rocky Mountain porphyry molybdenum deposits: *Arizona Geological Society Digest*, v. 14, p. 215-226.
- Bookstrom, A.A., Carten, R.B., Shannon, J.R., and Smith, R.P., 1988, Origins of bimodal leucogranite-lamprophyre suites, Climax and Red Mountain porphyry molybdenum systems, Colorado: Petrologic and strontium isotopic evidence, *in* Part 3, Cenozoic volcanism in the southern Rocky Mountains revisited- A tribute

- to Rudy C. Epis: Colorado School of Mines Quarterly, v. 83, no. 2, p. 1-24.
- Bosworth, W., Lambiase, J., and Keisler, R., 1986, A new look at Gregory's rift; The structural style of continental rifting: Eos, v. 67, no. 29, p. 577, 582-583.
- Brock, M.R., and Barker, F., 1972, Geologic map of the Mount Harvard quadrangle, Chaffee and Gunnison Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-952, scale 1:62,500.
- Buddington, A.F., 1959, Granite emplacement with special reference to North America: Geological Society of America Bulletin, v. 70, p. 671-748.
- Chapin, C.E., 1971, The Rio Grande rift; Part I, Modifications and additions: New Mexico Geological Society Guidebook 22, p. 191-201.
- Chapin, C.E., 1979, Evolution of the Rio Grande rift; A summary, *in* Riecker, R.E., ed., Rio Grande rift; Tectonics and magmatism: Washington D.C., American Geophysical Union, p. 1-5.
- Chapin, C.E., 1988, Axial basins of the northern and central Rio Grande rift, *in* Sloss, L.L., ed., Sedimentary cover- North American craton U.S.: Geological Society of America, The Geology of North America, v. D-2, p. 165-170.
- Chapin, C.E., and Cather, S.M., 1994, Tectonic setting of the axial basins of the northern and central Rio Grande rift, *in* Keller, G.R., and Cather, S.M., eds., Basins of the Rio Grande rift; structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291, p. 5-25.
- Chapin, C.E., and Lowell, G.R., 1979, Primary and secondary flow structures in ash-flow tuffs of the Gribbles Run paleovalley, central Colorado, *in* Chapin, C.E. and Elston, W.E., eds., Ash-flow tuffs: Geological Society of America Special Paper 180, p. 137-154.
- Clough, C.T., Maufe, H.B., and Bailey, E.B., 1909, The cauldron subsidence of Glen Coe, and the associated igneous phenomena: Quarterly Journal Geological Society of London, v. 65, p. 611-678.
- Colorado Division of Water Resources, 2006, Water well data.
- Coney, P.J., 1976, Plate tectonics and the Laramide orogeny: New Mexico Geological Society Special Publication 6, p. 5-10.
- Coolbaugh, M.F., 1985, Geology and economic mineral potential of upper Browns Creek

- basin, Chaffee County, Colorado: Phoenix, Ariz., University of Arizona, M.Sc. thesis, 243 p.
- Crawford, R.D., 1913, Geology and ore deposits of the Monarch and Tomichi mining districts, Colorado: Colorado Geological Survey Bulletin 4, 313 p.
- Cunningham, C.G., Naeser, C.W., Marvin, R.F., Luedke, R.G., and Wallace, A.R., 1994, Ages of selected intrusive rocks and associated ore deposits in the Colorado mineral belt: U.S. Geological Survey Bulletin 2109, 31 p.
- Czamanske, G.K., Foland, K.A., Hubacher, F.A., and Allen, J.C., 1990, The $^{40}\text{Ar}/^{39}\text{Ar}$ chronology of caldera formation, intrusive activity, and Mo-ore deposition near Questa, New Mexico, *in* Bauer, P.W., Lucas, S.G., Mawer, C.K., and McIntosh, W.C., eds., Tectonic development of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Geological Society Guidebook 41, p. 355-358.
- Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: *Geology*, v. 7, p. 558-560.
- De la Roche, H., Leterrier, J., Grandclaude, P., and Marchal, M., 1980, A classification of volcanic and plutonic rocks using R_1R_2 -diagram and major-element analyses- its relationship with current nomenclature: *Chemical Geology*, v. 29, p. 183-210.
- De Voto, R.H., 1971, Geologic history of South Park and geology of the Antero Reservoir quadrangle, Colorado: Colorado School of Mines Quarterly, v. 66, no. 4, 90 p., scale: 1:62,500.
- De Voto, R.H., 1972, Pennsylvanian and Permian stratigraphy and tectonism in central Colorado, *in* De Voto, R. H., ed., Paleozoic stratigraphy and structural evolution of Colorado: Quarterly of the Colorado School of Mines, v. 67, no. 4, p. 139-185.
- De Voto, R.H., 1990, Paleozoic stratigraphy, tectonism, thermal history, and basin evolution of central Colorado: Economic Geology Monograph 7, p. 29-44.
- De Voto, R.H., and Peel, F.A., 1972, Pennsylvanian and Permian stratigraphy and structural history, northern Sangre de Cristo Range, Colorado: Colorado School of Mines Quarterly, v. 67, p.283-320.
- DeWitt, E., 1987, Written communication.
- Denesha, C.V., 2003, Tertiary faulting and its relation to basin architecture in the Upper Arkansas basin, Northern Rio Grande rift: Manhattan, Kansas, Kansas State

- University, M.Sc. thesis, 50 p.
- Dings, M.R., and Robinson, C.S., 1957, Geology and ore deposits of the Garfield quadrangle, Colorado: U.S. Geological Survey Professional Paper 289, 110 p.
- Dippold, C.L., 1999, The geometry and kinematics of the Poncha Pass transfer zone, northern Rio Grande rift, south-central Colorado: Manhattan, Kansas, Kansas State University, M.Sc. thesis, 90 p.
- Dunn, L.G., 2003, Colorado Mining Districts: A Reference: Colorado School of Mines Library, ISBN: 0-918062-19-5.
- Eaton, G.P., 1979, A plate-tectonic model for Late Cenozoic crustal spreading in the western United States, *in* Riecker, R.E., ed., Rio Grande Rift; Tectonics and magmatism: Washington, D.C., American Geophysical Union, p. 7-32
- Emmons, S.F., 1886, Geology and mining industry of Leadville, Colorado: U.S. Geological Survey Monograph 12.
- Emmons, S.F., Irving, J.D., and Loughlin, G.F., 1927, Geology and ore deposits of the Leadville mining district, Colorado: U.S. Geological Survey Professional Paper 148, p. 1-20.
- Epis, R.C., and Chapin, C.E., 1968, Geologic history of the Thirtynine Mile volcanic field, central Colorado, *in* Epis, R.C., ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School of Mines Quarterly, v. 63, no. 3, p. 51-85.
- Epis, R.C., and Chapin, C.E., 1974, Stratigraphic nomenclature of the Thirtynine Mile volcanic field, central Colorado: U.S. Geological Survey Bulletin 1395-C, 23 p.
- Epis, R.C., and Chapin, C.E., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 45-74
- Epis, R.C., Scott, G.R., Taylor, R.B., and Chapin, C.E., 1980, Summary of Cenozoic geomorphic, volcanic, and tectonic features of central Colorado and adjoining areas, *in* Kent, H.C. and Porter, K.W., eds., Colorado geology: Denver, Colorado., Rocky Mountain Association of Geologists, p. 135-156.
- Folk, R.L., and Ward, W.C., 1957, Brazos River bar; A study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3-26.

- Fridrich, C.J., 1986, The Grizzley Peak cauldron, Colorado - Structure and petrology of a deeply dissected resurgent ash-flow caldera: Stanford, Calif., Stanford University, Ph.D. thesis, 201 p.
- Fridrich, C.J., and Mahood, G.A., 1984, Reverse zoning in the resurgent intrusions of the Grizzley Peak cauldron, Sawatch Range, Colorado: Geological Society of America Bulletin, v. 95, p. 779-787.
- Fridrich, C.J., DeWitt, E., Bryant, B., Richard, S., and Smith, R.P., 1998, Geologic map of the Collegiate Peaks Wilderness Area and the Grizzley Peak caldera, Sawatch Range, central Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-2565, scale 1:50,000.
- Gibbs, A.D., 1984, Structural evolution of extensional basin margins: Journal of the Geological Society of London, v.141, p. 609-620.
- Guilinger, J.R., and Keller, J.W., 2002, Directory of active permitted mines and mine permits in Colorado – 2002: Colorado Geological Survey Information Series 68, 40 p., map 1:500,000.
- Hayden, F.V., 1869, Preliminary field report [Third] Annual report of the United States Geological and Geographical Survey of the territories, Colorado and New Mexico: Washington, U.S. Govt. Printing Office, 155 p.
- Heimann, A., Spry, P.G., and Teale, G.S., 2005, Zincian spinel associated with metamorphosed Proterozoic base-metal sulfide occurrences, Colorado; A re-evaluation of gahnite composition as a guide in exploration: Canadian Mineralogist, v. 43, p. 601-622.
- Heinrich, E.W., 1981, Precambrian tungsten and copper-zinc skarn deposits of south-central Colorado: Colorado Geological Survey Resource Series 21, 115 p.
- Hubbard, M.S., Oviatt, C.G., Kelley, S., Perkins, M.E., Hodges, K.V., and Robbins, R., 2001, Oligocene-Miocene basin formation and modification in the northern Rio Grande rift; Constraints from $^{40}\text{Ar}/^{39}\text{Ar}$, fission track and tephrochronology [abstr.]: Geological Society of America Abstracts With Programs, v. 33, no.6, p. A-257.
- Humphreys, W.J., 1914 through 1924, Seismological reports for October 1914 to June 1924: U.S. Weather Bureau, Monthly Weather Review, Section V-Seismology.

- Hutchinson, R.M., and Hedge, C.E., 1967, Precambrian basement rocks of the central Colorado Front Range and its 700-million-year history: Geological Society America, Rocky Mountain Section, Annual Meeting, 20th, Golden, Colorado, Guidebook No. 1, 51 p.
- IUGS Classification: International Union of Geological Sciences Subcommittee of Systematics of Igneous Rocks: See Streckeisen (1973, 1976 and 1979).
- Ingram, R.L., 1989, Grain-size scales, *in* Dutro, J.T., Jr., Dietrich, R.V., and Foose, R.M., compilers, AGI data sheets—for geology in the field, laboratory, and office (3rd ed.): Alexandria, Va., American Geological Institute, sheet 29.1.
- International Commission on Stratigraphy, 2005, International stratigraphic chart: downloaded January 2006 from the International Commission on Stratigraphy website, www.stratigraphy.org/chus.pdf.
- Keller, J.W., McCalpin, J.P., and Lowry, B.W., 2004 Geologic map of the Buena Vista East quadrangle, Chaffee County, Colorado: Colorado Geological Survey Open-File Report 04-4, scale 1:24,000, 1 CD-ROM.
- Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p.
- Kirkham, R.M., and Rogers, W.P., 2000, Colorado earthquake information, 1867-1996: Colorado Geological Survey Bulletin 52, CD-ROM.
- Kluth, C.F., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: *Geology*, v. 9, p. 10-15.
- Knepper, D.H., 1974, Tectonic analysis of the Rio Grande rift zone, central Colorado: Golden, Colo., Colorado School of Mines, Ph.D. thesis (T-1593), 237 p.
- Knepper, D.H., 1976, Late Cenozoic structure of the Rio Grande rift zone, central Colorado, *in* Epis, R.C. and Weimer, R.J., eds., *Studies in Colorado field geology: Professional Contributions of the Colorado School of Mines*, no. 8, p.421-430.
- Knight, D.C., 1981, Stratigraphy and mineralogy of a zinc-rich sillimanite gneiss near Maysville, Chaffee County, Colorado: Winnipeg, Manitoba, University of Manitoba, M.Sc. thesis, 94 p.
- Kouther, M.J.H., 1969, Geology and mineralization of the northwest part of the Bonanza quadrangle, Chaffee and Saguache Counties, Colorado: Golden, Colo., Colorado

- School of Mines, M.Sc. thesis, 93 p.
- Larson, P.B., 1987, Stable isotope and fluid inclusion investigations of epithermal vein and porphyry molybdenum mineralization in the Rico Mining district, Colorado: *Economic Geology*, v. 82, p. 2141-2157.
- Layer, P., and Drake, J., 2006, $^{40}\text{Ar}/^{39}\text{Ar}$ step heat analysis of CGS samples: Unpub. Report to Colorado Geological Survey, Geochronology Laboratory, University of Alaska, Fairbanks, Alaska, 13 p.
- Lettis, W., Noller, J., Wong, I., Ake, J., Vetter, U., and LaForge, R., 1996, Draft report, Seismotectonic evaluation of Colorado River storage project- Crystal, Morrow Point, Blue Mesa dams, Smith Fork project-Crawford dam, west-central Colorado: Unpub. draft report prepared by William Lettis & Associates, Inc., Woodward –Clyde Federal Services, and Seismotectonics and Geophysical Group of the U.S. Bureau of Reclamation in Denver, Colorado, 177 p.
- Limbach, F.W., 1975, The geology of the Buena Vista area, Chaffee County, Colorado: Golden, Colo., Colorado School of Mines, M.Sc. thesis, 98 p., map plate, scale 1:24,000.
- Lipman, P.W., 1981, Volcano-tectonic setting of Tertiary ore deposits southern Rocky Mountains: *Arizona Geological Society Digest*, v. 14, p. 199-214.
- Lipman, P.W., 1982, Tectonic setting of the mid to late Tertiary in the Rocky Mountain region- A review; The genesis of Rocky Mountain ore deposits; Changes with time and tectonics: *Proceedings of the Denver Region Exploration Geologists Society Symposium*-p. 125-132.
- Lipman, P.W., 2007, Incremental assembly and prolonged consolidation of Cordilleran magma chambers; Evidence from the Southern Rocky Mountain volcanic field: *Geosphere*, v. 3, no. 1, p. 42-70
- Lindsey, D.A., Johnson, B.R., and Andriessen, P.A.M., 1983, Laramide and Neogene structure of the northern Sangre de Cristo Range, south-central Colorado, *in* Lowell, J.D., ed., *Rocky Mountain foreland basins and uplifts*: Rocky Mountain Association of Geologists, p. 219-228.
- Lister, G.S., and Snoke, A.W., 1984, S-C mylonites: *Journal of Structural Geology*, v. 6, p. 617-638.

- Litsey, L.R., 1958, Stratigraphy and structure of the northern Sangre de Cristo mountains, Colorado: Geological Society of America Bulletin, v. 69, p. 1143-1178.
- London, D., 1987, Written communication.
- McCalpin, J.P., and Shannon, J.R., 2005, Geologic map of the Buena Vista West quadrangle, Chaffee County, Colorado: Colorado Geological Survey Open-File Report 05-8, 96 p., scale 1:24,000.
- McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1-4.
- McIntosh, W.C., and Chapin, C.E., 2004, Geology of the central Colorado volcanic field, *in* Cather, S.M., McIntosh, W.C., and Kelly, S.A., eds, Tectonics, geochronology, and volcanism in the southern Rocky Mountains and Rio Grande rift: New Mexico Bureau of Geology and Mineral Resources Bulletin 160, p. 205-238.
- Michel-Levy, A., 1877, De l'emploi du microscope polarisant a lumiere parallele: Ann. Mines: v. 12, p. 392-471.
- Miller, M.G., 1999, Active breaching of a geometric segment boundary in the Sawatch Range normal fault, Colorado, USA: Journal of Structural Geology, v. 21, p. 769-776.
- Mutschler, F.E., Larson, E.E., Bruce, R.M., 1987, Laramide and younger magmatism in Colorado- New petrologic and tectonic variations on old themes: Colorado School of Mines Quarterly, v. 82, no. 4, p. 1-47.
- Naeser, C.W., Cunningham, C.G., Jr., Marvin, R.F., and Obradovich, J.D., 1980, Pliocene intrusive rocks and mineralization near Rico, Colorado: Economic Geology, v. 75, p. 122-127.
- Okulitch, A.V., 2002, Geological time chart: Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas)- Revision.
- Olson, H.J., and Dellechiaie, F., 1976, The Mount Princeton geothermal area, Chaffee County, Colorado, *in* Epis, R.C., and Weimer, R.J., eds., Studies in Colorado field geology: Colorado School of Mines Professional Contributions 8, p. 431-438.
- Olson, J.C., 1983, Geologic and structural maps and sections of the Marshall Pass Mining District, Saguache, Gunnison and Chaffee Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-1425, scale 1:24,000.

- Ostenaar, D.A., Losh, S.L., and Nelson, A.R., 1981, Evidence for recurrent late Quaternary faulting, Sawatch fault, Upper Arkansas Valley, Colorado, *in* Junge, W.R., ed., Colorado tectonics, seismicity and earthquake hazards; Proceedings and field trip guide: Colorado Geological Survey Special Publication 19, p. 27-29.
- Parker, B.H., 1974, Gold placers of Colorado: Colorado School of Mines Quarterly, v. 63, nos. 3 and 4, 262 p.
- Pearl, R.H., and Barrett, J.K., 1976, Geothermal resources of the upper San Luis and Arkansas Valleys, Colorado, *in* Epis, R.C., and Weimer, R.J., eds., Studies in Colorado field geology: Colorado School of Mines Professional Contributions 8, p. 439-445.
- Perry, H.A., 1971, Geology of the northern part of the Bonanza volcanic field, Saguache County, Colorado: Golden, Colo., Colorado School of Mines, M.Sc. thesis (T-1339), 72 p.
- Powers, W.E., 1935, Physiographic history of the upper Arkansas River valley and the Royal Gorge, Colorado: Journal of Geology, v. 43, no. 2, p. 184-199.
- Pulfrey, R.J., 1971, Geology and geochemistry of the Mount Antero Granite and contiguous units, Chaffee County, Colorado: Oklahoma State University, M.Sc. thesis, 84 p.
- Ramsay, C.R., Stoesser, D.B., and Drysdall, A.R., 1985, Guidelines to classification and nomenclature of Arabian felsic plutonic rocks: *in* Drysdall, A.R., Ramsay, C.R., and Stoesser, D.B., eds., Felsic plutonic rocks and associated mineralization of the Kingdom of Saudi Arabia: Deputy Ministry for Mineral Resources Bulletin 29, pp. 13-20.
- Reed, J.C., Jr., Bickford, M.E., Premo, W.R., Aleinikoff, J.N., and Pallister, J.S., 1987, Evolution of the early Proterozoic Colorado province - Constraints from U-Pb geochronology: Geology, v. 15, no. 9, p. 861-865.
- Reynolds, D.L., 1956, Calderas and ring complexes: Verhandelingen. Koninklijke Nederlands Geologisch Mijnbouwkundig Genootschap, v. 16, p. 355-379.
- Roberts, J.L., 1966, The emplacement of the main Glen Coe fault-intrusion at Stob Mhic Mhartuin: Geological Magazine, v. 103, no. 4, p. 299-316.
- Robinson, C.S., 1961, Pre-Pennsylvanian stratigraphy of the Monarch district, Chaffee

- County, Colorado, *in* Berg, R.R., and Rold, J.W., eds., Symposium on lower and middle Paleozoic rocks of Colorado: Rocky Mountain Association of Geologists, 12th Field Conference, p. 119-124.
- Russell, R.T., 1945, The Poncha fluorspar deposits, Chaffee County, Colorado: U.S. Geological Survey Strategic Mineral Investigations Preliminary Report 3-210, 12 p.
- Russell, R.T., 1950, The geology of the Poncha fluorspar district, Chaffee County, Colorado: Cincinnati, Ohio, University of Cincinnati, Ph.D. thesis, 70 p.
- Scott, G.R., 1975, Reconnaissance geologic map of the Buena Vista quadrangle, Chaffee and Park Counties, Colorado: U.S. Geologic Survey Miscellaneous Field Studies Map MF-657, scale 1:62,500.
- Scott, G.R., and Taylor, R.B., 1975, Post-Paleocene Tertiary rocks and Quaternary volcanic ash of the Wet Mountain Valley, Colorado: U.S. Geological Survey Professional Paper 868, p. 1-15.
- Scott, G.R., Van Alstine, R.E., and Sharp, W.N., 1975, Geologic map of the Poncha Springs quadrangle, Chaffee County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-658, scale 1:62,500.
- Scott, G.R., Taylor, R.B., Epis, R.C., and Wobus, R.A., 1978, Geologic map of the Pueblo 1° x 2° quadrangle, south-central Colorado: U.S. Geological Survey Miscellaneous Investigations Series, scale 1:250,000.
- Shannon, J.R., 1981, Unpublished data.
- Shannon, J.R., 1984, Unpublished data.
- Shannon, J.R., 1986, The Mount Antero and California intrusions, Chaffee County, Colorado; Evidence for early evolution of pegmatitic fluids: Colorado Pegmatite Symposium, Friends of Mineralogy, p. 84-86
- Shannon, J.R., 1988, Geology of the Mount Aetna cauldron complex, Sawatch Range, Colorado: Golden, Colo., Colorado School of Mines, Ph.D. thesis (T-3521), 434 p.
- Shannon, J.R., and Epis, R.C., 1987, Deeply-eroded, ring zone structures of the Mount Aetna cauldron, Colorado [abstr.]; Hawaii Symposium on How Volcanoes Work, Hilo, Hawaii, p.231.
- Shannon, J.R., Epis, R.C., Naeser, C.W., and Obradovich, J.D., 1987a, Correlation of

- intracauldron and outflow tuffs and an intrusive tuff dike related to the Oligocene Mount Aetna cauldron, central Colorado, *in* Part 1, Cenozoic volcanism in the southern Rocky Mountains revisited- A tribute to Rudy C. Epis: Colorado School of Mines Quarterly, v. 82, no. 4, p. 65-80.
- Shannon, J.R., Stein, H.J., and Smith, R.P., 1987b, Geology and geochemistry of Oligocene topaz rhyolites and A-type granites, northern Rio Grande rift, Colorado [abstr.]: Geological Society of America Abstracts With Programs, v. 19, no. 7, p. 840.
- Shannon, J.R., Naeser, C.W., DeWitt, E., and Wallace, A.R., 1987c, Timing of Cenozoic magmatism and tectonism in the Sawatch Uplift and northern Rio Grande rift, Colorado [abstr.]: Geological Society of America Abstracts With Programs, v. 19, no. 7, p. 839.
- Sharp, W.N., 1970, Extensive zeolitization associated with hot springs in central Colorado, Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-B, p. B14-B20.
- Sharp, W.N., 1976, Geologic map and details of the beryllium and molybdenum occurrences, Mount Antero, Chaffee County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-810, scale 1:24,000.
- Sheridan, D.M., and Raymond, W.H., 1984, Precambrian deposits of zinc-copper-lead sulfides and zinc spinel (gahnite) in Colorado: U.S. Geological Survey Bulletin 1550, 30 p.
- Sibson, R.H., 1975, Generation of pseudotachylite by ancient seismic faulting: Geophysical Journal of the Royal Astronomical Society, v. 43, p. 775-794.
- Simmons, E.C., and Hedge, C.E., 1978, Minor-element and Sr-isotope geochemistry of Tertiary stocks, Colorado mineral belt: Contributions Mineralogy and Petrology, v. 67, p. 379-396.
- Simpson, C., and Schmidt, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geological Society of America Bulletin, v. 94, p. 1281-1288.
- Smith, R.P., 1979, Unpublished reconnaissance geologic map, Climax Molybdenum Co.
- Smith, R.P., 1981, Personal communication.

- Stark, J.T., and Barnes, F.F., 1935, Geology of the Sawatch Range: Colorado Scientific Society Proceedings, v. 8, p. 467-479.
- Stover, C.W., Reagor, B.G., and Algermissen, S.T., 1984, Seismicity map of the State of Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-1694.
- Steven, T.A., 1975, Middle Tertiary volcanic field in the southern Rocky Mountains: Geological Society of America Memoir 144, p. 75-94.
- Steven, T.A., and Epis, R.C., 1968, Oligocene volcanism in south-central Colorado; *in* Epis, R.C. ed., Cenozoic volcanism in the southern Rocky Mountains: Colorado School of Mines Quarterly, v. 63, no. 3, p. 241-258.
- Streckeisen, A.L., 1973, Plutonic rocks- Classification and nomenclature recommended by the IUGS Subcommittee on the systematics of igneous rocks: Geotimes, October, 1973, p. 26-30.
- Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.
- Streckeisen, A.L., 1979, Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites, and melilitic rocks; Recommendations and suggestions of the IUGS Subcommittee on the Systematics of Igneous Rocks: Geology, v. 7, p. 331-335.
- Taubenack, W.H., 1967, Notes on the Glen Coe cauldron subsidence Argyllshire, Scotland: Geological Society of America Bulletin, v. 78, p. 1295-1316.
- Taylor, R.B., 1975, Neogene tectonism in south-central Colorado, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 211-226.
- Taylor, R.B., Scott, G.R., and Wobus, R.A., 1975, Reconnaissance geologic map of the Howard quadrangle, central Colorado: U. S. Geological Survey Miscellaneous Investigation Series, MAP I-892, scale 1:62,500
- Taylor, R.B., Stoneman, R.J., and Marsh, S.P., 1984, An assessment of the mineral potential of the San Isabel National Forest, south-central Colorado: U.S. Geological Survey Bulletin 1638, 42 p.
- Toulmin, P., III, 1963, *in* Geological Survey Research, 1963: U.S. Geological Survey Professional Paper 475, p. A88.

- Toulmin, P., III, 1975, Megabreccia in the Mount Aetna complex, Colorado: U.S. Geological Survey Professional Paper 975, p. 153.
- Toulmin, P., III, 1976, Oligocene volcanism near Mount Aetna, southern Sawatch Range, Colorado [abstr.]: Geological Society of America Abstracts With Programs, v. 8, no. 5, p. 640-641.
- Toulmin, P., III, and Hammarstrom, J.M., 1990, Geology of the Mount Aetna volcanic center, Chaffee and Gunnison Counties, Colorado: U.S. Geological Survey Bulletin 1864, 44 p., scale 1:24,000.
- Tweto, O., 1961, Late Cenozoic events of the Leadville district and upper Arkansas Valley, Colorado, *in* Short papers in the geologic and hydrologic science: U.S. Geological Survey Professional Paper 424-B, p. B133-B135
- Tweto, O., 1975, Laramide (Late Cretaceous-Early Tertiary) orogeny in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 1-44.
- Tweto, O., 1977, Tectonic history of west-central Colorado, *in* Veal, H.K., ed., Exploration frontiers of the central and southern Rockies: Denver, Colo., Rocky Mountain Association of Geologists, p. 11-22.
- Tweto, O., 1979a, The Rio Grande rift system in Colorado, *in* Riecker, R.E., ed., Rio Grande Rift; Tectonics and magmatism: Washington, D.C., American Geophysical Union, p. 33-56.
- Tweto, O., 1979b, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000.
- Tweto, O., 1980a, Tectonic history of Colorado, *in* Kent, H.C., and Porter, K.W., eds, Colorado geology: Denver, Colo., Rocky Mountain Association of Geologists, Denver, Colorado- 1980 Symposium, p.5-9.
- Tweto, O., 1980b, Precambrian geology of Colorado, *in* Kent, H.C., and Porter, K.W., eds., Colorado geology: Rocky Mountain Association of Geologists, Denver, Colorado- 1980 Symposium, p. 37-46.
- Tweto, O., 1980c, Summary of Laramide orogeny in Colorado, *in* Kent, H.C., and Porter, K. W., eds., Colorado geology: Rocky Mountain Association of Geologists, Denver, Colorado- 1980 Symposium, p. 129-134.

- Tweto, O., 1987, Rock units of the Precambrian basement in Colorado: U.S. Geological Survey Professional Paper 1321-A, 54 p., 1 plate.
- Tweto, O., and Sims, P.K., 1963, Precambrian ancestry of the Colorado Mineral Belt: *Geologic Society of America Bulletin*, v. 74, p. 991-1014, 1 plate.
- Tweto, O., Steven, T.A., Hail, W.J., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1° x 2° quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-761, scale 1:250,000.
- U.S. Forest Service, 1998, San Isabel National Forest, scale 1:126,720.
- U.S. Geological Survey 2002 National Seismic Hazard Maps source:
<http://eqint.cr.usgs.gov/eq-men/html/zipcode-06.html>
- U.S. Geological Survey, NEIC Internet catalog of earthquakes, 1973-2003.
http://neic.usgs.gov/neis/epic_circ.html
- U.S. Geological Survey, 2006 NWIS Web Data for Colorado:
<http://nwis.waterdata.usgs.gov/co/nwis>, Internet site accessed in June, 2006.
- Unruh, J.R., Sawyer, T.L., and Lettis, W.R., 1992, Seismotectonic evaluation of Green Mountain dam, Shadow Mountain dam, Granby dam, and Willow Creek dam, Colorado-Big Thompson Project: Unpub. Preliminary Report prepared by William Lettis & Associates for U.S. Bureau of Reclamation, Denver, Colorado, 78 p.
- Van Alstine, R.E., 1968, Tertiary trough between the Arkansas and San Luis Valleys, Colorado, *in Geological Survey research 1968*: U.S. Geological Survey Professional Paper 600-C, p. C158-160.
- Van Alstine, R.E., 1969, Geology and mineral deposits of the Poncha Springs Northeast quadrangle, Chaffee County, Colorado: U.S. Geological Survey Professional Paper 626, 52 p., 6 plates.
- Van Alstine, R.E., 1970, Allochthonous Paleozoic blocks in the Tertiary San Luis-Upper Arkansas graben, Colorado, *in Geological Survey research 1970*: U.S. Geological Survey Professional Paper 700-B, p. B43-B51.
- Van Alstine, R.E., 1974, Geology and mineral deposits of the Poncha Springs SE quadrangle, Chaffee County, Colorado: U.S. Geological Survey Professional Paper 829, 19 p.

- Van Alstine, R.E., and Lewis, G.E., 1960, Pliocene sediments near Salida, Chaffee County, Colorado, *in* Short papers in the geological sciences: U.S. Geological Survey Professional Paper 400-B, p. B245.
- Vanderwilt, J.W., 1947, Mineral resources of Colorado: Denver, Colo., Colorado Mineral Resources Board, 48 p.
- Varga, R.J., and Smith, B.M., 1984, Evolution of the early Oligocene Bonanza caldera, north San Juan volcanic field, Colorado: *Journal Geophysical Research*, v. 89, no. B10, p. 8810-8841.
- Wallace, C.A., Cappa, J.A., and Lawson, A.D., 1997, Geologic map of the Salida East quadrangle, Chaffee and Fremont Counties, Colorado: Colorado Geological Survey Open-File Report 97-6, 27 p., scale 1:24,000.
- Wallace, C.A., Cappa, J.A., and Lawson, A.D., 1999, Geologic map of the Gribbles Park quadrangle, Park and Fremont Counties, Colorado: Colorado Geological Survey Open-File Report 99-3, 21 p., scale 1:24,000.
- Wallace, C.A., Apeland, A.D., and Cappa, J.A., 2000, Geologic map of the Jack Hall Mountain quadrangle, Fremont County, Colorado: Colorado Geological Survey Open-File Report 2000-1, 27 p., scale 1:24,000.
- Wallace, C.A., and Keller, J.W., 2003, Geologic map of the Castle Rock Gulch quadrangle, Chaffee and Park Counties, Colorado: Colorado Geological Survey Open-File Report 2003-1, 65 p., scale 1:24,000.
- Wallace, C.A., and Lawson, A.D., 1998, Geologic map of the Cameron Mountain quadrangle, Chaffee, Park, and Fremont Counties, Colorado, Colorado Geological Survey Open-File Report 98-4, 23 p., scale 1:24,000.
- Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p.
- Witkind, I.J., 1976, Preliminary map showing known and suspected active faults in Colorado: U.S. Geological Survey Open-File Report 76-154.
- Wrucke, C.T., 1974, The Whitehorn Granodiorite of the Arkansas Valley in central Colorado: U.S. Geological Survey Bulletin 1394-H, p. 1-7.
- Wrucke, C.T., and Dings, M.G., 1979, Geologic map of the Cameron Mountain

- quadrangle, Colorado: U.S. Geological Survey Open-File Report 79-660, scale 1:62,500.
- Xu, T., 2001, Sedimentology and stratigraphy of Tertiary continental deposits in the Poncha Pass transfer zone and adjacent area, Colorado: Manhattan, Kansas, Kansas State University, M.Sc. thesis, 90 p.
- Xu, T., Oviatt, J., and Hubbard, M., 2001, Sedimentology and stratigraphy of Tertiary continental deposits of the Poncha Pass transfer zone and adjacent area, Colorado [abstr.]: Geological Society of America, Abstracts With Programs, v. 33, no. 6, p. A-74.

OPEN-FILE REPORT 06-10 Geologic Map of the Maysville Quadrangle, Chaffee County, Colorado

APPENDIX

APPENDIX 1. MAYSVILLE QUADRANGLE POINT-FILE DATABASE WITH LOCATION AND STRUCTURE DATA.

Datum NAD27 CONUS ZONE 13

ID	UTM E	UTM N	STRIKE	DIP	TYPE	FORMATION	COMMENT
3	395788	4262814			WR Chem	Ta	Tertiary (?) andesite hybrid dike; whole rock chemistry
4	395684	4262799	275		Adit; Geochem	Xmsg;Xcs	Calc-silicate w/ Sph and Chpy; geochem
5	395635	4263036			Shaft	Xag;Xbfg;Xcs;CuOx;Mag	
6	395641	4262959	224		Adit	Xbfg;Xcs;Mag	
6A	395629	4262931			Prospect	Xcs;CuOx;Ta	
7	395633	4262915			Shaft	Xmsg;Xag;Xcs;YXp;Ta;Mag;CuOx	
7A	395632	4262904			Prospect	Xcs;CuOx;Mag;Ta	Small prospect at base of 05-7 shaft dump
8	395529	4262884			Prospect	YXp; Xbfg	
8A	395445	4262842			Prospect	YXp	
11	395037	4262698			Prospect	YXp;Xmsg	
12	394827	4262598			Prospect	YXp;Xmsg;Ep	
15B	394207	4262301			Prospect	YXp;Xa;Xcs	
32	395761	4263049	245		Adit; Geochem	Xbfg;Xa;Xcs;Mag-Chpy;QV	Bon Ton NE Adit; calc-silicate w/ sph, gah, chpy; geochem
34	395945	4263262			Cat Cut	YXp;Xag	
40	396533	4263447			Prospect	Td2	
63	395791	4263435			Cat Cut	YXp	
64	395558	4263405			Cat Cut	YXp	Control Point;Old Claim Post
65	395822	4262849			Cat Cut	YXp;Xag	
65B	395840	4262834			Prospect	Xag;Xcs	Soil Grid in this area: 992+00N;1006+00E
66	395658	4262834	32		Adit	Xcs	Bio-Gar-Cpx-Act-Chl calc-silicate with Chpy
66A	395653	4262806			Prospects	Xag;Xcs	Xcs with CuOx
67	395656	4262870			Shaft	Xag;Xcs	Gar-Cpx-Bio calc-silicate with disseminated Chpy
67A	395641	4262875			Prospect	Xag;Xcs	Hbde-Act-Bio-Gar calc-silicate with CuOx
68	395549	4262983			Cat Cut	YXp	Top of Cat Cut
68A	395580	4263002			Cat Cut	YXp	Bottom of Cat Cut
78	391298	4263007			Adit; Geochem	Xag;Xcs;YXgp;CuOx	Cat Cut through area of old adit; calc-silicate w/ Cu; geochem
78A	391299	4263069	207		Adit	Xaa;Xcs;CuOx	Control Point
90A	391703	4263170			Prospect	Xmfs	

94A	391996	4263422			Prospect	YXp;Xbfg	
106	391647	4263962	84		Adit	BR(Xbfg)	
106A	391634	4263994	96		Adit; Geochem	Xmfs;Xag;Xcs;YXp	Como Cr; calc-silicate w/ Cu-Zn; geochem composite w/ 106B
106B	391575	4263957	82		Adit; Geochem	Xbfg;Xag;QV	Como Cr; calc-silicate w/ Cu-Zn; geochem composite w/ 106A
106C	391634	4263952			Prospect	Xbfg	
106D	391615	4263995	107		Adit	Xmfs;Yxgp	
106E	391656	4264003			Prospect	Xag;Xcs-CuOx	
106F	391692	4263968	110		Adit	Xbfg;Xmfs;Xag	
109	392014	4263802			Prospect	YXp	YXp in Xmfs
113	392034	4263739	135	16	Foliation	Xaa;Xhig	Xag/Xhig is biotitized(?)
113os			352	90	Vein_vert	Ep	
116	393456	4264042			Prospect	YXp;Xmfs	Control Point
117	393636	4264091			Prospect	YXgp	
117Aos			45		Vein	Quartz Vein cuts Xmfs	
118A	394076	4264100			Prospect	Xag	
122	394432	4264141			Prospect	Xcs;Xag	
123	394629	4264037			Prospect	Xag;Xcs-Ep;QV	
124	394729	4263987			Prospect	Xag;QV	
124A	394154	4264132			Prospect	YXp	
157C	395187	4263968			Shaft	Hematite Breccia;QV;YXp	
157D	395204	4263956	50		Cat Trench	YXp	Old Claim Post
158	394837	4263813			Prospect	VQ Vein;Xbfg;Xag;YXp	
158os			42	87	Vein/Fault	Vuggy Quartz Vein Breccia;Gossan	
159B	394809	4263520			Prospect	Xag;QV-Gossan	
176A	396752	4262460			Prospect	Td2	FeOx in Xag blocks
183A	395625	4262222			Pros; Geochem	Xhig	Quartz vein w/ chpy and amphibole; geochem
183Aos			9	62	Vein/Foliation	QV;Xhig	Qtz-Chpy VE w/ assoc Chl and Ep
192	395540	4262272	160		Adit	Xhig	
203	395891	4264554			Prospect	YXp;Xhig;BR	BR Fault in contact zone w/ Td
205A	395851	4264846			Prospect	YXp;QTZ;Xmfs	Pegmatite-Quartz Vein w/ RHD and CAL
207A	395280	4264929			Prospect	YXp;QTZ;CuOx	Also Xq and Xhig on Dump
207B	395264	4264950			Prospect	Xhig;Xcs;QTZ;Hem	Xcs w/ Ep and Gar
207D	395329	4264948			Prospect	Ta Dike	At Contact Ta-Xmfs
208	395238	4264738			Prospect	YXp;Ta	
213B	394733	4264020			Prospect	Xhig	
214	394960	4264093			Prospect	Xcs	Xcs w/ Ep;Gar;Act
214C	395338	4264204			Prospect	Xhfg	Silicious Hornfels
215	395442	4264204			Prospect	YXp-CuOx	3 ft thick Qtz-Peg in Xig;Xhf;Xag
229	391862	4265593			Prospect	YXgp	YXgp in Xag;Xmfs
230	391780	4265758			Prospect	Xhig	Gossan Horizon

237	392436	4265641	155		Adit; Geochem	Xbfg;Xa;QV;CuOx	Vuggy Quartz Veins with Chalcopyrite; geochem compos
237A	392649	4265301	57		Adit; Geochem	Xbfg;QV;Mag	Caved Adit on Hairpin/Switchback; geochem compos
237F	392589	4265297			Prospect	YXp	
238	392536	4265221			Shaft; Geochem	Xmfs;Xhig;YXp;QV	Gossan; QV w/ CuOx and Tr Gal(?); geochem compos
238A	392524	4265255	159		Adit	Xbfg;YXp	
238B	392563	4265171			Prospect	Xhig	
238C	392604	4265095			Prospect	Xhig	
238D	392701	4265035			Prospect	YXp	
238E	392687	4265018			Prospect	YXp;VQ	
238F	392684	4265001			Prospect	YXp;VQ	YXp in Xbfg
239	392703	4264930			Prospect	Xbfg;QV	
245A	393571	4265406			Prospect	Xag;Xcs;Xbfg	Abundant Chl and Ep
245B	393628	4265424			Prospect	Xag	
247	393431	4265814	45		Adit	YXp-CuOx-Xhig	
258	393329	4273526			WR Chem	Tqlp	quartz latite porphyry hybrid dike; whole rock analysis
264A	391985	4273916	334	60	Vein	Qtz-Ser-Pyr VE in Xgdf	
265	392136	4274206			Pros; Geochem	Xag;Xcs;Xhig;CuOx	Cluster 8 Prospects; Gar-Cpx-Ep-Mag calc-silicate; geochem
266	392069	4274245	95		Adit	Xag;Xcs;FeOx	
266A	392154	4274269			Prospect	Xag;Xcs	
267D	392134	4274370			Prospect	YXp;Xgdf	
269A	392781	4274832			Prospect	YXp;Xgdf	
278	394591	4272626	290		Adit	Qc	Blank Mine Adit(Caved) w/ Spring
279	394600	4272892	300		Adit	Xag;Xhig	
280	394410	4272693			Shaft; Geochem	Fault Breccia;Xag;Xhig;Or(?)	Blank Mine Shaft;Pyr and Gal in Or(?); geochem
281	394383	4272720	320		Adit	Fault Breccia;YXgp;Xhig;Xag	+20 Ft Thick Colluvium
282	394351	4272787	330		Adit	YXgp;Xhig	Some Brecciated and Silicified YXgp
282E	394414	4272815	317		Adit	YXgp;Xag;Xhig	
283	394450	4272827	317		Adit	BR;Xhig;YXgp	
283A	394438	4272800			Prospect	Yxgp	
283B	394506	4272834	280		Adit	GR;Xag;Xhig	Tr QV
285	394526	4272668			Drill Hole	Xag;Xhig	RC Drill Site;Road Cut Bank w/ 3 to 5 Ft of Colluvium
286	394522	4272586			Drill Hole		Cuttings are sandy with chips of YXgp
288	394496	4272501			Drill Hole		Sandy Cuttings
291	394357	4272346			Drill Hole		RC Drill Site
293	395517	4272639			Prospect	Qc	+15 Ft of Sandy Colluvium Exposed in Pit
307A	394232	4264625			Prospect	Xag;Xcs;Yxgp	Gar-Ep calc-silicate
314	394498	4263780			Prospect	Xmfs	
334A	396351	4274951			Prospect	Tr;Tr Crackle Breccia;QV	Trace Rounded Td Clasts:Tma and Badger Cr Tuff
334B	396326	4274937			Prospect	Trp;QV	
335	396288	4274952			Shaft; Geochem	Xgdf;Yxgp	Silicified breccia Shavano range front fault; geochem

336A	396189	4274961			Prospect	Xgdf	Broken Xgdf w/ BR Character
336B	396069	4274989			Prospect	Xgdf	Mylonitic Xgdf;M-S Chl
343A	396983	4275597	285		Adit	BR/GR;Xgdf;QV	
344	397005	4275643			Shaft	Fault Breccia;Xgdf;QV	
345	397080	4275609			Prospect	Fault Breccia;Xgdf;Trp	4 Ft Deep Prospect and Smaller pits on 150 Trend
346	397135	4275583			Shaft	Fault Breccia;Trp	
346os			45		Fault	Fault Breccia;Trp/Tr	50 Ft Long Rib Silicified Fault Breccia
346A	397109	4275554	335		Adit	Fault Breccia;Trp/Tr	
346B	397275	4275520			Prospect	Qc(?);Xgdf;YXgp;Fault Breccia	
354	397245	4276007			Prospect	Xgdf	Silicified Xgdf
356	397154	4275953			Prospect	Xag;Xgdf	2 Prospect Pits w/ Silicified Slips
359	397095	4275748			Prospect	GR/BR;Xag;Xgdf	
441B	393318	4270544			Prospect	Xgp	
447A	392173	4270923			Age Det.	Tqm	Age determination sample
486C	401877	4271485			Placer Cut	Qk;Td	Placer Cuts
487	401835	4271430			Placer Cut	Qk;Td	
488	401736	4271443			Placer Cut	Qk;Td	
488A	401708	4271430			Placer Cut	Qk;Td	
488Bos					Placer Cut	Qk;Td	
488C	401704	4271461			Placer Cut	Qk;Td	Qk w/ Xgd Blocks to 5 Ft
488D	401816	4271495			Placer Cut	Qk;Td	Top of Large Placer Cut;Qk w/ imbricate Clasts;Fe-Mn
495B	395872	4274377			Prospect	Xgdf	
495C	395879	4274384			Prospect	Xgdf;QV	
504	394053	4275539			WR Chem	Tmpp	Mount Pomeroy subunit; whole rock analysis
516os			143	79	Vein	QV	Chalcedonic QV in Tcm
540os			194	28	Vein	1-3 mm thick QV in Trp Dike	
542	393081	4272971			WR Chem	Trp	Alkali rhyolite porphyry dike; whole rock analysis
564os			262	81	Vein	QV	4 In Thick QV Cutting Xig
575A	392177	4271791			WR Chem	Tnfg	Alkali granite w/ Tr Red Garnet; whole rock analysis
575Aos			60	51	Vein	QV	2 to 3 mm Thick QV w/ Trace Pyrite Cutting Tnfg
601	396301	4265404			Shaft	Xhig;QV;CuOx	Open Shaft;'+40Ft Deep
601osb			275	86	Vein	QV;Mag;YXp;CuOx	Qtz-Mag-CuOx;Probably was Chpy
608	396645	4264970	223		Adit	Or(?)	Trace Silicified Material;Mostly Chert and Brecciated Chert
609	396724	4264927	188		Adit	Or(?)	Some Brecciated Silicified Material;Carbonate Breccia
614A	396562	4264842			Prospect	Td-Or(?)	Sm Prospect Pit on Contact
622	395768	4265177	272	48	Prospect	Xmfs;YXgp	Sillimanite in Xmfs;Black Tourmaline in YXp
630D	395769	4265633			Prospect	YXgp	
631	395783	4265654	200		Adit; Geochem	Xhig;YXgp;MAG;CuOx	CuOx mostly in Xig; some in YXp; geochem
631A	395761	4265678	227		Prospect;Cut	Xhig;YXgp	
631B	395780	4265693	230		Prospect;Cut	YXgp	

631C	395814	4265704	185		Prospect;Cut	YXgp;CuOx	CuOx in YXp
632	395836	4265705			Pros; Geochem	YXgp;CuOx	Two Pits w/ CuOx and chpy in YXp;Geochem
632B	395834	4265729	195		Prospect;Cut	Xag;Xcs(Ep);CuOx	Poss Caved Adit?;CuOx in YXp
632C	395861	4265679	225		Adit	Xag;YXgp	
633	395969	4265676	264	73	Prospect	Xmfs;YXgp	10Ft Deep Pit w/ OC
639C	393924	4266030			Prospect	YXgp	
640	393919	4266014			Prospect	YXgp;Xag	Cluster of 4 Prospect Pits All In YXp w/ CuOx
641A	393819	4265963			Prospect	YXgp;BR(Xhig)	
642A	393847	4265955			Prospect	Xcs;Xag	
643	393860	4265952			Prospect	Xcs;Xag	Cpx-Act-Ep calc-silicate w/ Minor Gar
643A	393867	4265802	173	51	Foliation	Xhig	
644	393886	4265796	90		Adit	Xag;Xhig;YXp;CuOx	Chlorite Schist After Sheared Xag;Minor CuOx in CHL Sch
644A	393899	4265778			Shaft	Xag;Xhig;YXgp	Large Dump w/ Flat Pad;Trace CuOx in Chlorite Schist
645	393938	4265784	100		Adit	Xag;YXp;CuOx	Most CuOx in YXp
647A	394285	4265672			Prospect	YXp	Prospect Below Road(w/ Cut on YXp)Trace CuOx in YXp
647B	394342	4265766			Adit	YXp	
647D	394323	4265826			Prospect-Cut	YXp	
648	394403	4265882	150		Adit; Geochem	YXgp;VQV;Xcs;CuOx	Vuggy Quartz Veins w/ Trace Chpy;Gar calc-sil; Geochem
648A	394398	4265956	163		Adit; Geochem	Xag;Xhig;Xcs;QV;YXp	Composite geochem with 648 and 649
648Aosb			170	74	Vein	QV;VQV	QV w/ Spec HEM and Trace Pyrite
648C	394399	4265930			Prospect-Cut	YXp;Xcs	
649	394425	4265992	148		Adit; Geochem	Xag;Xcs;QV;VQV;MnOx	Vuggy Quartz Veins w/ Chpy;Mn Wade; composite geochem
649A	394420	4265773			Prospect	YXp;VQV;MnOx	Pick Up Xmfs in Float
651C	394383	4265414			Prospect	Or	
652A	394381	4265299			Prospect	Xhig;Xag	
653B	394525	4265319			Prospect	Xag;Xcs(Ep)	
657	394863	4265288			Prospect	Or	St Limonite w/ Abundant Fine Carb VE
657A	394868	4265275			Prospect	Or	Fault Breccia and Brecciated Silicified Or
658A	394901	4265406			Prospect	YXgp;Xhig;Xmfs	Veneer of Conc Or Float on Surface
662	394808	4265668	225		Adit	Xhig;YXgp;Ta;CuOx	Control Point;2 Log Cabins;Trace CuOx in Ta Dike
662A	394792	4265651			Prospect-Cut	Ta;Xhig;YXgp	Cut on Ta Dike Above Adit
663A	394728	4265633			Prospect	Xhig;YXgp;Ta	Retrograde(?) Muscovite in Xhig
664	394692	4265610			Shaft	Xhig;Or	
668	395161	4265692			Prospect	Or;Xhig	Suggestion of Or-Xhig Contact in pit(Az 310)
680	394125	4266477			WR Chem	Ta	Tertiary (?) andesite hybrid dike; whole rock chemistry
718A	390945	4266779			Prospect	Xag;YXgp	Some CHL Slips and Striated Slicks;Ep calc-silicate
729	399619	4275444			Prospect	Td	Gravel w/ 20%Tma;10%Tpm;More PC:Xgdf;Xag;YXgp
821	390619	4269368			WR Chem	Tqm	Tertiary quartz monzodiorite; whole rock analysis
832	392045	4268970			Prospect	Xgp	Xgp is locally weakly foliated
843	391220	4269599			Prospect	Xhig	

854	391849	4268852	42	Adit; Geochem	Xgp;Xcs;QV;CuOx	Silicified Xgp;chpy QV; calc-sil; composite geochem
855	391867	4268864	24	Adit; Geochem	Xgp;QV;VQV	Silicified Xgp;QV and Vuggy QV;Trace Gal; comp geochem
855A	391878	4268853		Prospect	Xgp	
856	391920	4268851	10	Adit	Xgp;QV;VQV	Some Silicified Xgp Crackle Breccia
856A	391934	4268859	7	Adit	Xgp	Minor Silicified Xgp
857	391958	4268821	55	Adit; Geochem	Xgp;Fault Breccia	Abund Silicified Xgp;Silicified Fault Breccia; comp geochem
857A	391964	4268807		Prospect	Xgp	Xgp w/ Silicification
858	391989	4268784		Adit	Xgp;Xhig	Yellow Punky Fines-Fault?;Closed Depression Below, Till?
859	391714	4268951		Cut(?)	Xgp	Natural(?) Cut in BR;Poss Drill Pad Here?
860	391644	4268920	33	Adit	Xgp	Med Sized Dump All Xgp;No Qpt Blocks Here
873	393507	4269445		Prospect	Xgp	Some MUS Pegmatite;No OC or SC
953A	391510	4270345		Prospect	Qc	
953B	391427	4270357		Prospect	Qc	
953C	391231	4270554		Prospect	Qc	
954	391297	4270723	344	Adit	Xhig	
954A	391307	4270759		Prospect	Xhig	
954B	391353	4270506		Prospect	Tqm	
963	394239	4266597		Prospect	Xgp	
964C	394644	4266542		Prospect	Xhig/Xgp	
964D	394674	4266522		Prospect	Xhig	
964E	394693	4266535		Prospect	Xhig	