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Geologic Map of the Jack Hall Mountain Quadrangle, Fremont County, Colorado

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 00-1, *Geological Map of the Jack Hall Mountain quadrangle, Fremont County, Colorado* is to describe the geologic setting and mineral resource potential of this 7.5 minute quadrangle located in the southern Mosquito Range of central Colorado. The staff of the Mineral Resources and Geological Mapping Section of the Colorado Geological Survey and two consultants, Chester A. Wallace and Allison Apeland, completed the field work on this project from July 1999 to October 1999. The objective of this publication is to provide geologic maps in the mineral rich area of the southern Mosquito Range to resource developers, government planners, and interested citizens.

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INTRODUCTION

The Jack Hall Mountain quadrangle is located in western Fremont County in the southern part of the Mosquito Range. This quadrangle includes a deeply dissected terrane that is transitional from the high plains upland located north of this map area to the deeply incised canyon of the Arkansas River that is located south of this quadrangle.

The oldest rocks exposed in the quadrangle are Early Proterozoic metamorphic and igneous rocks, which are overlain unconformably by Paleozoic sedimentary rocks, Tertiary volcanic and sedimentary rocks, and Quaternary alluvial, terrace, and colluvial deposits. The Late Cretaceous Whitehorn Granodiorite intruded Paleozoic sedimentary rocks. Steep faults offset Proterozoic and Paleozoic rocks. Lower Paleozoic rocks occur as isolated exposures in the northern and central parts of the map area, and a folded sequence of upper Paleozoic rocks occurs in the southwestern part of the map area. Late Cretaceous plutonic rocks and Tertiary volcanic and sedimentary rocks are not cut by faults. Tertiary volcanic rocks and volcanogenic sedimentary rocks cover Proterozoic and Paleozoic rocks over much of the quadrangle. Volcanic rocks are composed mainly of silicic welded tuff and air-fall tuff, but in the eastern part of the map area flow rocks of intermediate composition overlie silicic tuffs. Remnants of Quaternary pediments occur in the southwestern part of the map area and terraces occur along prominent drainages. Loess occurs as isolated deposits in some drainages and alluvial and colluvial deposits occur in modern streams.

Structures in the Jack Hall Mountain quadrangle are dominated by the north-trending Weston-Pleasant Valley fault in the central part of the map area. The Weston-Pleasant Valley fault was active during deposition of late Paleozoic strata, and slip on that fault ceased before intrusion of the Late Cretaceous Whitehorn Granodiorite. Some slip on the Weston-Pleasant Valley fault was probably strike-slip motion because a negative flower structure occurs along the fault. In the southwestern part of the map area the Badger Creek fault also was active during late Paleozoic time, and slip on this fault may have controlled thicknesses of late Paleozoic rock units. Slip on the Badger Creek fault may be related to slip on the Weston-Pleasant Valley fault. Medium-scale folds and faults of small separation occur scattered through lower and upper Paleozoic rocks

Mineral deposits in the Jack Hall Mountain quadrangle consist primarily of precious- and base-metal vein deposits in Late Proterozoic rocks and stratabound copper and silver deposits that occur at the angular unconformity at the base of member four of the Pennsylvanian and Permian Sangre de Cristo Formation. Surface exposures of these copper and silver deposits are of local extent, and an adit was excavated into one of these stratabound occurrences. Davis and Streufert (1990) and Vanderwilt (1947) mention the presence of small gold vein and placer occurrences in Whitehorn Granodiorite near the abandoned settlement of Whitehorn in the Cameron Mountain quadrangle. There are no readily available detailed descriptions of these occurrences.

PREVIOUS STUDIES

Numerous geologic studies in the vicinity of the Jack Hall Mountain quadrangle, most dating from 1960 to 1980, established the regional geologic framework. Reports on regional stratigraphic studies of lower and middle Paleozoic rocks by Campbell (1972), Conley (1972), Gerhard (1972), Nadeau (1972), and Ross and Tweto (1980) established the regional stratigraphic sequence and regional lithofacies relations. Upper Paleozoic rocks were studied by Peel (1971), Pierce (1969, 1972), De Voto (1972, 1980), and De Voto and Peel (1972), and the reports and maps that resulted determined the local stratigraphic sequence and integrated the local succession into the regional stratigraphic and lithofacies pattern. Wrucke (1974) described the Late Cretaceous Whitehorn Granodiorite, the main plutonic body in the map area, and determined that the pluton was a laccolith. Volcanic rocks and deposits in this region were described by Lowell (1969), Epis and Chapin (1974), Chapin and Lowell (1979), and McIntosh and Chapin (1994). A series of geologic maps by the U.S. Geological Survey, all at a scale of 1:62,500, described relations among Proterozoic and Paleozoic successions, Cretaceous plutonic rocks, Tertiary intermediate and silicic volcanic rocks, and Quaternary deposits in the region of the Jack Hall Mountain quadrangle.

The original Cameron Mountain 15-minute quadrangle was subdivided into four 7.5-minute quadrangles that were named the Salida East, Cameron Mountain, Gribbles Park, and Jack Hall Mountain quadrangles; the same name given to quadrangles of different vintage and scale is the source of some confusion. Wrucke and Dings (1979) published an open-file map of the Cameron Mountain 15-minute quadrangle (scale 1:62,500), which includes the Jack Hall Mountain quadrangle (1:24,000). Taylor and others (1975) published a geologic map of the Howard 15-minute quadrangle (scale 1:62,500), which borders the Jack Hall Mountain 7.5-minute quadrangle on the south. The Black Mountain quadrangle (scale 1:62,500) of Epis and others (1979a) adjoins the Cameron Mountain 15-minute quadrangle on the east, and the Guffey 15-minute quadrangle (Epis and others, 1979b) borders the Cameron Mountain 15-minute quadrangle to the northeast. The geology of the Jack Hall Mountain quadrangle is shown in a generalized form in the western part of the Pueblo 1° X 2° quadrangle (Scott and others, 1978). Figure 1 shows a generalized geological map and the location of the quadrangles in this mapping program.

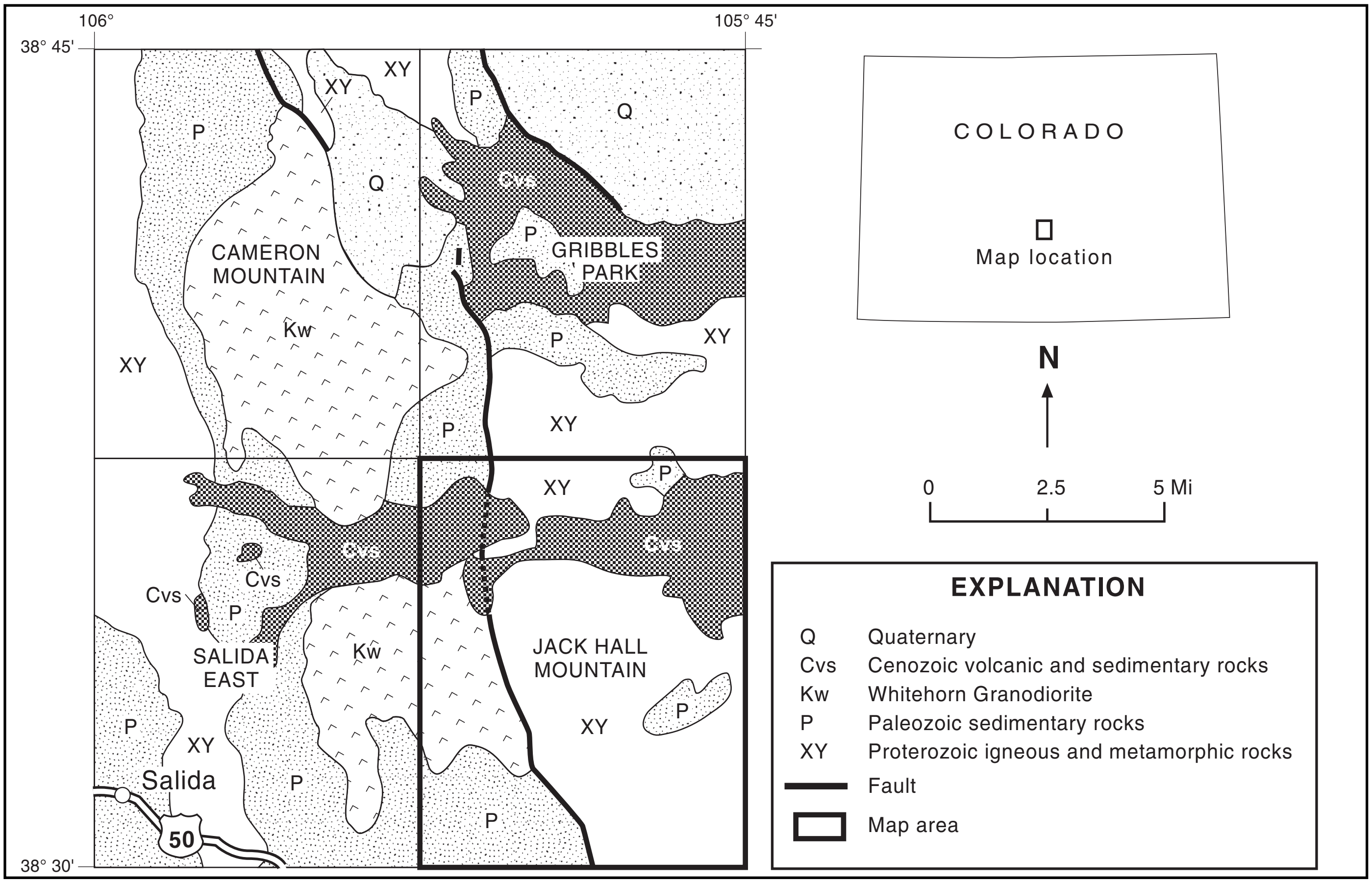

Figure 1. Location of Jack Hall Mountain quadrangle.

PRESENT STUDY

The present study focuses on geologic mapping of the Jack Hall Mountain quadrangle at a scale 1:24,000. Most geologic mapping was completed in June and July, 1999. Wallace, Apeland, and Cappa compiled the geologic map, and Wallace prepared cross sections and wrote much of the explanatory text. Rock names in this report are field terms: sedimentary rocks are named according to the scheme proposed by Pettijohn (1957), metamorphic rock names follow the system proposed by Best (1982), and volcanic and igneous rocks were named according to the I.U.G.S classifications proposed by Strekeisen (1973, 1978).

ACKNOWLEDGMENTS

We are indebted to ranchers and landowners in the map area for granting us access to their property and for providing advice regarding access to nearby state and federal land; they are Glenn and Jean Everett, Aaron Carter, Alfred and Frank Black, Denzel Goodwin, and Bill Duncan. The staff of the U.S. Forest Service in Salida, Charles Medina, District Ranger, aided this project in many ways. The staff of the Bureau of Land Management in Canyon City, Colorado, helped identify landowners in the Jack Hall Mountain quadrangle, and Jim Cunio, Bureau of Land Management, Canyon City, Colorado, provided information about land access in the map area. James A. Messerich (Laboratory for Geologic Photogrammetry and Digital Mapping at the U.S. Geological Survey, Denver, CO) set photogrammetric models on PG-2 plotters at the compilation stage of this project. Richard H. De Voto and John W. Keller provided technical reviews that improved the map and report, and Jane S. Ciener edited the text, map, and cross sections.

STRATIGRAPHY AND STRUCTURE

PROTEROZOIC ROCKS

Proterozoic rocks consist mainly of igneous rocks and lesser amounts of metamorphic rocks. The metamorphic rocks are moderately to slightly foliated, and are composed of gabbro, bimodal metavolcanic rocks, and metasedimentary rocks. Moderately and slightly foliated rocks are intruded by Early Proterozoic granodiorite and quartz monzonite batholiths and by Middle Proterozoic quartz monzonite stocks.

Regionally, the Early Proterozoic metamorphic unit (Xvs) is composed of interbedded, tan, felsic volcanic rocks, dark-gray and black basalt flows, and medium-gray to black, light-gray, and grayish-tan, fine-grained to very fine-grained quartzite, siltstone, graywacke, conglomerate, and calc-silicate hornfels, phyllite, and muscovite-biotite schist. In the Jack Hall Mountain quadrangle metasedimentary rocks are the dominate lithology, and the felsic volcanic rocks and basalt flows are rare. The highest metamorphic grade of this metasedimentary and metavolcanic unit is lower amphibolite in this quadrangle; however, to the north and west in the Salida East quadrangle (Wallace and others, 1997) metamorphism reached upper amphibolite facies. Commonly quartzite consists of very fine quartz grains and up to 10 percent feldspar grains. Porphyroblasts of plagioclase up to a few millimeters in size occur in some quartzite and can constitute up to 20 percent of the quartzite. Poorly to moderately foliated chlorite and biotite can constitute from 5 to 30 percent of the quartzite.

Glomeroporphyritic biotite occurs in association with magnetite grains. Other accessory mineral constituents include garnet, zircon, and magnetite, probably of detrital origin. Crossbedding, graded couplets, microlamination, planar lamination, and ripple cross-lamination, and load-casts are commonly well preserved in quartzite, metasiltite, and metagraywacke. Thin conglomerate beds cut channels into metasiltite and metagraywacke, and calc-silicate layers represent former calcareous beds. Locally the quartzite beds contain quartz veinlets that are 5 to 10 mm wide and contain rare pyrite. Epidote is common on fracture surfaces, in veinlets, and, rarely, as a replacement of chlorite and hornblende. The basalt flows and felsic volcanic rocks described by Boardman (1971, 1986) in the adjoining Salida East quadrangle occur rarely as thin interbeds in the Jack Hall Mountain quadrangle. Four zircon fractions from a metadacite in this unit east of Salida in the Salida East quadrangle were dated by the uranium-lead method by Bickford and others (1989) at 1728±6 Ma.

This assemblage of interbedded sedimentary and volcanic rocks was probably deposited in a probable marine or marginal basin environment near the toe of a shelf slope or on a relatively shallow ocean floor. The conglomeratic graywacke and graded graywacke beds were probably deposited by density flows, and interbedded calc-silicates suggest that deposition occurred above the carbonate compensation depth. The felsic volcanic rocks, basalt flows and flow breccias probably erupted on the ocean floor from rifts; the larger volume of basaltic flows in the Salida East quadrangle to the west, suggests that the main island arc was west of the Jack Hall Mountain quadrangle.

Stocks of Early Proterozoic gabbro (Xg) occur scattered in the northern and central parts of the Jack Hall Mountain quadrangle. This unit is a dark-gray to black, medium- to coarse-grained gabbro. Megascopically the rock contains light-orangish-tan crystals of plagioclase feldspar in a black aegerine-augite matrix. Contact relations with the surrounding rock units are generally obscured. The gabbro contains approximately 30 to 50 percent medium-grained (2-5 cm) labradorite (An_{50}-An_{60}) and 50 to 70 percent strongly pleochroic, prismatic, fine-grained (0.5-1.0 mm) crystals of aegerine-augite. A fine-grained phase of pyroxene occurs within a sub-ophitic texture of larger plagioclase crystals and along plagioclase fractures. In the Salida East quadrangle to the west the pyroxene crystals have been replaced by hornblende (Wallace and others, 1997). Chlorite and rare epidote occur as alteration products of the pyroxene. Opaque minerals, probably iron oxides and ilmenite, occur in trace amounts to as much as a few percent.

Early Proterozoic granodiorite (Xgd) forms plutons that are widely distributed through the Jack Hall Mountain quadrangle. This granodiorite is gray, grayish-orange, and grayish-yellow, speckled, coarse- to very coarse-grained, moderately foliated to non-foliated granodiorite and, rarely, it is gneissic. Commonly this unit contains phenocrysts of quartz and microcline feldspar 2 to 4 cm in length and minor amounts of muscovite and biotite. Where foliation is developed phenocrysts of microcline are sheared into augen that are as much as 6 cm in length. In the adjoining Salida East and Cameron Mountain quadrangles, outcrops of the granodiorite are part of a strongly foliated border phase of a pluton that extends for approximately 60 km north of the quadrangle (Wrucke and Dings, 1979). Granodiorite in the Jack Hall Mountain quadrangle appears to represent the interior and less foliated parts of the pluton.

Early Proterozoic quartz monzonite (Xqm) occurs as relatively small plutons scattered through the Jack Hall Mountain quadrangle. The quartz monzonite unit is a reddish-orange to red, fine-, medium-, and rarely coarse-grained, granular, biotite quartz monzonite; it forms prominent ridges and steep hills in the southern and central parts of the map area. Wrucke and Dings (1979) mapped much of this unit as a Middle Proterozoic age intrusive. In places the gabbro (Xg) is engulfed by the quartz monzonite (Xqm), which suggests that the gabbro is a xenolith or roof pendant and confirms that the quartz monzonite is later than the gabbro. The presence of locally developed foliation in the quartz monzonite suggests, but does not prove, that the quartz monzonite unit is of Early Proterozoic age—the age of peak metamorphism.

PALEOZOIC ROCKS

The exposed Paleozoic sequence is estimated to be about 4060 m thick in the map area, but nowhere is the sequence continuous. Regionally, the complete stratigraphic sequence is, in ascending order, the Sawatch Quartzite (Upper Cambrian), Manitou Limestone (Lower Ordovician), Harding Quartzite (Middle Ordovician), Fremont Dolomite (Upper and Middle Ordovician), Chaffee Formation (Upper Devonian), Leadville Limestone (Lower Mississippian), Kerber Formation (Pennsylvanian), Sharpsdale Formation (Pennsylvanian), Minturn Formation (Pennsylvanian), and Sangre de Cristo Formation (Pennsylvanian and Permian). In the map area the lower Paleozoic Sawatch Quartzite was probably not deposited, or it was eroded after deposition. The Chaffee Formation and Leadville Limestone, in the middle part of the Paleozoic sequence, were eroded after deposition or faulted out of the sequence in the map area. In the upper Paleozoic sequence the Kerber Formation and most of the Sharpsdale Formations were eliminated by faulting along the Weston-Pleasant Valley fault in the map area. Most of the lower Paleozoic units are separated by disconformities that represent long periods of nondeposition, or long periods of deposition and later erosion. Several upper Paleozoic units have angular unconformities that separate members and that record compressional deformation during deposition.

LOWER PALEOZOIC ROCKS

In the Jack Hall Mountain quadrangle the Manitou Limestone overlies Proterozoic igneous and metamorphic rocks as isolated exposures. Above the Manitou Limestone is the Harding Quartzite, which at some places is a quartzite breccia. Overlying the Harding Quartzite on a disconformable contact is the Fremont Dolomite.

The Manitou Limestone (Om) is Early Ordovician in age and regionally overlies the Late Cambrian Sawatch Quartzite on a disconformable contact (Ross and Tweto, 1980), but in the Jack Hall Mountain quadrangle the Manitou Limestone overlies Proterozoic crystalline and metasedimentary rocks. Dark-, moderate-, and light-gray, thin- to thick-bedded dolomite and cherty dolomite and rare beds of dark-gray limestone comprise a section that is about 30 m thick. The Manitou Limestone thickens northward to about 75 m in the Cameron Mountain and Gribbles Park quadrangles (Wallace and Lawson, 1998; Wallace and others, 1999). The Manitou Limestone is mostly dolomite in the Jack Hall Mountain quadrangle. Dolomite and limestone are laminated and mottled, and beds range between 2 cm and 1 m in thickness. A distinctive characteristic of the Manitou Limestone is the occurrence of black and light-grayish-white chert nodules and lenses in the dolomite. The chert is internally laminated parallel to bedding. In the adjoining Salida East quadrangle the Manitou Limestone commonly is composed of a silicified breccia of pebble- and cobble-sized laminated chert in a matrix of silicified dolomite that, in some places, forms the entire thickness of the unit, but silicified breccia is rare in the Jack Hall Mountain quadrangle and in the adjoining Cameron Mountain and Gribbles Park quadrangles.

The Harding Quartzite (Oh) is Middle Ordovician in age and regionally overlies the Manitou Limestone on a disconformable contact (Ross and Tweto, 1980). The Harding Quartzite is a dark-reddish-gray, dark-grayish-orange, dark-grayish-red, light-gray, moderate-gray, and rusty-orange, fine- to medium-grained, well-sorted, silica-cemented, mottled orthoquartzite. The sandstone is completely cemented by silica, and it has the conchoidal fracture of a quartzite. In the Jack Hall Mountain quadrangle most exposures are eroded at the top because this resistant-weathering quartzite caps ridges and peaks. Only one location in the Jack Hall Mountain quadrangle has a complete section of the Harding Quartzite and there the unit is about 21 m thick. The Harding quartzite appears to thicken northward in the southern Mosquito Range because the Harding thickens to 46 m in the northern part of the Cameron Mountain quadrangle and thickens to 67 m in most of the Gribbles Park quadrangle. Quartzite beds range from 2.5 cm thick to about 20 cm thick. They contain planar lamination and planar crossbeds, which are obscured by pervasive replacement by diagenetic silica. Although phosphatic bony plates of primitive fish occur locally in the adjacent Salida East quadrangle, none were found in this map area. Locally the unit contains lenses of breccia composed of angular clasts of rusty-, red-, and orange-colored quartzite. Extensive masses of quartzite breccia that characterize the Harding Quartzite in the Salida East (Wallace and others, 1997) and Cameron Mountain (Wallace and Lawson, 1998) quadrangles are mostly absent from the Jack Hall Mountain quadrangle.

The Fremont Dolomite (Of) is Late and Middle Ordovician in age and overlies the Harding Quartzite on a disconformable contact (Ross and Tweto, 1980). This dolomite unit occurs at only one place in the south-central part of the map area and the dolomite is eroded at the top. The Fremont Dolomite is a dark-, moderate-, and light-gray, massive-weathering, crystalline, fetid dolomite that contains echinoid debris and rare dolomitized coral in a fine-grained dolomite matrix. Dolomite may be mottled light-gray and dark-gray, or it is laminated and microlaminated. Rare black chert nodules are irregularly distributed through the dolomite. Beds are generally 5 cm to 1 m thick and bedding is poorly developed. This dolomite resists weathering and has a rough, uneven, sharply ridged weathering surface. The incomplete sequence of the Fremont Dolomite in the Jack Hall Mountain quadrangle is about 25 m thick, and in adjacent quadrangles the thickness of the Fremont Dolomite is consistently 60 to 67 m thick (Wallace and others, 1997; Wallace and Lawson, 1998; Wallace and others, 1999). Although trilobite and brachiopod fragments occur on some bedding planes in adjoining Salida East quadrangle, these fossil fragments were not found in this map area.

Upper Paleozoic Rocks

In the region of the Jack Hall Mountain quadrangle, Pierce (1969) and De Voto and Peel (1972) developed the stratigraphic system for Pennsylvanian and Permian sedimentary rocks, but no single report exactly follows previous subdivisions Fig. 2). Pierce (1969) subdivided seven informal units in the Pennsylvanian and Permian sequence in which his unit 1 is equivalent to the Kerber Formation, his unit 2 is equivalent to the Sharpsdale Formation, and his unit 3 is equivalent to the Minturn Formation according to De Voto and Peel (1972) (Fig. 2, this report). De Voto and Peel (1972) grouped units 4 and 5 of Pierce (1969) into their lower member of the Sangre de Cristo Formation, and they grouped units 6 and 7 of Pierce (1969) in their upper member of the Sangre de Cristo Formation. Following De Voto and Peel (1972) we subdivided the Kerber, Sharpsdale, and Minturn in this region, but we subdivided the Sangre de Cristo Formation into five informal members (members 1 through 5, Fig. 2) in place of units four, five, six and seven used by Pierce (1969) and in place of the informal upper and lower members of De Voto and Peel (1972). Member five of Pierce (1969) is subdivided into members two and three of the Sangre de Cristo Formation in this report (Fig. 2). Our member two of the Sangre de Cristo Formation corresponds to the lower part of member five of Pierce

<table>
<tr><th>Pierce, 1969</th><th colspan="2">DeVoto and Peel, 1972</th><th colspan="2">This Report</th><th>Age DeVoto and Peel, 1972; Devoto, 1980</th><th colspan="2">Depositional Cycles</th></tr>
<tr><td>Unit 7</td><td rowspan="5">Sangre de Cristo Fm</td><td rowspan="2">Upper Member</td><td rowspan="5">Sangre de Cristo Fm</td><td>Member 5</td><td rowspan="4">Wolfcampian
? ?
Virgilian</td><td rowspan="2">Cycle 4</td><td>Continental</td></tr>
<tr><td>Unit 6</td><td>Member 4</td><td>Deltaic paralic</td></tr>
<tr><td rowspan="2">Unit 5</td><td rowspan="3">Lower Member</td><td>Member 3</td><td rowspan="2">Cycle 3</td><td>Continental</td></tr>
<tr><td>Member 2</td><td>Marine</td></tr>
<tr><td>Unit 4</td><td>Member 1</td><td>Missourian</td><td rowspan="2">Cycle 2</td><td>Continental</td></tr>
<tr><td>Unit 3</td><td colspan="2">Minturn Fm</td><td colspan="2">Minturn Fm</td><td>Des Moinesian</td><td>Marine</td></tr>
<tr><td>Unit 2</td><td colspan="2">Sharpsdale Fm</td><td colspan="2">Sharpsdale Fm</td><td>Atokan</td><td rowspan="2">Cycle 1</td><td>Continental</td></tr>
<tr><td>Unit 1</td><td colspan="2">Kerber Fm</td><td colspan="2">Kerber Fm</td><td>Morrowan</td><td>Marine</td></tr>
</table>

Figure 2. Stratigraphic nomenclature, ages, and marine-continental cycles in Pennsylvanian and Permian strata in the region of the Jack Hall Mountain quadrangle.

(1969), which is mainly a dark-colored shale, siltstone, sandstone, limestone, dolomite, and gypsum. Our member three of the Sangre de Cristo Formation corresponds to the upper part of member five of Pierce (1969), which is mainly grayish-red sequence of arkose conglomerate, arkose sandstone, feldspathic siltstone, and micaceous shale. Member two and three vary in thickness because both units are bound at the top by an angular unconformity. Our members two and three of the Sangre de Cristo Formation have distinctive rock types that can be easily separated in the Jack Hall Mountain quadrangle.

Pennsylvanian and Permian strata in the region of the Jack Hall Mountain quadrangle form a complex sequence of clastic rocks and minor carbonate rocks that record three cyclic repetitions of marine to continental sequences (Fig. 2) in a north-northwest-trending, fault-bounded arm of the Pennsylvanian-Permian interior seaway, known as the Central Colorado Trough (De Voto, 1972; De Voto and Peel, 1972; Wallace and others, 1997, Wallace and Lawson, 1998; Wallace and others, 1999). In the southern part of the Central Colorado Trough, the base of the first depositional cycle is represented by the shallow-marine Kerber Formation. The Kerber is overlain by the Sharpsdale Formation, which is mainly a continental deposit. The second depositional cycle in this seaway is represented by the predominantly marine Minturn Formation and the overlying member one, as used in this report, of the Sangre de Cristo Formation, a continental deposit. A third cycle in the seaway is represented by member two of the Sangre de Cristo Formation in this report, a marine unit, and by member three of the Sangre de Cristo Formation in this report, a continental unit. Cyclic repetition of marine and continental deposits is more subdued above member three, which is truncated at an angular discordance by member four of the Sangre de Cristo Formation; member four was deposited in a delta channel, paludal, and paralic environment, and member five was deposited mostly in a fluvial and flood-plain environment. In the Jack Hall Mountain quadrangle, which contains rocks preserved along the eastern margin of the Central Colorado Trough, the lower part of the first marine to continental cycle, the Kerber Formation, is not present. The cyclic repetition of marine and non-marine strata was controlled by syndepositional tectonism on the Weston-Pleasant Valley fault, which is exposed in the central and western parts of this map area and in the western part of the Gribbles Park quadrangle (De Voto, 1972; De Voto and Peel, 1972; Wallace and others, 1999).

The Sharpsdale Formation (IPs), of Middle Pennsylvanian age, overlies the Kerber Formation, where it occurs adjacent to the Jack Hall Mountain quadrangle, on a contact that appears gradational and conformable. The Sharpsdale Formation is composed mainly of grayish-red and reddish-gray, coarse-grained arkose, pebbly and granular arkose, subarkose, and orthoquartzite interbedded with grayish-red and reddish-gray, medium- and fine-grained, feldspathic sandstone and lesser amounts of dark-red, micaceous siltstone and purplish-red, silty, micaceous shale. Only the uppermost part of this formation is exposed in the northwestern corner of the map area where the lower part of the unit was eliminated by a fault. This incomplete exposure is about 60 m thick in the Jack Hall Mountain quadrangle. To the north in the Gribbles Park quadrangle the Sharpsdale Formation is estimated to be a maximum of about 150 m thick (Wallace and others, 1999), and to the west in the Salida East quadrangle this unit is about 335 m thick (Wallace and others, 1997). Grayish-red, purplish-red, and bright-grayish-red, coarse-grained arkose, pebbly arkose, and medium- and fine-grained arkose is interbedded with dark-red argillaceous feldspathic sandstone, argillaceous and micaceous siltstone, and dark-red micaceous shale. Coarse-grained arkose beds have channeled bases that overlie the fine-grained upper parts of fining-upward sequences. Primary sedimentary structures include trough and planar crossbeds, shale-chip conglomerates, dispersed-pebble conglomerate, ripple cross-lamination, climbing ripples, cuspate and linguoid ripples, rib-and-furrow structures, planar lamination, flasers, and microlamination. Some intervals in the Sharpsdale Formation are olive-drab and grayish-green, tan- and rusty-weathering, medium- and coarse-grained arkose, pebbly arkose, and arkose conglomerate. Sandstone beds within the olive-drab and rusty-weathering intervals commonly contain calcite, dolomite, and ankerite cement. Rare beds of tan- and moderate-gray-weathering limestone and dolomite occur interbedded with coarse-grained rocks near the top of the Sharpsdale Formation. Poor exposures of the limited stratigraphic sequence of the Sharpsdale Formation in the map area preclude more detailed descriptions of the rocks. More complete descriptions of the Sharpsdale and its contact relations with the underlying Kerber Formation accompany the Salida East (Wallace and others, 1997) and Gribbles Park quadrangles (Wallace and others, 1999). The base of the Sharpsdale Formation is not exposed in the map area.

The Minturn Formation (IPm) is Middle Pennsylvanian in age (Des Moinesian) according to De Voto and Peel (1972), and in the adjacent Salida East quadrangle the Minturn Formation overlies the Sharpsdale Formation on a gradational and conformable contact (Wallace and others, 1997). The Minturn Formation is composed mainly of dark-gray, gray, olive-drab, grayish-green, greenish-gray, and black fine-grained sandstone, siltstone, shale, and less common limestone and dolomite. Gray, grayish-green, and olive-drab sandstone beds are fine grained and flaggy weathering. Sandstone beds contain planar lamination, ripple cross-lamination, low-amplitude hummocky crossbeds, and shallow channels. Dark-gray and olive-drab siltstone is planar laminated and microlaminated and contains ripple cross-lamination. Some beds of olive-drab and grayish-green, medium- and coarse-grained arkose occur interbedded with finer grained rocks in the lower part of the Minturn, and shale and siltstone beds occur more commonly in the middle and upper parts of this unit. Limestone beds are thin, laminated and microlaminated, black and dark-gray, fetid micrite. Commonly limestone beds are 1 to 15 cm thick and are interbedded with black and dark-gray, silty shale; zones of interbedded limestone and shale form bedding units that are 1 to 3 m thick, but some individual limestone beds are as thick as 1 m. Limestone beds are more common in the upper part of the Minturn Formation. Near the top of the Minturn Formation, red, micaceous silty shale and some fine- and medium-grained sandstone beds are interbedded with more characteristic olive-drab, grayish-green, dark-gray, and black micaceous shale, silty shale, and siltstone of the Minturn Formation. In a road-cut in the adjoining Salida East quadrangle, a black micaceous shale bed that contains casts of salt crystals occurs at the contact with the overlying Sangre de Cristo Formation (Wallace and others, 1997), but salt crystal casts were not found in the Jack Hall Mountain quadrangle. Gypsum beds occur locally in the upper part of the Minturn Formation south of Tombstone Gulch and west of Badger Creek. In the northwestern part of the map area a fault-bounded block of the Minturn Formation is estimated to be about 425 m thick. To the west of the map area in the Salida East quadrangle, the Minturn Formation is 550 m thick, and that thickness was used to construct cross sections.

Overlying the Minturn Formation is the Sangre de Cristo Formation, of Late Pennsylvanian and Early Permian age (De Voto and Peel, 1972). We subdivide the Sangre de Cristo Formation into five informal units in the southern Mosquito Range, and De Voto and Peel (1972) estimated that the Sangre de Cristo Formation totaled about 4,570 m thick. Member one of the Sangre de Cristo Formation is present in the northwestern corner of the Jack Hall Mountain quadrangle, but overlying members are not exposed in that area. Members one though five of the Sangre de Cristo Formation are present in the southwestern part of the Jack Hall Mountain quadrangle and these members are estimated to have a maximum thickness of about 3,500 m. Undifferentiated Pennsylvanian and Permian rock units (PIPu) are shown on the map east of Badger Creek where these rocks are metamorphosed by the Whitehorn Granodiorite. These undifferentiated units are composed of biotite-rich hornfels and metasiltite, and tan-weathering, biotite- and muscovite-bearing arkose.

Member one of the Sangre de Cristo Formation (IPsc1) is of Late Pennsylvanian age (Missourian) according to De Voto and Peel (1972) and De Voto (1980) (fig. 2). In the Jack Hall Mountain quadrangle, member one overlies the Minturn Formation on a sharp contact in which red, coarse-grained arkose of the Sangre de Cristo Formation overlie black and olive-drab shale, siltstone, fine-grained sandstone, and carbonate beds of the Minturn Formation. To the west in the Salida East quadrangle, the contact appeared to be gradational (Wallace and others, 1997), but De Voto and Peel (1972) reported that the contact was unconformable regionally. The basal member of the Sangre de Cristo Formation is composed mainly of grayish-red and reddish-gray, coarse-grained to granular arkose, subarkose, and orthoquartzite, and arkose conglomerate, and lesser amounts of dark-grayish-red and purplish-red, micaceous siltstone, and dark-red, silty, micaceous shale. Grayish-red and reddish-gray, coarse-grained arkose, pebbly arkosic conglomerate, and medium- and fine-grained arkose form composite bedding units that generally range between 60 cm and 15 m thick. Polymict conglomerate beds are generally matrix-supported and composed of subangular to subrounded, granitic, metamorphic, and sedimentary clasts. Heavy mineral placers are common in arkose. Channeled bases of these composite bedding units commonly overlie the fine-grained upper parts of fining-upward sequences. Within coarse-grained zones channeled contacts are common among multiple co-sets of crossbeds. An ideal fining-upward sequence is composed of coarse-grained, pebbly and granular arkose overlain by grayish-red beds of medium- and fine-grained arkose, siltstone, and less common red silty shale at the top. As in the Salida East quadrangle, many fining-upward sequences in the Jack Hall Mountain quadrangle are incomplete and coarse-grained basal parts of fining-upward sequences rest on medium-grained sequences where the siltstone and shale tops of the sequences were eliminated. Primary sedimentary structures in the coarse-grained rocks are large- and medium-scale trough and planar crossbeds that form multiple co-sets, channels, shale-chip conglomerates, and dispersed pebble conglomerate. In medium- and fine-grained arkose and subarkose, primary structures are predominantly small-scale trough and planar crossbeds, shallow channels, ripple cross-lamination, climbing ripples, cuspate and linguoid ripples, rib-and-furrow structures, parting lineation, and planar lamination. Primary bedding structures in siltstone and silty shale beds at the tops of fining-upward sequences are predominantly ripple cross-lamination, planar lamination, flasers, and microlamination. Secondary sedimentary structures are rare and poorly exposed. Some rare, thin lenticular beds of olive-drab, dark-greenish-gray, dark-gray, and moderate-gray, fine-grained sandstone, siltstone, and shale are interbedded with the dominant red-bed sequence in member one of the Sangre de Cristo Formation; these fine-grained intervals are generally less than 10 m thick. Dark-gray and moderate-gray beds of limestone and dolomite are interbedded with redbeds and with olive-drab and greenish-gray intervals. These carbonate beds are commonly 1 to 3 m thick and where limestone and dolomite is interbedded with red shale, siltstone, and arkose, the transition is abrupt and gradational greenish-gray beds are absent. Member one has a maximum thickness of about 610 m in the southwestern part of the map area.

Member two of the Sangre de Cristo Formation (IPsc2) is mainly a fine-grained unit composed of olive-drab, grayish-green, dark-gray, greenish-black, and black micaceous shale, siltstone, and fine-grained sandstone, and rare interbeds of moderate-gray limestone, dolomite, and gypsum. De Voto and Peel (1972) and De Voto (1980) concluded that member two is most likely Late Pennsylvanian (Virgilian) in age. Member two varies in thickness from about 55 m to about 300 m in the Jack Hall Mountain quadrangle; the thickness varies because erosion occurred before continental arkose conglomerates of member three were deposited above member two. The drastic difference in thickness is clear east and west of Badger Creek in the southern part of the map area. Siltstone and sandstone beds are generally between 2 to 30 cm thick and contain planar lamination, ripple cross-lamination, parting lineation, shallow channels, small-scale planar lamination, and water-expulsion structures. Generally the siltstone and sandstone beds are fining-upward sequences capped by silty, micaceous black shale. Limestone, dolomite, and gypsum beds occur at the base of this member, and these beds range in thickness between 30 cm and 2 m. Limestone and dolomite beds are impure argillaceous and silty micrite that is laminated or mottled. Mottled, dark-gray gypsum beds containing some silt and sand grains occur at the base of member two.

Member three of the Sangre de Cristo Formation (IPsc3) is probably Late Pennsylvanian in age (Virgilian) according to interpretations by De Voto and Peel (1972) and De Voto (1980). This unit is absent below member 4 at some places, and it has a maximum thickness of about 300 m. The thickness variation resulted from an unconformity at the base and an angular unconformity at the top. Although in the Salida East quadrangle member three had an apparent gradational contact with underlying member two, this contact is clearly an angular discordance as the contact is traced to the east in the Jack Hall Mountain quadrangle. Member three is composed of grayish-red and reddish-gray, pebbly and granular coarse-grained arkose, subarkose, and orthoquartzite interbedded with grayish-red and reddish-gray, medium- and fine-grained feldspathic sandstone and lesser amounts of dark-red, micaceous, siltstone and dark-red, silty, micaceous shale. Polymict conglomerate beds in member three are similar in composition and texture to conglomerates of member one, and bedding characteristics and primary bedding structures in member three are also similar to those of member one. Heavy mineral placers and laminations are common in arkose. Interbeds of olive-drab, dark-greenish-gray, and grayish-black fine-grained sandstone, siltstone, and shale are interbedded with the dominant red-bed sequence as in member one. Olive-drab and grayish-green, coarse-grained conglomeratic arkose is commonly associated with interbeds of olive-drab and grayish-black, fine-grained rocks. Beds of dark-gray and grayish-black limestone and dolomitic limestone, which are 1 to 2 m thick, are interbedded with grayish-red arkose, conglomerate, and siltstone, and the contacts between red clastic rocks and dark-colored carbonate rocks are abrupt.

Member four of the Sangre de Cristo Formation (PIPsc4) is probably of Early Permian age (Wolfcampian) although member four could be partly Late Pennsylvanian (Virgilian) based on interpretation of published fossil data by De Voto and Peel (1972) and De Voto (1980). This member has a maximum thickness of about 1,600 m along the south border of the map area. Member 4 overlies member three on an angular discordance and is overlain by member 5 on an angular discordance in the Jack Hall Mountain quadrangle (Pierce, 1969; De Voto and Peel, 1972). The lower part of member four is a sequence of olive-drab, grayish, green-light-gray, and moderate-gray arkose conglomerate, coarse-, medium, and fine-grained arkose, feldspathic siltstone, shale, and rare limestone beds. Fining-upward sequences dominate in coarse-grained sequences, and heavy mineral placers and laminations are common in arkose. Laminated and microlaminated argillaceous black and grayish-green siltstone and black shale form interbedded zones 2 to 20 m thick. In coarse-grained rocks primary sedimentary structures are dominated by large-scale and medium-scale planar and trough crossbeds, channels, ripple cross-lamination, cuspate and linguoid ripple marks, climbing ripples, and planar lamination that forms parting lineation. In fine-grained rocks primary sedimentary structures are ripple-cross-lamination, rib-and-furrow structures, planar lamination, microlamination, and water-expulsion structures. Locally, black shale and olive-drab siltstone contain fragments of plant fossils, and at the copper prospect in T. 49 N., R. 10 E., Section 2, location 99070, pieces of tree trunks are preserved as casts in fine-grained arkose, and tree limbs and leaves occur in dark-colored argillaceous siltstone and black shale. Conglomeratic and sandy units have coarse-grained rocks at the base, and become finer grained upward. Contacts between the upper part of a fine-grained sequence and the lower part of a coarse-grained sequence are generally channeled contacts. In the lower part of this member rare zones of redbeds are dominated by dark-red shale, siltstone, and fine-grained arkose; in the upper part of this member light-grayish red, coarse-grained and conglomeratic arkose become more common. Upward in member four of the Sangre de Cristo Formation zones of redbeds become more common, but this member is mainly a greenish-gray and gray rock unit. De Voto and Peel (1972) described abrupt lateral changes in lithofacies in the upper part of the Sangre de Cristo Formation, from about 1,800 m of boulder conglomerate in the Crestone area south of this map area, to an interbedded sequence of pebbly arkose, sandstone, siltstone, and shale in the Jack Hall Mountain quadrangle. These lithofacies changes were interpreted by De Voto

(1980) as coalesced alluvial fans in the south that grade northward into fluvial, flood-plain, lacustrine, and paludal depositional environments. The sedimentary structures and rock types are also compatible with paralic, delta channel, and delta-plain marine and brackish-water environments (Coleman and Prior, 1982).

Member five of the Sangre de Cristo Formation (Psc5) is of Early Permian age, probably Wolfcampian, but a more precise determination is not possible (Devoto and Peel, 1972). Member five is dominantly a coarse-grained redbed sequence. Only the lower part of member five is present in the map area because the Weston-Pleasant Valley fault truncates the Sangre de Cristo Formation; only about 670 m of this member occurs in the Jack Hall Mountain quadrangle. Pierce (1969) indicated that about 1,330 m of member 5 occurs to the south of this map area, and that section too, is truncated at the top by the Weston-Pleasant Valley fault. Member five is similar in composition, texture, and bedding structures to members one and three of the Sangre de Cristo Formation. This member is composed of grayish-red and reddish-gray, pebbly and granular coarse-grained arkose and subarkose interbedded with grayish-red and reddish-gray, medium- and fine-grained feldspathic sandstone and equal amounts of dark-red, micaceous siltstone and dark-red, silty, micaceous shale. Heavy mineral placers and laminations are common in arkose beds. Interbeds of olive-drab, dark-greenish-gray, and grayish-black, fine-grained sandstone, siltstone, and shale are common. Olive-drab and grayish-green, coarse-grained conglomeratic arkose is commonly associated with interbeds of olive-drab and grayish black fine-grained rocks. Fining-upward sequences dominate in coarse-grained sequences. Laminated and microlaminated, argillaceous, black and grayish-green siltstone and black shale form interbedded zones 2- to 100-m thick. Primary sedimentary structures in coarse-grained rocks are dominated by large-scale and medium-scale planar and trough crossbeds, channels, ripple cross-lamination, cuspate and linguoid ripple marks, climbing ripples, and planar lamination that forms parting lineation. Primary sedimentary structures in fine-grained rocks are ripple-cross-lamination, rib-and-furrow structures, planar lamination, microlamination, and water-expulsion structures. Locally, black shale and olive-drab siltstone contain fragments of plant fossils.

MESOZOIC ROCKS

The Whitehorn Granodiorite (Kw), of Late Cretaceous age, is the only Mesozoic rock unit in the Jack Hall Mountain quadrangle. This pluton was described by Wrucke (1974) as a large laccolith that occupies parts of the adjoining Salida East, Cameron Mountain, and Gribbles Park quadrangles (Wrucke and Dings, 1979). In the western part of the Jack Hall Mountain quadrangle the Whitehorn Granodiorite intruded the Minturn and Sangre de Cristo Formations, and intruded Early Proterozoic rocks along the eastern margin of the laccolith. Only the upper contact of the laccolith is exposed in the map area. The basal contact of the laccolith is exposed in the Salida East quadrangle where the contact dips gently eastward at about 35° (Wallace and others, 1997). Small feeder stocks that were located in the Salida East quadrangle penetrated lower and middle Paleozoic rocks west of the main body of the laccolith and these stocks have steeply dipping contacts (Wrucke and Dings, 1979; Wallace and others, 1997). Most of the Whitehorn Granodiorite is a fine- and medium-grained, equigranular and hypidiomorphic-seriate, biotite granodiorite that contains varietal hornblende and pyroxene. Biotite- and plagioclase-rich xenoliths are locally common along borders in some places. The contacts of the laccolith generally have a prominent porphyritic texture and contain plagioclase crystals, 1 to 5 mm long, in a fine-grained equigranular or aphanitic matrix. Generally, interior parts of the granodiorite are not foliated. Foliation is prominent along the border of the laccolith in the nearby Cameron Mountain quadrangle, but foliation near the border of the granodiorite is subdued in the Salida East quadrangle (Wallace and others, 1997; Wallace and Lawson, 1998). Wrucke (1974) reported a potassium-argon age of 70.0±2.6 Ma from biotite for the Whitehorn Granodiorite. McDowell (1971) reported concordant ages of 70.4±2.1 Ma from biotite and 69.4±2.1 Ma from hornblende for the age of intrusion.

TERTIARY ROCKS AND DEPOSITS

Tertiary units are mainly volcanic rocks of mafic, intermediate, and silicic composition and upper Tertiary boulder gravel. The Wall Mountain Tuff (late Eocene) is a rhyolite ash-flow tuff that occurs mainly in the western part of the map area. Silicic ignimbrites from the Thirtynine Mile volcanic field formed the Badger Creek Tuff (late Eocene). Latite flows of Oligocene? age locally overlie the Badger Creek Tuff in the east-central part of the map area. The Gribbles Park Tuff (early Oligocene) is a densely welded rhyolite ash-flow tuff that occurs in the northeastern part of the Jack Hall Mountain quadrangle. Latite of Waugh Mountain (Miocene) formed flows and flow breccia above the Gribbles Park Tuff. The andesite of Waugh Mountain (Miocene) is an assemblage of andesite and basalt flows that is exposed in the east-central part of the quadrangle.

After about 36 Ma rhyolitic ash-flow tuffs were erupted from west of the map area, and basalt and rhyolite were erupted from the Thirtynine Mile volcanic field northeast of the Gribbles Park quadrangle. The Wall Mountain Tuff was erupted from the southern Sawatch Range northwest of Salida, Colorado, (Chapin and Lowell, 1979) at 36.64±0.06 Ma (McIntosh and Chapin, 1994) and the ash-flow tuff flowed over a pre-existing topography that filled the Gribbles Run paleovalley (Chapin and Lowell, 1979), which drained from west to east across the northern part of the map area in Early Oligocene time. This paleovalley was part of a larger drainage system that trended east and southeast, according to Chapin and Lowell (1979). Eruptive activity from the Thirtynine Mile volcanic field produced the Badger Creek Tuff at 34.35±0.09 Ma (McIntosh and Chapin, 1994). Latite flow rocks of probable Oligocene age are preserved in the Waugh Mountain paleovalley, but correlation is uncertain between these flow rocks and units younger than the Badger Creek Tuff (Wrucke and Dings, 1979). The Gribbles Park Tuff erupted from the Thirtynine Mile volcanic field at 32.76±0.14 Ma (McIntosh and Chapin, 1994). The latite of Waugh Mountain was erupted during Miocene time as flows and flow breccias from the Waugh Mountain volcanic center 9 km east of the Jack Hall Mountain quadrangle (Epis and others, 1979a). Andesite and basalt flows of Waugh Mountain were erupted during Miocene time from the Waugh Mountain volcanic center at about 19 Ma (Epis and Chapin, 1974).

The Wall Mountain Tuff (Twm) is of late Eocene age and it is the oldest Tertiary volcanic unit exposed in the Jack Hall Mountain quadrangle (Epis and Chapin, 1974). The Wall Mountain Tuff is a welded rhyolite ash-flow tuff exposed in the northern part of the quadrangle. The tuff is predominantly eutaxitic in texture and is moderately to densely welded, although no pattern in the distribution of different degrees of welding was determined from our mapping. The degree of welding varies from pumice-rich flow bands to densely welded glassy tuff. The welded tuff is mostly light-gray, moderate-gray, light-brownish-gray, and grayish-red rhyolite that contains prominent sanidine and plagioclase phenocrysts (Epis and Chapin, 1974). McIntosh and Chapin (1994) reported an argon^{40}/argon^{39} age of 36.64±0.06 Ma for the Wall Mountain Tuff. Flow foliation in glassy welded tuff is prominent at some places. Chapin and Lowell (1979) identified the caldera source of the Wall Mountain Tuff in the southern part of the Sawatch Range, northwest of Salida, Colorado. Chapin and Lowell (1979) described primary and secondary deformation structures from the Wall Mountain Tuff in the Gribbles Run paleovalley where this glassy tuff formed a single cooling unit that slid and folded into the paleovalley as the plastic and mobile tuff degassed and compacted. Folds occur in the Wall Mountain Tuff in the Salida East quadrangle (Wallace and others, 1997), but structures described by Chapin and Lowell (1979) were not mapped in the Jack Hall Mountain quadrangle. Regionally the thickness of the Wall Mountain Tuff varies markedly, and it has a maximum thickness of more than 150 m (Epis and Chapin, 1974). The thickness of this unit was not estimated in the Jack Hall Mountain quadrangle because elevation control is absent for the topographic surface over which the Tuff flowed, and the top is always erosional.

The Badger Creek Tuff is Oligocene in age, and regionally this formation consists of a nonwelded tuff member (Tbcn) and a welded tuff member (Tbc). Both units are widespread in the northern and eastern parts of the Jack Hall Mountain quadrangle where they filled the Gribbles Run paleovalley (Chapin and Lowell, 1979).

The welded tuff member is a light-gray, light-yellowish-gray, and light-reddish-gray quartz latite welded tuff. This tuff contains abundant biotite and plagioclase phenocrysts and lesser amounts of sanidine and hornblende phenocrysts. Light-pink and light-grayish-white pumice and lapilli and lithic fragments are abundant, and the welded tuff is weakly foliated. The thickness of the welded tuff is difficult to estimate because the topographic relief of the surface below the welded tuff cannot be determined; however, the welded tuff is at least 180 m thick and could be 300 m thick in the northwestern part of the map area. An $argon^{40}/argon^{39}$ age on the Badger Creek welded tuff of 34.35 ± 0.09 Ma was obtained by McIntosh and Chapin (1994).

The nonwelded tuff member is a white, light-grayish-white, and light-gray, ash-flow and air-fall tuff that forms prominent hoodoos and easily eroded cliffs. Although most of the unit is nonwelded ash-flow tuff, some slightly welded and moderately welded flow units occur locally in the upper part of the nonwelded tuff member. The nonwelded tuff is composed of multiple flow units that are interbedded with air-fall tuff. As in the welded tuff, abundant volcanic rock fragments are a distinguishing feature of this unit. A common thickness of the nonwelded member of the Badger Creek Tuff is about 75 m in the Jack Hall Mountain quadrangle, but this member could be as thick as 120 m in the map area. The non-welded tuff member is about 90 m thick to the south in the Salida East quadrangle (Wallace and others, 1997). The nonwelded tuff member is the same age as the welded tuff member.

The latite of East Badger Creek (Tl) of Wrucke and Dings (1979) is probably Oligocene? in age (Lowell, 1971, p. 216). This unit is a dark-greenish-gray and blackish-gray porphyry that contains prominent phenocrysts of plagioclase and sanidine, and a trace of olivine and pyroxene phenocrysts in a glassy, dense matrix. Lowell (1971) reported that plagioclase comprised 10 percent of the latite and sanidine accounted for about 8 percent. Lava flows of latite appear to have been confined to the area of the Gribbles Run paleovalley in the northern part of the map area where this unit is about 75 m thick. Latite flows overlie the Badger Creek Tuff. Columnar jointing is prominent in cliffs of latite on the north side of East Badger Creek, and flow breccia is locally common.

Gribbles Park Tuff (Tgp) is Oligocene in age (Epis and Chapin, 1974) and consists of ash-flow tuffs composed of moderate-gray, light-gray, pinkish-gray, brownish-gray, and reddish-gray rhyolite porphyry. Phenocrysts are quartz, chatoyant sanidine, and biotite. Chatoyant sanidine is a distinguishing feature of this unit. Volcanic rock fragments are common. Compound cooling units form moderately to densely welded, glassy tuff. The Gribbles Park Tuff overlies the Badger Creek Tuff in the eastern and northern part of the Jack Hall Mountain quadrangle. According to Epis and Chapin (1974, p. 18) the Gribbles Park Tuff contains 15–30 percent phenocrysts, of which sanidine forms 40 to 70 percent, plagioclase (andesine) forms 10 to 25 percent, and biotite and opaque minerals form 5 to 20 percent. Pyroxene, hornblende, and sphene are present in trace amounts (Epis and Chapin, 1974, p. 18). This ash-flow tuff has an $argon^{40}/argon^{39}$ isotopic age of 32.90 ± 0.08 Ma (McIntosh and Chapin, 1994). The type locality is north of the map area in the Gribbles Park quadrangle in W½ sec. 16 and E½ sec. 17, T. 51 N., R. 11 E. (Epis and Chapin, 1974). Thickness at the type locality is about 100 m (Epis and Chapin, 1974), and in the Jack Hall Mountain quadrangle about 50 m of the tuff is exposed.

The latite of Waugh Mountain (Twl), of Miocene age (Epis and Chapin, 1979a), is exposed at high elevations in the eastern part of the Jack Hall Mountain quadrangle. This unit is a light-gray, moderate-gray, and light-pinkish-gray flow breccia and flow rock that is sanidine and plagioclase rich; biotite and hornblende phenocrysts occur in minor amounts in a glassy matrix (Epis and Chapin, 1979a). Flow breccias are prominent in the lower part of the latite. Lowell (1969) reported that this latite contains 10 to 20 percent phenocrysts of plagioclase, sanidine, and biotite in a glassy matrix. Trace amounts of hornblende and sphene occur in this unit. This unit overlies the Gribbles Park Tuff.

The andesite of Waugh Mountain (Twa) is of Miocene age (Epis and Chapin, 1974; Epis and others, 1979a). This unit is a dark-gray, greenish-black, and dark-greenish-brown andesite and basalt. The unit occurs at high elevations in the east-central part of the Jack Hall Mountain quadrangle where it overlies the latite of Waugh Mountain. Andesite and basalt of this unit is composed of vesicular and non-vesicular flow breccia and dense flow rock that consists of small plagioclase phenocrysts in a matrix of glass and a felted intergrowth of plagioclase microlites. Phenocrysts of pyroxene and plagioclase are common in basalt flows and flow breccia, and olivine and hornblende are less common as phenocrysts (Epis and Chapin, 1974). Epis and Chapin (1974, p. 21) reported a potassium-argon whole-rock age of about 18.9±0.2 Ma for this unit, but they noted that similar appearing andesitic clasts in conglomerate of Fear Creek yielded ages of about 26 to 28 Ma. Alluvial gravel (Tg) is probably of Pliocene age, and it occurs at high elevations northwest of Little Baldy Mountain and in the southern part of the map area north of Little Badger Creek and west of Badger Creek. Tertiary gravel deposits are preserved as isolated remnants of previously more extensive deposits. These deposits occur at elevations of about 9,500 ft (2,900 m) and 8,100 ft (2,500 m). Tertiary gravels are composed of rounded and well-rounded boulders and cobbles of Proterozoic, Paleozoic, and volcanic rocks in a sandy and silty matrix.

QUATERNARY DEPOSITS

Quaternary units are mainly pediment and terrace deposits, talus, eolian deposits, landslide debris, and colluvial and alluvial deposits. The oldest Quaternary units occur at the highest elevations and younger units occur at successively lower elevations. A large landslide deposit was mapped in the east-central part of the map area. Rare eolian deposits of loess occur in some drainages, and a few discontinuous deposits of outwash occur in Tombstone, Mayflower, and Hells Hole Gulches. Deposits of colluvium and alluvium formed in modern drainages during late Quaternary time and these deposits consist of gravel, sand, silt, and clay. Our nomenclature for Quaternary deposits in the Jack Hall Mountain quadrangle uses a relative time scale suggested by R.M. Kirkham (Colorado Geological Survey, written commun., 1997). According to Kirkham a purely relative scale is best applied to surficial deposits in terraces in the map area, because correlation of surficial deposits to continental glacial events, as reported by Wrucke and Dings (1979), requires more detailed study than has been accomplished for this report.

Pleistocene pediment deposits are composed of poorly stratified sand and silt that contain matrix-supported boulders, cobbles, and pebbles. Pediment surfaces and terrace remnants reach elevations of about 9,600 ft in the eastern part of the map area. Clasts are composed of quartz monzonite, granodiorite, metamorphic rocks, quartzite, cherty dolomite, red and olive-drab sandstone and siltstone, welded tuff, and vein quartz. Gravel composition reflects a strong local provenance. Wrucke and Dings (1979) mapped only one pediment unit, Qsp1, in the area of the Jack Hall Mountain quadrangle, whereas we show three pediments in this map area. The terminology used in the Jack Hall Mountain quadrangle is the same as that used in the Gribbles Park quadrangle (scale 1:24,000). Pediment deposit three (Qp3) in the Jack Hall Mountain quadrangle is equivalent to Qsp2 mapped by Wrucke and Dings (1979) in the Herring Park area of the Gribbles Park quadrangle; and pediment deposit two (Qp2) in the Jack Hall Mountain quadrangle is equivalent to Qsp1 mapped by Wrucke and Dings (1979) in the Herring Park area of the Gribbles Park quadrangle. Pediment deposit one (Qp1) in the Jack Hall Mountain quadrangle is equivalent to Qv of Wrucke and Dings (1979) of the Gribbles Park quadrangle, which they equated to the Verdos Alluvium formed during the Yarmouth interglacial stage or the Kansan glaciation.

Pediment deposit one (Qp1) is the highest and oldest of the pediments in the Jack Hall Mountain quadrangle and the pediment is composed of poorly stratified gravel of pebbles, cobbles, and boulders in a silty and sandy matrix. This pediment is Pleistocene in age. Clasts exhibit a strong local provenance, and north of Little Badger Creek boulders are composed mainly of Proterozoic quartz monzonite (Xqm). Clasts are rounded to subrounded. A grayish-red, grayish-brown, and red-brown soil marks the upper surface of the pediment at some places; boulders, cobbles, and pebbles are weathered, and commonly clasts have caliche on the surface. At many places in the map area matrix sand and silt has been eroded and a jumbled boulder field remains at the pediment surface. The upper surface of this pediment is about 60 m above the modern stream in Badger Creek. Remnants of this pediment deposit reach an elevation of about 8,000 ft in the southwestern part of the map area, and 10,000 ft at the eastern border of the map area. Correlative deposits were mapped as Qp1 in the Cameron Mountain quadrangle (Wallace and Lawson, 1998) and Gribbles Park quadrangle (Wallace and others, 1999), as T2 in the Salida East quadrangle (Wallace and others, 1997), and as Qv by Wrucke and Dings (1979).

Pediment deposit two (Qp2) is preserved as mid-level terraces and pediment remnants in the Badger Creek drainage, and these deposits extend northward into the Gribbles Park quadrangle where they form extensive remnants of pediment deposits. This pediment deposit is of Pleistocene age and is composed of poorly stratified sand and silt that contains matrix-supported boulders, cobbles, and pebbles. Boulders are rounded, subrounded, and subangular. The upper surface is about 15 m above alluvium and colluvium in adjacent drainages. Correlative deposits were mapped as Qp2 in the Cameron Mountain and Gribbles Park quadrangles (Wallace and Lawson, 1998; Wallace and others, 1999), grouped with T3 by Wallace and others (1997) in the Salida East quadrangle, and mapped as Qsp1 by Wrucke and Dings (1979). Wrucke and Dings (1979) suggested these deposits formed during the Yarmouth interglacial stage or the Kansan glaciation.

Pediment deposit three (Qp3), of Pleistocene age, is preserved as the lowest of the terraces in the Badger Creek drainage. This lower level terrace extends northward into the Gribbles Park quadrangle where it connects to the lowest level of a regional pediment. This pediment is composed of poorly stratified sand and silt that contains matrix-supported boulders, cobbles, and pebbles. Boulders are subrounded to angular and as large as 0.5 m in diameter. The upper surface is 3 to 9 m above alluvium and colluvium in adjacent drainages. Correlative deposits were mapped as T3 in the Salida East quadrangle (Wallace and others, 1997) and as Qp3 in the Cameron Mountain and Gribbles Park quadrangles (Wallace and Lawson, 1998; Wallace and others, 1999).

Quaternary outwash deposits are likely of late Pleistocene age, and rare outwash deposits occur in lower Tombstone and Mayflower Gulches, and in an unnamed tributary in the drainage of Hells Hole Gulch in the western part of the Jack Hall Mountain quadrangle. Outwash deposits are interstratified layers of rounded elongate cobbles and boulders in a sandy matrix and crossbedded and planar laminated pebbly sand, and lenticular and planar beds of sand. Shallow channels occur at the base of coarse beds. Small Pleistocene glaciers on the east side of Big Baldy Mountain (Wallace and others, 1997) discharged meltwater down Tombstone Gulch.

Landslide deposits (Qls) are of Holocene and Pleistocene? age. Small landslide deposits occur widely scattered in the Jack Hall Mountain quadrangle, but an extensive landslide deposit occurs in volcanic rocks in the east-central part of the map area. This landslide is composed of clasts of Proterozoic granodiorite, Gribbles Park Tuff, latite of Waugh Mountain, and andesite of Waugh Mountain. This mass failure deposit is a heterogeneous mass of unsorted, non-stratified rock debris, gravel, sand, and silt that has a hummocky surface dotted with local ponds and swamps.

Quaternary eolian deposits (Qes) are probably Holocene and probably Pleistocene in age, and occur mainly in the southern part of the quadrangle. These light-tan, tan, and grayish-light-brown deposits are composed of a mixture of silt and very fine- to fine-grained sand. Rare angular pebbles occur as isolated clasts; most likely these pebbles were emplaced as sheet wash. A thin layer of eolian silt and sand overlies alluvium and colluvium and pediment deposits at many places, but these eolian deposits are too thin and laterally discontinuous to show on the map. Eolian deposits clearly postdate formation of alluvial and colluvial deposits.

Older alluvial deposits (Qao), of probable early Holocene and late Pleistocene age? occur in fans along Badger Creek in the northern part of the quadrangle. The older alluvium is composed of nonconsolidated, interbedded layers of silty clay, clayey silt, silt, silty sand, sand, and pebble, cobble, and boulder gravel. Boulders and cobbles are commonly angular and subangular. The alluvium forms prominent fan-shaped deposits where tributaries join Badger Creek. Older alluvial deposits predate alluvium and colluvium deposits (Qac) in Badger Creek.

Talus (Qta) occurs as isolated patches in the central part of the map area, and these masses of angular rock debris are probably of Holocene age. On the south-facing cliff north of East Badger Creek, prominent talus deposits formed below Tertiary latite flows. Talus formed below cliffs of metamorphosed volcanic and sedimentary rocks south of East Badger Creek. Other talus deposits occur in Badger Creek drainage in exposures of the Whitehorn Granodiorite and in Early Proterozoic quartz monzonite. Talus is composed of angular boulders and cobbles that range up to 4 m in diameter.

Alluvium and colluvium (Qac) is of Holocene age, and is common in most drainages where Wrucke and Dings (1979) showed only alluvial deposits. In active stream channels, alluvium consists of nonconsolidated, interbedded, lenticular layers of poorly sorted, matrix- and framework-supported boulder, cobble, and pebble gravel deposits containing rounded, sub-rounded, and sub-angular clasts in a matrix of pebbles, sand, silt, and clay. Stratification is generally crude. Modern streams contain numerous abandoned channels that are 1 to 2 m above active braided channels, and modern stream channels are incised 1 to 5 m into interlayered alluvium and colluvium that is composed of tan and grayish-yellow-brown, fine-grained, nonconsolidated sediment and interbedded lenses of matrix-supported to clast-supported, angular cobbles and pebbles in a clayey and sandy matrix. Interlayered alluvium and colluvium is crudely stratified. Some lenses of coarse sediment in the interlayered alluvial and colluvial deposits are channel gravels that contain crossbeds and planar bedding.

STRUCTURE

The principal structures in the map area are steeply dipping normal faults that trend north, northwest, northeast, and east, and local anticlines and synclines. Most faults dip steeply and offset Proterozoic and Paleozoic rocks. The Weston-Pleasant Valley fault strikes generally north-south in the central and western part of the map area, and the fault continues into the Gribbles Park quadrangle. The Whitehorn Granodiorite stoped the Weston-Pleasant Valley fault in the central part of the map area, and volcanic rocks cover much of north part of that fault. At the northernmost extent of the Weston-Pleasant Valley fault a series of normal faults flank the main fault, and these normal faults form a negative flower structure, which suggests that the Weston-Pleasant Valley fault had a component of strike-slip separation. In Badger Creek a covered northeast-trending fault is probably an oblique reverse fault that may have been active during slip on the Weston-Pleasant Valley fault. East-west and north-south striking faults of small separation offset Pennsylvanian and Permian strata; these faults post-date northwest- and southeast-trending anticlines and synclines in late Paleozoic strata

STRUCTURAL SETTING

The Jack Hall Mountain quadrangle is located in the southern part of the Central Colorado Trough of De Voto (1972), which is synonymous with the southern part of the "Colorado Sag" as described by Ross and Tweto (1980). Regionally, bounding faults of the Central Colorado Trough trend north-northwest, but the segment of the Weston-Pleasant Valley fault in the Jack Hall Mountain quadrangle strikes mainly northward.

Many of the northwest- and north-trending faults in this region originated in Early and

Middle Proterozoic time. The orientation of the faults in lower and upper Paleozoic strata may have been controlled by rejuvenated slip on these older faults. Many of these faults produced highlands adjacent to shallow basins (Tweto, 1980) and these faults controlled erosion and sedimentation since Proterozoic time (Tweto, 1980; Ross and Tweto, 1980).

The main regional tectonic elements that influenced sedimentation during Paleozoic time are: (1) the Sawatch anticline of De Voto (1972), which is located west of the map area; (2) the Colorado Front Range and the Apishapa highlands to the east (Ross and Tweto, 1980), which are equivalent to the Front Range and Wet Mountains anticlines of De Voto (1972); (3) the Uncompaghre and San Luis Valley uplifts to the southwest (De Voto, 1972; Ross and Tweto, 1980); and (4) the Central Colorado Trough, which extended northwest between the Uncompaghre uplift to the southwest and the Front Range-Apishapa uplift to the northeast (De Voto, 1972). During the period 70 to 36 Ma (Maastrichtian to Rupelian Age) sedimentary, metamorphic, and plutonic rocks in the map area were uplifted and the southern part of the Central Colorado Trough, which received a large volume of sediment during late Paleozoic time, became a source area for sediment during early Tertiary time. After emplacement and crystallization of the Whitehorn Granodiorite, which presumably was emplaced at shallow depth, uplift initiated erosion of rock units in the map area.

FAULTS

The principal fault in the Jack Hall Mountain quadrangle is the Weston-Pleasant Valley fault, which extends from the south-central border of the map area to the western quadrant of the map area. This fault is covered for most of its trace by the andesite of Waugh Mountain, the Badger Creek Tuff, and by nonconsolidated Quaternary deposits. In the central part of the Jack Hall Mountain quadrangle the Weston-Pleasant Valley fault juxtaposes undifferentiated metamorphosed Pennsylvanian and Permian rocks against lower Paleozoic rocks. At the northern border of the map area the Weston-Pleasant Valley fault forms a complex of normal faults that juxtaposes Early Proterozoic crystalline rocks, the Manitou Formation, Harding quartzite, and Sharpsdale and Minturn Formations. At the southern boundary of the adjoining Gribbles Park quadrangle this segment of the Weston-Pleasant Valley fault was shown in cross section B-B′ as a series of steep normal faults, but mapping farther south in the Jack Hall Mountain quadrangle suggested that the southernmost fault curved toward the main segment of the fault where this array of faults merged with the main fault. As shown in cross section A-A′, this set of faults appears to form what has been called a negative flower structure by Harding (1985). Restorations that would show slip directions across the Weston-Pleasant Valley fault are unconstrained because similar rock units do not occur on opposite sides of the fault.

The Badger Creek fault is a north-northeast-trending fault in the southwestern quadrant of the Jack Hall Mountain quadrangle in Badger Creek; the fault is covered by Quaternary deposits. The trace of the Badger Creek fault is tightly constrained by differently oriented and offset members of the Sangre de Cristo Formation. The northward offset of members of the Sangre de Cristo Formation suggests oblique slip on the Badger Creek fault which moved the west block to move up and to the right.

In the southwestern part of this map area east-west striking faults offset the Minturn Formation and member one of the Sangre de Cristo Formation, and a north-south striking fault offsets members two and three of the Sangre de Cristo Formation; all of these faults are of small separation.

FOLDS

Most folds in the Jack Hall Mountain quadrangle are medium-scale structures that deform Paleozoic rocks. In the area of Jack Hall Mountain a gentle syncline trends north-south and deforms lower Paleozoic rocks.

In the southwestern quadrant of this map area, medium-scale, northwest- and southeast-plunging anticlines and synclines occur in upper Paleozoic rocks; the most prominent of these folds are labeled one through three on the geologic map. Fold one is a syncline that deforms members three and four of the Sangre de Cristo Formation. This fold, which trends at 100° and 280° azimuth, terminates against a normal fault at the west end and plunges gently toward the southeast. Fold one cannot be traced east of Badger Creek. The age of folding post-dates member four of the Sangre de Cristo Formation, but the time relations of folding to member five cannot be determined. Fold two is an anticline that trends at 125° and 325° azimuth and plunges gently to the southeast. The northwestern end of the fold is stoped by the Whitehorn Granodiorite, and the contact of the laccolith appears to be parallel to adjoining sedimentary rock units where the granodiorite intruded folded rocks. The nose of this anticline bends to the south near the Badger Creek fault, and it may terminate against the fault. Fold 3 is a syncline that trends at 120 and 330 azimuth and plunges toward the southeast. Like fold two, this syncline is stoped by the Whitehorn Granodiorite, and the contact of the laccolith appears to be parallel to adjoining sedimentary rock units where the laccolith intruded the syncline. The axis of this syncline also appears to bend to the south near the Badger Creek fault.

Locally overturned upper Paleozoic rocks occur west of the Weston-Pleasant Valley fault in the northwestern part of the map area, but folds cannot be reconstructed in these overturned sections.

INTERPRETATION OF STRUCTURES

Our interpretation of minor faults along the Weston-Pleasant Valley fault suggest that this fault had a lateral component of slip. In addition, slip on principal faults during deposition of the Pennsylvanian and Permian succession in the Jack Hall quadrangle produced stratigraphic sequences and unit thickness that are unique to specific fault blocks.

Analysis of slip direction and amount of slip cannot be determined from the scale of our mapping because similar rocks on opposite blocks of the Weston-Pleasant Valley fault are absent, but Pierce (1969) and De Voto and Peel (1972) indicated that normal slip, up on the east block, accommodated about 3,000 m of coarse-grained sediment in the region of this map area. Our mapping suggests that a component of strike-slip motion affected the Weston-Pleasant Valley fault because negative flower structures are associated with strike-slip motion on divergent wrench faults as indicated by Harding (1985) and by Harding and others (1985). Divergent wrench faults occur in extensional and contractional continental settings (Harding and others, 1985). The period of strike-slip and normal slip on this northern segment of the Weston-Pleasant Valley near the negative flower structure post-dates deposition of the Minturn Formation (Middle Pennsylvanian) and pre-dates intrusion of the Whitehorn Granodiorite (Late Cretaceous), which stopes the fault in the region of Badger Creek. This strike-slip motion could have accompanied normal slip on the Weston-Pleasant Valley fault during deposition of the Sangre de Cristo Formation to produce the thick sequence of clastic sediment during Pennsylvanian and Permian time, or strike-slip motion could have occurred during the period Permian to Late Cretaceous.

Adjacent fault blocks in the southwestern part of the Jack Hall quadrangle show markedly different depositional and erosional histories, which were governed by slip on the Weston-Pleasant Valley fault and on the Badger Creek fault. On the fault block west of the Badger Creek fault, folds grew during deposition of the Sangre de Cristo Formation, as documented by Pierce (1969) and De Voto and Peel (1972). Our mapping west of Badger Creek shows that several members of the Sangre de Cristo Formation thin over the crest of fold two, the anticline. Our member two of the Sangre de Cristo Formation thins toward the axis of the anticline shown as fold two, but the initial folding event of this anticline post-dates deposition of member two because this member does not show coarsening of lithofacies proximal to the nose of the fold. The unconformity at the top of member two reflects post-depositional erosion over the nose of the anticline. The anticline continued to grow during deposition of the Sangre de Cristo Formation because member three is truncated below member four near the axis of this anticline, and like lithofacies relations of member two, member three shows no obvious coarsening in the direction of the crest of the anticline. Member three was eliminated by erosion below member four on the southwestern flank of the anticline after deposition of member three, so that member four locally overlies member two of the Sangre de Cristo Formation west of the Badger Creek fault.

On the fault block east of the Badger Creek fault and west of the Weston-Pleasant Valley fault, the depositional and erosional history were clearly different from the fault block west of the Badger Creek fault, and these differences reflect slip on the bounding faults during Pennsylvanian and Permian time. East of the Badger Creek fault, folds that produced erosional boundaries between members two and three of the Sangre de Cristo Formation did not develop during Virgilian time as on the fault block west of the Badger Creek fault. East of the Badger Creek fault a thick sequence of member two and three was deposited during the same period that thin, unconformity-bounded members two and three were deposited west of that fault. Directly east of the Badger Creek fault member three of the Sangre de Cristo Formation is again present below member four. On the fault block east of the Badger Creek, member four successively truncated members three, two, and one of the Sangre de Cristo Formation toward the northeast, and member five truncates member four toward the northeast on that fault block. Thinning of member four of the Sangre de Cristo Formation could have resulted from a slower sedimentation rate near the Weston-Pleasant Valley fault or from erosion of member four before deposition of member five; either cause of the thinning trend of member four suggests concomitant slip on the Weston-Pleasant Valley fault.

The different structural and depositional histories of blocks east and west of the Badger Creek fault indicate that the oblique and up-on-the-west slip on that fault occurred during Pennsylvanian to Permian time and caused local compression. The upward oblique slip of the west block may have been responsible for growth of the folds during Virgilian and possibly Wolfcampian time. This event of right-lateral oblique slip on the Badger Creek fault probably caused southward deflection of the axial traces of fold two and fold three after the folds formed. The relations of fold one, the syncline, to slip on the Badger Creek fault is not clear.

The period of slip on the Badger Creek fault was probably coincident with slip on the Weston-Pleasant Valley fault. The local compressional folds and the contractional oblique reverse slip on the Badger Creek fault are compatible with normal and strike-slip motion on the Weston-Pleasant Valley fault in a tectonic setting of divergent wrench faults (Harding and others, 1985).

Regionally, periods of slip on the Weston-Pleasant Valley fault have been documented from pre-Pennsylvanian and Middle and Late Pennsylvanian to early Permian. In the Antero quadrangle to the north of this map area, De Voto (1971) showed that rocks of the Maroon Formation (Des Moinesian age, Middle Pennsylvanian) overlie Proterozoic rocks east of the fault that bounded the west side of the Ancestral Front Range; this fault is presumably the northern extension of the Weston-Pleasant Valley fault. These geologic relations suggest a period of erosion before Middle Pennsylvanian time on the highland east of the bounding fault of the Ancestral Front Range while the Kerber, Belden, and lower Maroon Formations were being deposited west of the Ancestral Front Range in the Central Colorado trough (De Voto, 1971). Similarly, east of the Weston Pleasant Valley fault in the Jack Hall Mountain quadrangle, the absence of the Chaffee and Leadville Formations could have resulted from the period of pre-Middle Pennsylvanian identified by De Voto (1971). In the southwestern part of the Jack Hall Mountain quadrangle, different depositional and tectonic histories of fault blocks adjacent the Weston-Pleasant Valley fault record slip on that fault during Middle Pennsylvanian to Early Permian time. Apparently the Weston-Pleasant Valley fault was not active after Late Cretaceous time because the Whitehorn Granodiorite is not offset by the fault, nor can fracture zones be traced along the probable extension of this fault in the Badger Creek area. Elsewhere in the Jack Hall Mountain quadrangle Oligocene volcanic rocks of the Badger Creek Tuff are not offset by the fault, and in the adjoining Gribbles Park quadrangle to the north the Weston-Pleasant Valley fault was not active after Oligocene time because the fault is covered by deposits of the Antero Formation that show no offset. The influence of north- and northwest-striking faults on Laramide tectonism in the Jack Hall Mountain quadrangle is not known because Mesozoic sedimentary rocks are absent.

METALLIC MINERAL RESOURCES

PROTEROZOIC ROCK UNITS

Mineral occurrences in the Jack Hall Mountain quadrangle consist of metallic vein and replacement deposits in Proterozoic rocks, stratabound deposits in Proterozoic and Paleozoic rocks, and industrial mineral deposits of gypsum. Mineral resource potential of these mineral occurrences has not been evaluated as part of this project, but the mineral occurrences identified in the quadrangle are discussed briefly.

VEIN AND REPLACEMENT MINERAL DEPOSITS

Quartz veins hosted by Early Proterozoic gabbro (Xg) occur at the Copperhead Mine north of Two Creek in the north-central part of the Jack Hall Mountain quadrangle. These quartz veins are probably of Early Proterozoic age. Numerous adits, shafts, and test pits expose veins for short distances. The absence of deep shafts and adits suggests that the veins are discontinuous at depth. Most veins trend northeast, are steeply dipping, and are from 0.3 m to 1 m thick. Veins contain malachite where they are oxidized, chalcopyrite on fresh surfaces, and locally biotite. At the Copperhead Mine sample 99JC04 of vein material yielded 20,665 ppm (parts per million) copper, 7.4 ppm silver, and 7.67 ppm gold; a second sample at the same locality yielded 68,849 ppm copper, 3.6 ppm silver, and 0.098 pppm gold (Table 1).

The Cooper Mine in sec. 30 T. 50 N., R. 11 E. is another quartz vein deposit hosted by the Early Proterozoic gabbro. A sample here, number 99084.5, of the vein material yielded geater than 10 percent copper, 6.4 ppm silver, and 0.151 ppm gold (Table 1).

STRATABOUND ROCK OCCURENCES

One occurrence of possible stratabound mineralization was located at sample locality 99125 where malachite stains occur in a metasiltstone of the Proterozoic metavolcanic and metasedimentary unit. Non-foliated metasiltstone is interlayered with well-foliated biotite schist, but the lateral extent of mineralized rock is not known because exposures are poor. This sample contains concentrations of copper and manganese that are anomalously high, but the concentration of copper is significantly lower than high copper anomalies associated with Phanerozoic stratabound copper deposits (Table 1). Other elements do not show prominent anomalous concentrations.

PALEOZOIC ROCK UNITS

STRATABOUND ROCK OCCURENCES

Disseminated stratabound mineral deposits have been identified in upper Paleozoic rocks in the map area. These deposits resemble "red-bed" copper-uranium or copper-silver occurrences that are widespread in the western United States in rocks ranging in age from Middle Proterozoic to Cretaceous (Kirkham, 1989; Harrison, 1972; Connor and McNeal, 1988; Lindsey and Clark, 1995; Thorson and Hahn, 1995). Occurrences of highly anomalous amounts of copper, silver, zinc, barium, and manganese were identified from grab samples from the Sangre de Cristo Formation in the map area (Table 1). The stratabound mineralized zones occur in chemically reduced zones of fine- and coarse-grained arkose, black shale beds, dark-gray siltstone, and carbonized plant remains adjacent to fine- and coarse-grained, chemically oxidized beds. Mineralized zones are commonly several meters thick. Stratabound mineral deposits occur mainly in rocks deposited in nearshore marine, deltaic, and paludal environments. Oxidizing fluids carrying dissolved metals moved through adjacent coarse-grained rocks deposited in fluvial, deltaic, and alluvial environments.

The most extensive areas of stratabound mineralization in the Jack Hall Mountain quadrangle occur at the angular unconformity between member three and member four in the Sangre de Cristo Formation where two lenses of sulfide mineralization were identified during this study. Mineralization in the Sangre de Cristo Formation occurs in chemically reduced rocks above the angular unconformity where reduced conglomeratic arkose, fine-, medium-, and coarse-grained arkose, feldspathic siltstone, and black shale overlie grayish-red, conglomeratic arkose, fine- medium-, and coarse-grained arkose, feldspathic siltstone, and dark-red shale. Sulfides were preferentially precipitated on carbonized plant remains and in black shale in reduced rocks. Rock samples commonly show secondary hydrous copper-carbonate minerals on weathered surfaces. Nonweathered rock contains silt-sized grains of pyrite, chalcopyrite, chalcocite, and bornite.

Table 1. Geochemical analyses of mineral occurrences in the Jack Hall Mountain quadrangle. Analyses by Cone Geochemical, Inc., Lakewood, Colorado. All analyses by total digestion inductivity coupled plasma method. All concentrations in parts per million (ppm) except oxides and sulfur, which are in percent.

Sample Number	Au	Ag	As	Cd	Co	Cu	Hg	Pb	Sb	Zn	Mo	Ni	B	Be	Li	Mn	P
96788	<.001	<0.2	<1	<0.5	<1	71	0.03	<10	<1	44	4	<1	<1	<1	3	4,246	88
99023	0.008	0.8	8	0.0	5	41	0.10	12	<1	652	7	8	13	3	16	123	397
99034	0.001	<0.2	<1	<0.5	5	19	0.02	<10	<1	12	1	5	8	<1	8	6,181	352
99048	0.098	3.6	<1	<0.5	33	60,243	0.20	<10	<1	124	32	31	10	6	21	585	1,175
99070	<.001	152.7	<1	<0.5	9	68,849	1.84	16	<1	50	9	8	6	2	12	1,315	552
99125	0.036	0.5	2	<0.5	9	1,112	0.04	<10	<1	62	5	4	5	2	19	2,245	<10
98207	0.007	1.1	18	<0.5	19	214	0.11	20	<1	36	14	18	16	2	16	373	487
99213	0.002	5.3	<4	<0.5	10	15,192	0.29	<10	<1	28	4	9	10	1	10	389	248
99JCO4	7.67	7.4	19	<0.5	84	20,665	0.48	123	<1	167	10	231	4	1	9	201	98
99JCO5	2.35	3.7	<1	<0.5	41	2,808	0.05	<10	<1	90	15	41	<1	2	3	334	23
99045.5	0.287	8.2	7	<0.5	87	49,707	0.14	27	<1	68	37	81	14	1	13	1,298	791
99045.6	0.376	5.2	4	<0.5	63	36,251	0.10	23	<1	59	22	68	12	1	15	1,111	939
99084.5	0.151	64	7	<0.5	121	>10%	0.03	<10	<1	286	104	191	4	<1	2	127	96

Table 1. Continued.

Sample Number	Sr	V	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	BaO	TiO_2	ZrO_2	S
96788	119	25	4.7	0.41	1.15	30.71	19.01	0.19	0.15	0.650	0.005	0.02	0.002	0.06
99023	76	39	69.1	14.72	4.72	0.35	1.44	3.21	3.80	0.019	0.063	0.63	0.058	0.02
99034	410	21	24.1	4.60	1.42	37.43	1.08	1.29	0.80	0.944	0.024	0.25	0.012	0.02
99048	215	180	54.9	12.03	10.64	2.78	2.48	2.42	0.89	0.093	0.063	0.39	0.004	<.01
99070	73	34	61.7	11.92	1.98	0.69	1.75	3.15	3.26	0.197	0.104	0.56	0.058	0.09
99125	130	19	75.6	10.07	4.56	6.89	1.04	1.93	0.22	0.355	0.013	0.19	0.066	0.01
98207	138	58	68.1	13.82	5.58	0.66	1.80	3.04	4.35	0.057	0.144	0.96	0.056	0.02
99213	99	33	72.1	13.20	1.49	0.69	1.77	3.48	4.13	0.058	0.137	0.34	0.026	0.08
99JCO4	31	178	82.1	1.08	12.00	0.11	0.42	0.11	0.11	0.032	0.013	0.03	0.001	0.06
99JCO5	66	24	90.6	2.94	3.53	0.80	0.18	0.97	0.19	0.017	0.010	0.02	0.001	<.01
99045.5	948	541	39.7	11.93	18.56	10.47	3.94	1.19	1.09	0.205	0.048	0.57	0.007	0.15
99045.6	685	411	44.7	13.87	13.78	8.77	3.24	2.33	1.50	0.167	0.044	0.71	0.011	0.07
99084.5	30	233	19.5	0.60	31.46	0.11	0.44	0.10	0.04	0.026	0.035	0.05	0.001	0.93

A mineral identified in the field as tennantite occurs on fracture surfaces. Secondary remobilization of original sulfide minerals produced copper carbonate minerals on bedding planes and fractures, and precipitated sulfide minerals on fracture surfaces and bedding planes. Oxidized fluids moved through redbeds of the Sangre de Cristo Formation and dissolved trace amounts of copper, silver, gold, lead, zinc, phosphorous, and manganese as acidity and temperature increased during diagenesis. Members one, two, and three of the Sangre de Cristo Formation were folded into broad anticlines and synclines, which were partly eroded before member four was deposited. After deposition of member four, fluids moved updip from buried lower and upper Paleozoic sedimentary rock units. As oxidized fluids moved through redbeds of the Sangre de Cristo Formation, trace amounts of copper, silver, zinc, manganese, and phosphorous were dissolved as acidity and temperature increased during diagenesis. Sulfide precipitation occurred where the oxidized fluid encountered carbon- and sulfur-bearing reduced sediment above the unconformity. The factors that controlled fluid pathways are not known.

The stratabound deposit at location 99070 appears to be lens shaped; the mineralized zone has a vertical extent of about 7 m and a lateral extent of about 80 m. An adit extends down dip for about 15 m in the mineralized zone, but the full extent of mineralization down dip is not known. Grab samples from the mine location contain anomalous high concentrations of silver, copper, manganese, and phosphorous (Table 1). At location 99213 two lenses of copper mineralization occur in coarse-grained and conglomeratic arkose above the angular unconformity in the basal part of member four of the Sangre de Cristo Formation. Reduced beds of member four overlie oxidized beds of member three, and sulfide minerals were precipitated in porous reduced rocks. Mineralized zones at this place are lens shaped and are about 3 m thick, but the lateral extent of these lenses is not known. Highly anomalous concentrations of copper characterize this deposit, but silver, manganese, and phosphorous, which characterize the deposit at location 99070, are absent from samples at 99213.

Several grab samples were analyzed from rusty-weathering carbonate and clastic rocks of the Sangre de Cristo Formation to evaluate the potential for mineral occurrences. The sample from location 96788 contains a highly anomalous concentration of manganese, but no other elements appear to be anomalous concentrations, which is expected for a rusty-weathering dolomite. The rusty-weathering arkose of sample 99023 is anomalous only in the zinc concentration, whereas rusty-weathering arkose of sample 99207 shows no anomalous concentrations.

Lindsey and Clark (1995) described stratabound copper and uranium mineral occurrences in the Minturn and Sangre de Cristo Formations from the northern Sangre de Cristo Range south of the Jack Hall Mountain quadrangle. The deposits they described are similar occurrences to those described from the Salida East (Wallace and others, 1997), Cameron Mountain (Wallace and Lawson, 1998), and Gribbles Park (Wallace and others, 1999) quadrangles, but those stratabound deposits are not associated with angular unconformities as in the Jack Hall Mountain quadrangle. Table 2 shows concentrations in parts per million of anomalous elements of mineralized rocks from the Jack Hall Mountain quadrangle compared to concentrations of stratabound deposits from the northern Sangre de Cristo Range (Lindsey and Clark, 1995), the Salida East quadrangle (Wallace and others, 1997), the Cameron Mountain quadrangle (Wallace and Lawson, 1998), and the Gribbles Park quadrangle (Wallace and others, 1999). The depositional environments are similar in each area, but some differences in element concentrations are apparent: (1) The concentrations of arsenic, barium, boron, cobalt, chromium, and lead are lower in upper Paleozoic rocks in the Jack Hall Mountain quadrangle than in the northern Sangre de Cristo Range, (2) The concentrations of copper, silver, and molybdenum are higher in upper Paleozoic rocks in the Jack Hall Mountain quadrangle than in the northern Sangre de Cristo Range, and (3) The concentration of silver and copper appears to increase toward the north in stratabound mineral deposits as shown by comparison of concentrations obtained from the Cameron Mountain, Gribbles Park, and Jack Hall Mountain quadrangles as compared to data from the northern Sangre de Cristo Range.

Table 2. Comparision of element concentrations in mineralized rocks from stratabound mineral occurrences in upper Paleozoic rocks from the northern Sangre de Cristo Range, and the Salida East, Cameron Mountain, and Gribbles Park, and Jack Hall Mountain quadrangles. [All concentrations given in parts per million, except Au where the concentrations are measured in parts per billion (ppb). nr = not reported]

	Salida East quadrangle (Wallace, Cappa, and Lawson, 1997)		Northern Sange de Cristo Range (Lindsey and Clark, 1995)		Cameron Mountain quadrangle (Wallace and Lawson, 1998)	
Element	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**
Ag	0.7	<.2–6.4	<1	<1–16	5.3	<0.5–17.0
Au	<5(ppb)	<5–20	nr		0.02	0.001–0.078
As	3.6	<2–10	5.7	0.7–26	14.3	<5–31
B	nr		52	10–150	15.5	<5–42
Ba	155	20–940	957	196–3,400	95.8	4–244
Co	10.6	4–32	16	6–34	12.3	<10–16
Cr	56	21–91	61	21–679	nr	
Cu	1,649	<1–>10,000	161	2–8,500	19,515	74–53,085
La	48	20–110	nr		nr	
Mo	1.5	<1–6	5	<2-43	2.5	<1–7
Ni	21	9–52	30	7-61	31.3	27–35
Pb	8.9	<2–22	51	5–7,480	7.25	1–18
Sc	6.1	3–8	nr		<50	<50
Sr	121	16–865	nr		19	8–31
Th	nr		14.3	7.3–30.1	nr	
U	<10	<10–30	52.7	3.55–1,080	nr	

Table 2. Continued.

	Gribbles Park quadrangle (Wallace, Cappa, and Lawson, 1999)		Jack Hall Mountain quadrangle (Wallace, Apeland, and Cappa, 2000)	
Element	**Median**	**Range**	**Median**	**Range**
Ag	2.04	<0.5–12.2	79	5.3–152.7
Au	0.0005	<0.001–0.038	0.001	<0.001–0.002
As	44.15	<1–380	<2.5	<1–<-1
B	<4	<4	8	6–10
Ba	nr		1,205	1,040–1,370
Co	<1	<1	9	9–10
Cr	nr		nr	
Cu	5,105.30	7–24,005	42,000	15,192–68,849
La	nr		nr	
Mo	4.43	<1–23	18.5	9–28
Ni	12.6	2–37	8.5	8–9
Pb	85.9	<10–991	8	<10–16
Sc	nr		nr	
Sr	134.1	8–995	83	73–99
Th	nr		nr	
U	nr		nr	

INDUSTRIAL MINERAL OCCURRENCES

GYPSUM

Gypsum occurs in the Minturn Formation and in member two of the Sangre de Cristo Formation. In the upper part of the Minturn Formation west of Badger Creek excavations were made in gypsum-bearing beds, but no production amounts are known from this location. Exploration adits were excavated in gypsum beds at several locations in member two of the Sangre de Cristo Formation east of Badger Creek; production is not known from these exploration pits. Excavations in gypsum-bearing beds are covered and slumped and adjacent to excavations gypsum beds are covered by slopewash, so the thickness of gypsum beds is not known.

DIMENSION STONE

The Whitehorn Granodiorite was quarried for dimension stone at several localities in the region of the Jack Hall Mountain quadrangle, but no quarries are located in this map area.

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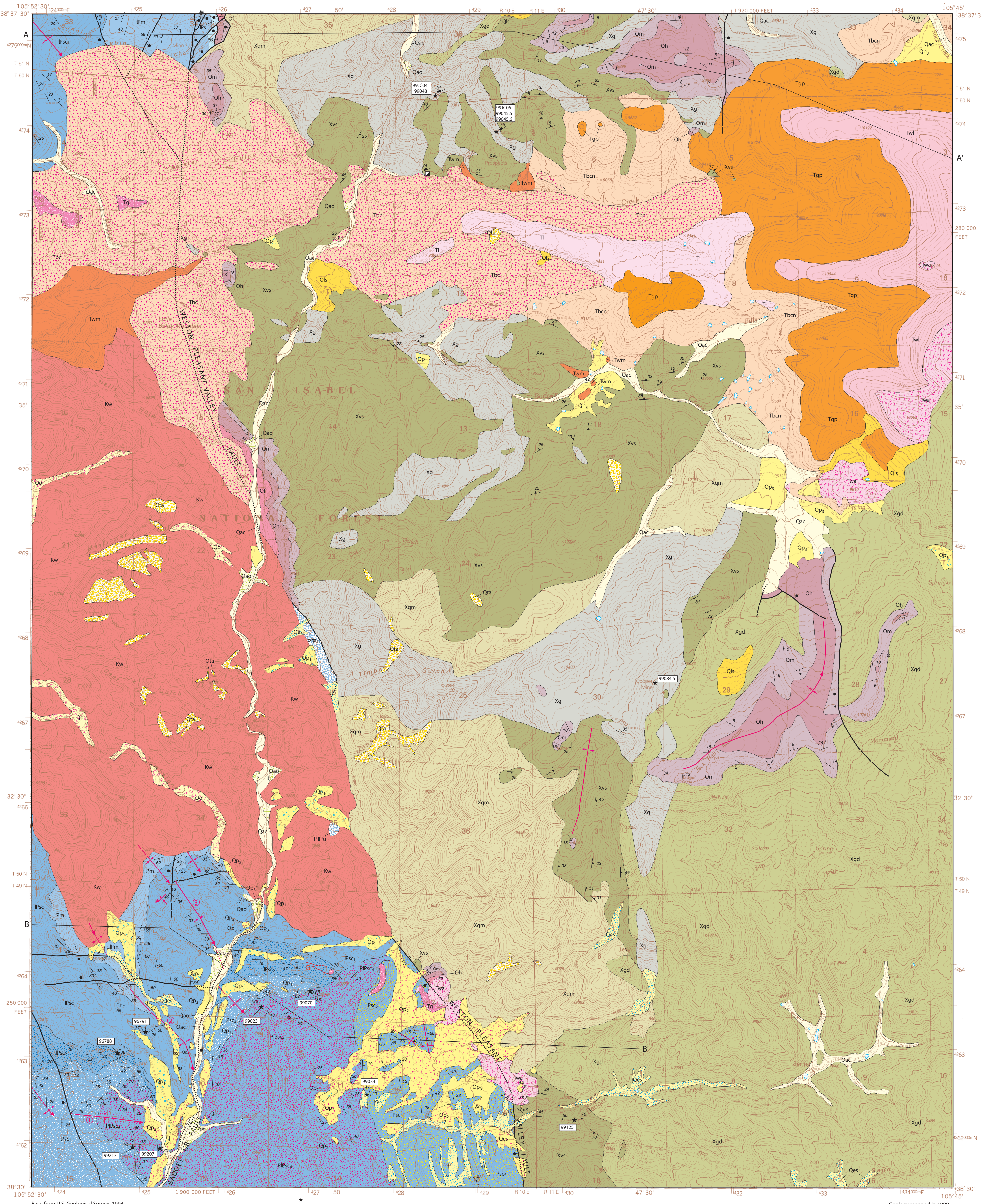
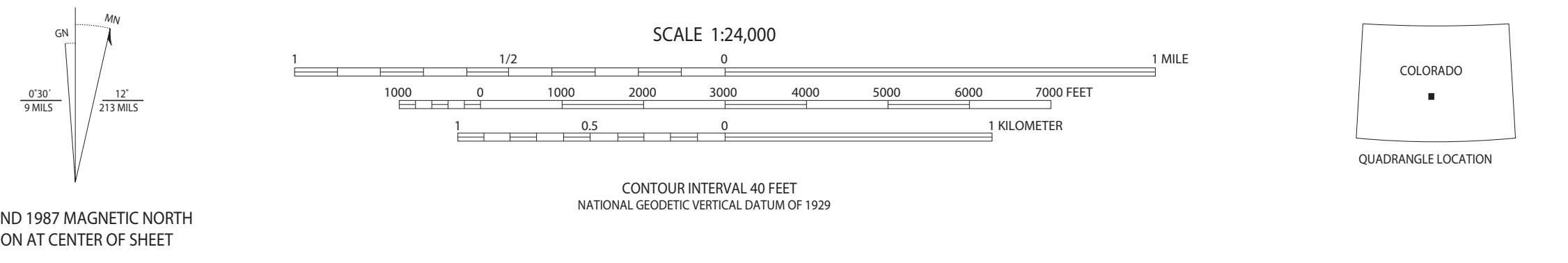
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

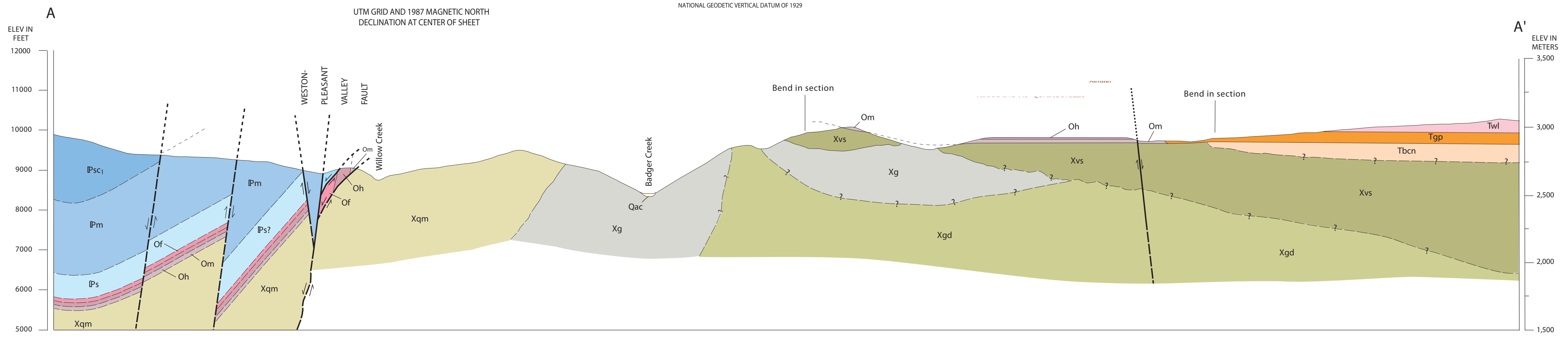
OPEN FILE MAP 00-1
GEOLOGIC MAP OF THE JACK HALL MOUNTAIN QUADRANGLE
FREMONT COUNTIES, COLORADO
Booklet accompanies map

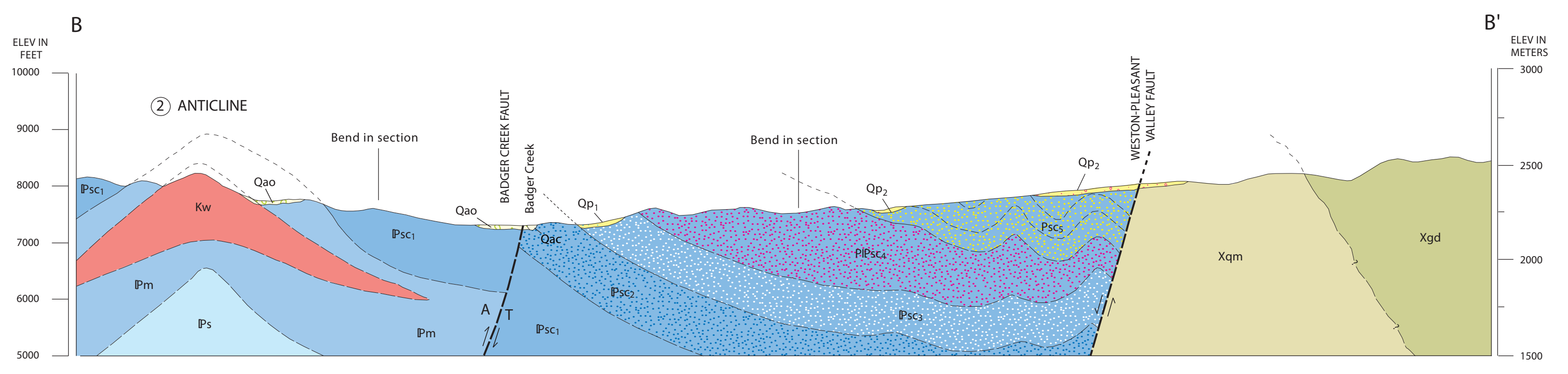


Base from U.S. Geological Survey, 1994
10,000-foot grid based on Colorado coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 13



Geology mapped in 1999
Digital cartography by Cheryl Brchan





DESCRIPTION OF MAP UNITS

The complete discussion of map units and references is in the accompanying booklet.

QUATERNARY SURFICIAL DEPOSITS

Qac Alluvium (Holocene)—Nonconsolidated, interbedded, lenticular layers of poorly sorted, matrix- and framework supported, boulder, cobble, and pebble gravel deposits that contain rounded, sub-rounded, and sub-angular clasts in a matrix of pebbles, sand, silt, and clay. Colluvium composed of tan and grayish-yellow-brown, fine-grained, nonconsolidated sediment and interbedded lenses of matrix-supported to clast-supported angular cobbles and pebbles in a sandy matrix. Some coarse-grained channel deposits occur in colluvial materials. Interlayered alluvium and colluvium crudely stratified. Braided streams are common and contain numerous abandoned channels 1 to 2 m above the active channels

Qta Talus deposits (Holocene)—Angular boulders and cobbles that form rubbly deposits below cliff faces of latite flows and metamorphosed volcanic and sedimentary rocks of Early Proterozoic age. Clasts up to 4 m in diameter

Qao Older Alluvium (early Holocene and late Pleistocene?)—Nonconsolidated, interbedded layers of silty clay, clayey silt, silt, silty sand, sand, and pebble, cobble, and boulder gravel. Boulders and cobbles are commonly angular to rounded. Most common in Badger Creek

Qes Eolian sand and silt deposits (Holocene and Pleistocene?)—Light-tan, tan, and grayish-light-brown, silt, and very-fine-grained sand, and silty sand. Rare angular pebbles occur as isolated clasts. Eolian deposits are incised by modern alluvial channels

Qls Landslide deposits (Holocene and Pleistocene?)—Heterogeneous mass of unsorted, non-stratified rock debris, gravel, sand, and silt that has a hummocky surface. Angular rock debris composed of Early Proterozoic granodiorite, Gribbles Park Tuff, latite of Waugh Mountain, Badger Creek Tuff, and andesite of Waugh Mountain

Qo Outwash (late Pleistocene)—Composed of boulders and cobbles in a sandy matrix and crossbedded and planar laminated pebbly sand, and lenticular and planar beds of sand. Shallow channels occur at the base of coarse-grained beds. Occurs only in Tombstone, Mayflower, and Hells Hole Gulches

Pediment deposits (Pleistocene)

Qp$_3$ Pediment deposit three—Poorly stratified sand and silt that contains matrix-supported boulders, cobbles, and pebbles. Pediment surface and terrace remnants about 3 to 9 m above Quaternary alluvium and colluvium in Badger Creek. Correlates with T$_3$ in Salida East quadrangle (Wallace and others, 1997 and with Qp$_3$ in Cameron Mountain (1:24,000-scale) and Gribbles Park quadrangles (Wallace and Lawson, 1998; Wallace and others, 1999)

Qp$_2$ Pediment deposit two—Poorly stratified sand and silt that contains matrix-supported boulders, cobbles, and pebbles. Boulders rounded, subrounded, and subangular. Upper surface about 15 m above alluvium and colluvium in Badger Creek. Correlative deposits mapped as T$_3$ in Salida East quadrangle (Wallace and others, 1997) and as Qp$_2$ by Wallace and Lawson (1998) in the Cameron Mountain quadrangle (1:24,000 scale) and Wallace and others (1999) in the Gribbles Park quadrangle, and as Qpsl by Wrucke and Dings (1979) in their Cameron Mountain quadrangle (1:65,000 scale)

Qp$_1$ Pediment deposit one—Poorly stratified gravel of pebbles, cobbles, and boulders in a sandy and silty matrix. Clasts rounded and subrounded. A grayish-red, grayish-brown, and red-brown soil marks the upper surface of pediment. Clasts are weathered and commonly have a coating of caliche on lower surface, and clasts have strong local provenence. Silt and sand matrix is eroded and a boulder field mantles the surface. Remnants of surface reach 8,100 ft in Badger Creek drainage. Upper surface occurs about 60 m above alluvium and colluvium in Badger Creek. Correlates with T$_2$ in Salida East quadrangle (Wallace and others, 1997) with Qp$_1$ in the Cameron Mountain quadrangle (1:24,000 scale) of Wallace and Lawson (1998) and the Gribbles Park quadrangle of Wallace and others (1999) and with Qv in the Cameron Moutain quadrangle (1:62,500 scale) mapped by Wrucke and Dings (1979)

TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Tg Alluvial gravel (Pliocene?)—Rounded and well-rounded boulders, cobbles, and pebbles in a sandy and silty matrix. Clasts consist of Proterozoic, Paleozoic, and volcanic rocks. Exposed as isolated small patches at several places in the northwestern and south-central parts of quadrangle

Twa Andesite of Waugh Mountain (Miocene)—Dark-gray, greenish-black, and dark-greenish-brown andesite and basalt. Vesicular and non-vesicular flow breccia of aa flows and dense flow rock of pahoehoe flows. Contains phenocrysts of plagioclase, olivine, and pyroxene. Occurs only in eastern part of map area. K-Ar whole-rock age 18.9 ± 1.2 Ma (Epis and Chapin, 1974)

Twl Latite of Waugh Mountain (Miocene)—Light-gray, moderate-gray, and light-pinkish-gray flow breccia and welded tuff that contains phenocrysts of plagioclase, sanidine, and hornblende in a glassy or devitrified matrix. Flow breccias common in lower part of unit. Overlies Gribbles Park Tuff in eastern part of map area

Tgp Gribbles Park Tuff (Oligocene)—Moderate-gray, light-gray, pinkish-gray, brownish-gray, and reddish-gray rhyolite porphyry. Moderately to densely welded ash-flow tuff. Phenocrysts of quartz, chatoyant sanidine, and biotite. Common volcanic rock fragments. ^{40}Ar/^{39}Ar age of 32.76 ± 0.14 Ma (McIntosh and Chapin, 1994)

Tl Latite of East Badger Creek (Oligocene?)—Dark-greenish-gray and blackish-gray porphyry. Phenocrysts of plagioclase, sanidine, olivine, and pyroxene in a glassy, dense matrix. Lava flows confined to Gribbles Run paleovalley. Columnar jointing prominent north of East Badger Creek

Badger Creek Tuff (Oligocene)

Tbc Welded tuff member—Light-gray, light-yellowish-gray, and light-reddish-gray quartz latite welded tuff. Unit contains abundant biotite and plagioclase phenocrysts and lesser amounts of sanidine and hornblende phenocrysts. Also contains abundant light-pink and light-grayish-white pumice and lapilli and lithic fragments. Weakly foliated. ^{40}Ar/^{39}Ar age 33.35 ± 0.19 Ma (McIntosh and Chapin, 1994)

Tbcn Nonwelded tuff member—White, light-grayish-white, and light-gray, ash-flow and air-fall tuff. Composed of multiple flows and forms prominent hoodoos. Abundant volcanic rock fragments. Nonwelded tuff same age as welded tuff

Twm Wall Mountain Tuff (Early Oligocene)—Light-gray, moderate-gray, light-brownish-gray, and grayish-red, eutaxitic, welded rhyolite ash-flow tuff that contains prominent sanidine and plagioclase phenocrysts (Epis and Chapin, 1974). Flow foliation in glassy welded tuff is prominent, and degree of welding varies in map area from pumice-rich flow bands to densely welded glassy tuff. ^{40}Ar/^{39}Ar age of 36.7 ± 30.07 Ma reported by McIntosh and Chapin (1994)

CRETACEOUS ROCKS

Kw Whitehorn Granodiorite (Late Cretaceous)—Fine- and medium-grained, equigranular and hypidiomorphic-seriate, biotite granodiorite. Contains varietal hornblende and pyroxene. Border phases are commonly porphyritic and contain plagioclase crystals 1 to 5 mm long in a fine-grained equigranular or aphanitic matrix. Biotite- and plagioclase-rich xenoliths locally common along borders at some places. May be weakly foliated near contacts, but not foliated in central parts of laccolith. Only upper contact exposed in map area

PALEOZOIC SEDIMENTARY ROCKS

Pℙu Sangre de Cristo Formation, undivided (Lower Permian and Upper Pennsylvanian)—Pierce (1969) subdivided four informal units in the Sangre de Cristo Formation, members four through seven. De Voto and Peel grouped these four members into informally designated lower and upper members (De Voto and Peel, 1972). We subdivide five members in the Sangre de Cristo Formation. The boundary between the Pennsylvanian and Permian periods occurs in upper member 4 (Virgilian?) or member 5 (Wolfcampian?) (De Voto and Peel, 1972). Pℙu shown on map east of Badger Creek where rocks are metamorphosed to biotite-rich hornfels and metasiltstone, and biotite- and muscovite-bearing arkose

Psc$_5$ Member five (Early Permian)—Grayish-red and reddish gray, pebbly and granular coarse-grained arkose and subarkose interbedded with grayish-red and reddish-gray, medium- and fine-grained feldspathic sandstone and equal amounts of dark-red, micaceous siltstone and dark-red, silty, micaceous shale. Heavy mineral placers and laminations common. Interbedded with red rocks are zones of olive-drab, dark-greenish-gray, and grayish-black, fine-grained feldspathic sandstone, siltstone, and shale, and zones of olive-drab and grayish-green, coarse-grained conglomeratic arkose. Green and gray zones 2- to 100-m thick. Fining upward sequences dominate in coarse-grained rocks. Primary sedimentary structures are planar and trough crossbeds, channels, ripple marks, parting lineation, planar lamination, rib-and-furrow structures, microlamination, and water-expulsion structures. Green, gray, and black siltstone and shale contain fragments of plant fossils

Pℙsc$_4$ Member four (Late Pennsylvanian? and Early Permian?)—Lower part is olive-drab, grayish-green, light-gray, and moderate-gray arkose conglomerate, coarse-, medium-, and fine-grained arkose, feldspathic siltstone, shale, and rare limestone beds. Fining-upward sequences dominate in coarse-grained sequences and heavy mineral placers are common in arkose. Interbedded zones of laminated and microlaminated argillaceous black and grayish-green siltstone and black shale 2 to 20 m thick. Upper part contains common redbed zones composed of dark-red micaceous shale, siltstone, and fine-grained arkose, and light-grayish red, coarse-grained and conglomeratic arkose. Primary bedding structures are planar and trough crossbeds, channels, ripple marks, planar lamination, parting lineation, rib-and-furrow structures, microlamination, and water expulsion structures. Fining-upward sequences dominate in coarse- and fine-grained rocks. Plant fossils locally common in green, gray, and black sandstone, siltstone, and shale

ℙsc$_3$ Member three (Late Pennsylvanian)—Grayish-red and reddish-gray, pebbly and granular coarse-grained arkose, subarkose, and orthoquartzite interbedded with grayish-red and reddish-gray, medium- and fine-grained feldspathic sandstone and lesser amounts of dark-red micaceous siltstone and dark-red, silty, micaceous shale. Polymict conglomerate beds are generally matrix supported and composed of sub-angular to sub-rounded, granitic, metamorphic, and sedimentary clasts. Heavy-mineral placers and laminations are common in arkose. Rare, thin, lenticular beds of olive-drab, dark-greenish-gray, and grayish-black fine-grained sandstone, siltstone, and shale are interbedded with dominant red-bed sequence. Dark-gray and grayish-black limestone and dolomitic limestone are interbedded with grayish-red arkose, conglomerate, and siltstone. Trough crossbeds and channeled basal contacts are common in sandstone. Planar crossbeds, ripple marks, and parting lineation are common in medium- and fine-grained sandstone beds

ℙsc$_2$ Member two (Late Pennsylvanian)—Olive-drab, grayish-green, dark-gray, greenish-black, and black micaceous shale, siltstone, and fine-grained sandstone, and rare interbeds of moderate-gray limestone, dolomite, and gypsum. Member two is overlain by member three on a regional angular discordance. Sandstone and siltstone beds range from 2 to 30 cm thick and are fining-upward sequences commonly capped by argillaceous siltstone and shale. Primary sedimentary structures are most common in fine-grained sandstone and siltstone; structures include planar lamination, ripple marks, shallow channels, small-scale planar crossbeds, and water-expulsion structures. Limestone, dolomite, and gypsum beds occur at the base of this member; these beds range in thickness between 30 cm and 2 m

ℙsc$_1$ Member one (Late Pennsylvanian)—Grayish-red and reddish-gray, conglomeratic coarse-grained arkose, medium- and fine-grained arkose, subarkose, and orthoquartzite and lesser amounts of dark-grayish-red and purplish-red, micaceous siltstone and dark-red, silty, micaceous shale that is interbedded with grayish-red and reddish-gray, medium- and fine-grained feldspathic sandstone. Polymict conglomerate beds are generally matrix-supported and composed of sub-angular to sub-rounded, granitic, metamorphic, and sedimentary clasts. Rare, thin, lenticular beds of olive-drab, dark-greenish-gray, and grayish-black fine-grained sandstone, siltstone, and shale interbedded with dominant red-bed sequence. Trough crossbeds, channels, ripple marks, rib-and-furrow structures, and parting lineation are common in coarse-grained rocks; ripple marks, planar lamination, flasers and microlamination dominate in fine-grained rocks

ℙm Minturn Formation (Middle Pennsylvanian)—Dark-gray, gray, olive-drab, grayish-green, greenish-gray, and black fine-grained sandstone, feldspathic, argillaceous, and micaceous siltstone, and silty micaceous shale. Sedimentation units are fining-upward sequences that are capped by dark-colored shale. Sandstone beds are more common in the lower part of this unit and shale and siltstone are more common in the middle and upper parts. Primary sedimentary structures include small-scale planar crossbeds, planar lamination, ripple marks, shallow channels, low-amplitude hummocky crossbeds, lamination, microlamination, and rib-and-furrow structures. Shallow channels occur at the base of some sandstone beds. Some siltstone and shale beds contain abundant plant fragments and some beds in the upper part of the formation are impure coal. Rare dark-gray and black limestone and dolomite beds of fine-grained, argillaceous, fetid micrite are generally 2 to 15 cm thick. Gypsum beds occur locally

ℙs Sharpsdale Formation (Middle Pennsylvanian)—Composed mainly of grayish-red and reddish-gray, coarse-grained arkose, pebbly and granular arkose, subarkose, and orthoquartzite interbedded with grayish-red and reddish-gray, medium- and fine-grained, feldspathic sandstone and lesser amounts of dark-red, micaceous siltstone and purplish-red, silty, micaceous shale. Only uppermost part exposed in the northwestern corner of the map area where the lower part of unit was eliminated by a fault. Coarse-grained beds have channeled bases above fine-grained upper parts of fining-upward sequences. Primary sedimentary structures include trough and planar crossbeds, shale-chip conglomerate, dispersed-pebble conglomerate, ripple cross-lamination, climbing ripples, cuspate and linguoid ripples, rib-and-furrow structures, planar lamination, flasers, and micro-lamination. Interbedded zones of olive-drab and grayish-green, tan- and rusty-weathering, medium- and coarse-grained arkose, pebbly arkose, and arkose con-glomerate that contain calcite, dolomite, and ankerite cement. Rare beds of tan- and moderate-gray-weathering limestone and dolomite interbedded with coarse-grained rocks near top of unit. Base of unit not exposed in map area

Of Fremont Dolomite (Late and Middle Ordovician)—Dark-, moderate-, and light-gray, massive-weathering, crystalline, fine-grained, fetid, fossiliferous dolomite. Mottled in light-gray and dark-gray colors and laminated and microlaminated. Massive-weathering beds are 5-cm to 1-m thick. Contains rare black chert nodules. Fossils are dolomitized coral and fragments of echinoids

Oh Harding Quartzite (Middle Ordovician)—Dark-reddish-gray, dark-grayish-orange, dark-grayish-red, light-gray, moderate-gray, and rusty-orange, fine- and medium-grained, well-sorted orthoquartzite. Bedding and primary sedimentary structures are obscured by pervasive replacement by diagenetic silica. Commonly mottled. The dense, conchoidal-weathering quartzite is locally brecciated. Some exposures contain sandstone conglomerate at the base

Om Manitou Limestone (Early Ordovician)—Dark-, moderate-, and light-gray, thin- to thick-bedded dolomite and cherty dolomite that contain a few beds of dark-gray limestone. Dolomite and limestone are laminated and mottled, and beds range between 2 cm to 1 m in thickness. Laminated black and light-grayish-white chert lenses and nodules occur parallel to bedding planes. Breccia, common in adjacent quadrangles, is rare in this map area, and where present is composed of lenses of pebble- and cobble-sized laminated chert in a matrix of silicified dolomite

PROTEROZOIC ROCKS

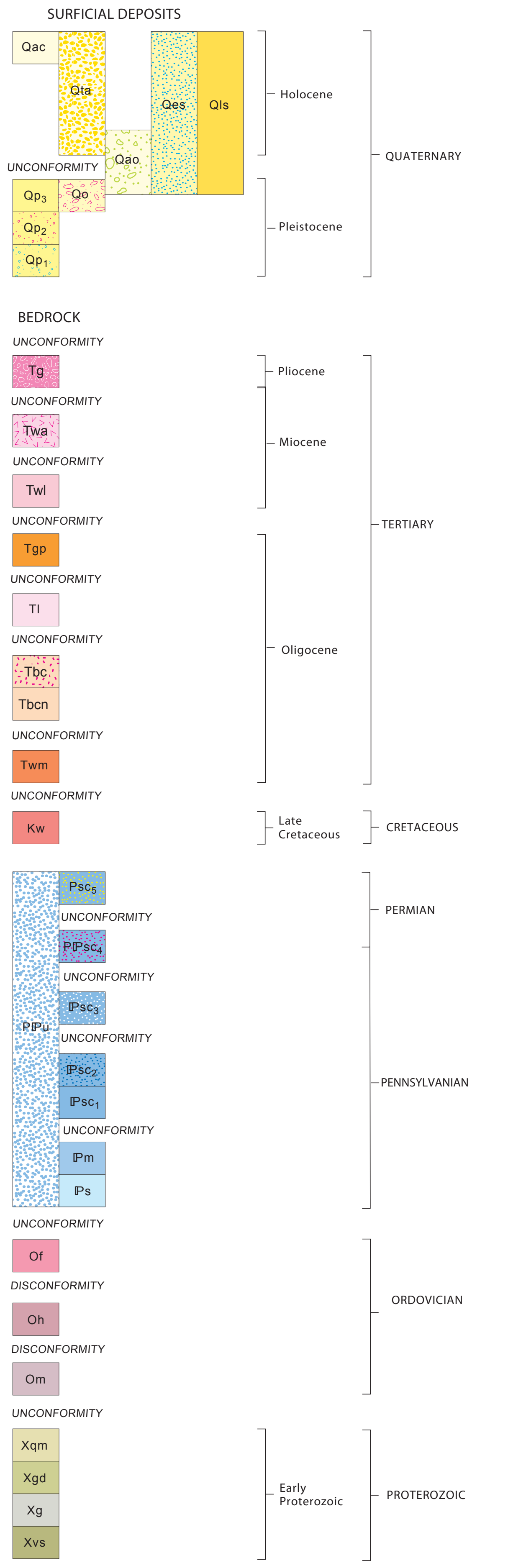
Xqm Quartz monzonite (Early Proterozoic)—Reddish-orange to red, fine-, medium-, and rarely coarse-grained, granular, biotite quartz monzonite. Generally poorly exposed. Wrucke and Dings (1979) mapped much of this unit as a Middle Proterozoic intrusive; however, contact relations with the Early Proterozoic volcanic and sedimentary metamorphic (Xvs) and the gabbro (Xg) units and the presence of locally developed foliation indicate that is unit is likely of Early Proterozoic age

Xgd Granodiorite (Early Proterozoic)—Gray, speckled, coarse- to very coarse-grained, moderately foliated granodiorite and granite gneiss. In places contains augen of quartz and microcline feldspar up to 6 cm in length and minor amounts of muscovite and biotite. Foliation well developed near the contact with older units. The outcrops in the Jack Hall Mountain quadrangle are not as prominently foliated as Early Proterozoic granodiorite in the Gribbles Park quad-rangle to the north. A sample of six zircons from granodiorite in the nearby Cameron Mountain quadrangle was dated by the uranium-lead method by Bickford and others (1989); the resultant age is 1672 ± 5 Ma

Xg Gabbro (Early Proterozoic)—Dark-gray to black, medium- to coarse-grained gabbro. Megascopically, contains light-orangish-tan crystals of plagioclase feldspar in a black aegerine-augite matrix. Contact relations with surrounding rock units are generally obscured. Chlorite and rare epidote occur as alteration product of pyroxene. Opaque minerals, probably iron oxides and ilmenite, occur in trace amounts up to a few percent

Xvs Interbedded volcanic and sedimentary rocks (Early Proterozoic)—Interbedded, tan, bimodal volcanic and volcaniclastic rocks, and medium-gray to black, light-gray, and grayish-tan, fine-grained to very fine-grained quartzite, metasiltstone, and metagraywacke. Quartzite consists primarily of very fine quartz grains and up to 10 percent feldspar grains. Porphyroblasts of plagioclase up to 1 mm in size occur in some locations in quadrangle and can constitute up to 20 percent of the rock. Poorly to moderately foliated chlorite and biotite can constitute from 5 to 30 percent of the rock. Cross-bedding and other sedimentary structures such as graded couplets, microlamination, planar lamination, and ripple cross-lamination are commonly well pre-served. Four zircon fractions from a metadacite in the Xvs unit just east of Salida in the Salida East quadrangle yielded a uranium-lead of 1728 ± 6 Ma (Bickford and others, 1989)

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximate

Fault—Dashed where approximately located and dotted where covered by younger deposits. Ball and bar on downthrown block

A T Fault—On cross section only; dashed where approximately located. Shows relative direction of movement; T, toward observer, A, away from observer

Anticline—Trace of axial surface. Dashed where approximately located and dotted where covered by younger deposits. Large arrowhead shows direction of plunge and small arrows show direction of dip away from the axial trace. Number refers to discussion in booklet

Syncline—Trace of axial surface. Dashed where approximately located and dotted where covered by younger deposits. Large arrowhead shows direction of plunge and small arrows show direction of dip toward the axial trace. Number refers to discussion in booklet

Strike and dip of beds

20 Inclined

20 Overturned

75 Strike and dip of vein

Strike and dip of foliation in metamorphic rocks

35 Inclined

27 Strike and dip of foliation in volcanic rocks

Form lines—Show approximate trends of beds in subsurface. Used only on cross sections

G Gypsum bed in the Minturn Formation or in member two of the Sangre de Cristo Formation

Adit

★ 97200 Sample location and sample number—See Tables 1 and 2

A ——— A' Alignment of cross section

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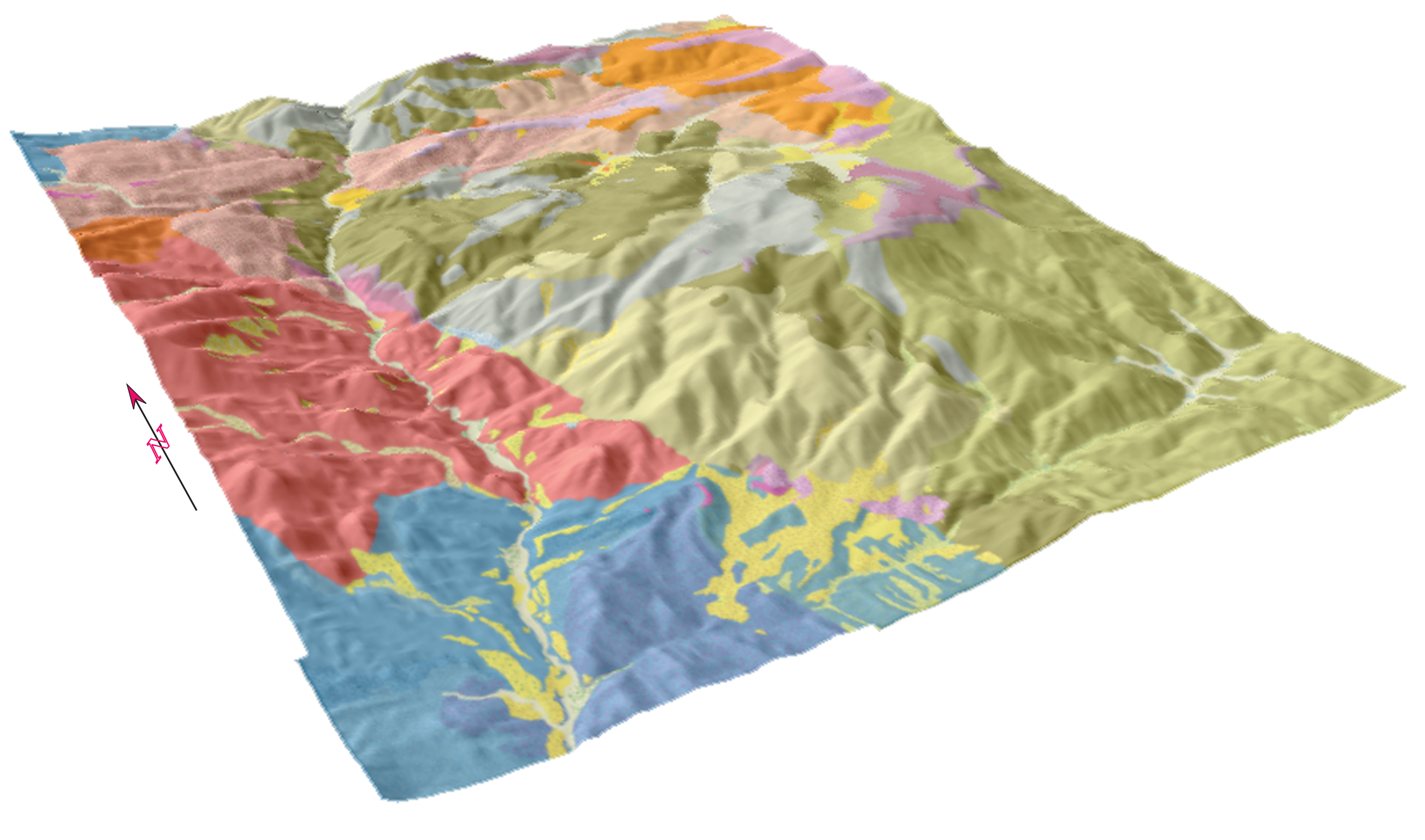
SHADED-RELIEF MAP OF THE JACK HALL MOUNTAIN QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTHEAST



GEOLOGIC MAP OF THE JACK HALL MOUNTAIN QUADRANGLE, FREMONT COUNTY, COLORADO

By C. A. Wallace, Allison D. Apeland, and James A. Cappa

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Jack Hall Mountain v18 11/9/00