RECONNAISSANCE GEOLOGY OF THE
MISSISSIPPIAN LEADVILLE LIMESTONE
AND IMPLICATIONS FOR MINERALIZATION CONTROLS,
FULFORD MINING DISTRICT, EAGLE COUNTY, COLORADO

by

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A MASTER'S THESIS

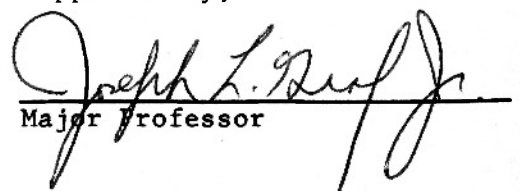submitted in partial fulfillment of the

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INTRODUCTION

The major mining districts of Colorado are in the Colorado Mineral Belt, a
narrow, irregular strip that extends 250 miles southwestward across the
mountain provinces from near Boulder to the San Juan Mountains (Fig. 1). The
belt is characterized by the mineralized districts and by porphyritic igneous
intrusive bodies of Late Cretaceous and Tertiary age.

In northwest-central Colorado, the Leadville, Alma, Fairplay, Tennessee
Pass, Gilman, Redcliff, and Aspen mining districts form a mineralized ring
around the Sawatch Range (Fig. 2). Ore production has come primarily from the
Leadville Limestone (Mississippian), which is upturned on the flanks of the
range. In these economic areas, the major controls of mineralization seem to
be the following: (1) karst solution features, (2) Tertiary igneous and hydro-
thermal activity, (3) sedimentological, stratigraphic, and diagenetic features
of the Leadville Limestone, and (4) Laramide tectonic activity. The
mineralization is fairly continuous along the east side of the range, but on
the west side there are unmineralized gaps.

The Fulford district, directly opposite the productive Gilman district
(Fig. 2), is on the west flank of the Sawatch Range within a relatively
unmineralized area just north and east of the edge of the mineral belt.
Similarities between the Fulford and Gilman districts include simple homoclinal
structure of the Paleozoic rocks, presence of Tertiary intrusive bodies, and
evidence of prospecting and mining activity (economically productive at Gilman,
minor at Fulford).

PURPOSE

These factors helped to identify the Fulford district as a target for a
geological reconnaissance study of the Leadville Limestone. The goal of the
study was to compare the Fulford district to areas where economic concentra-
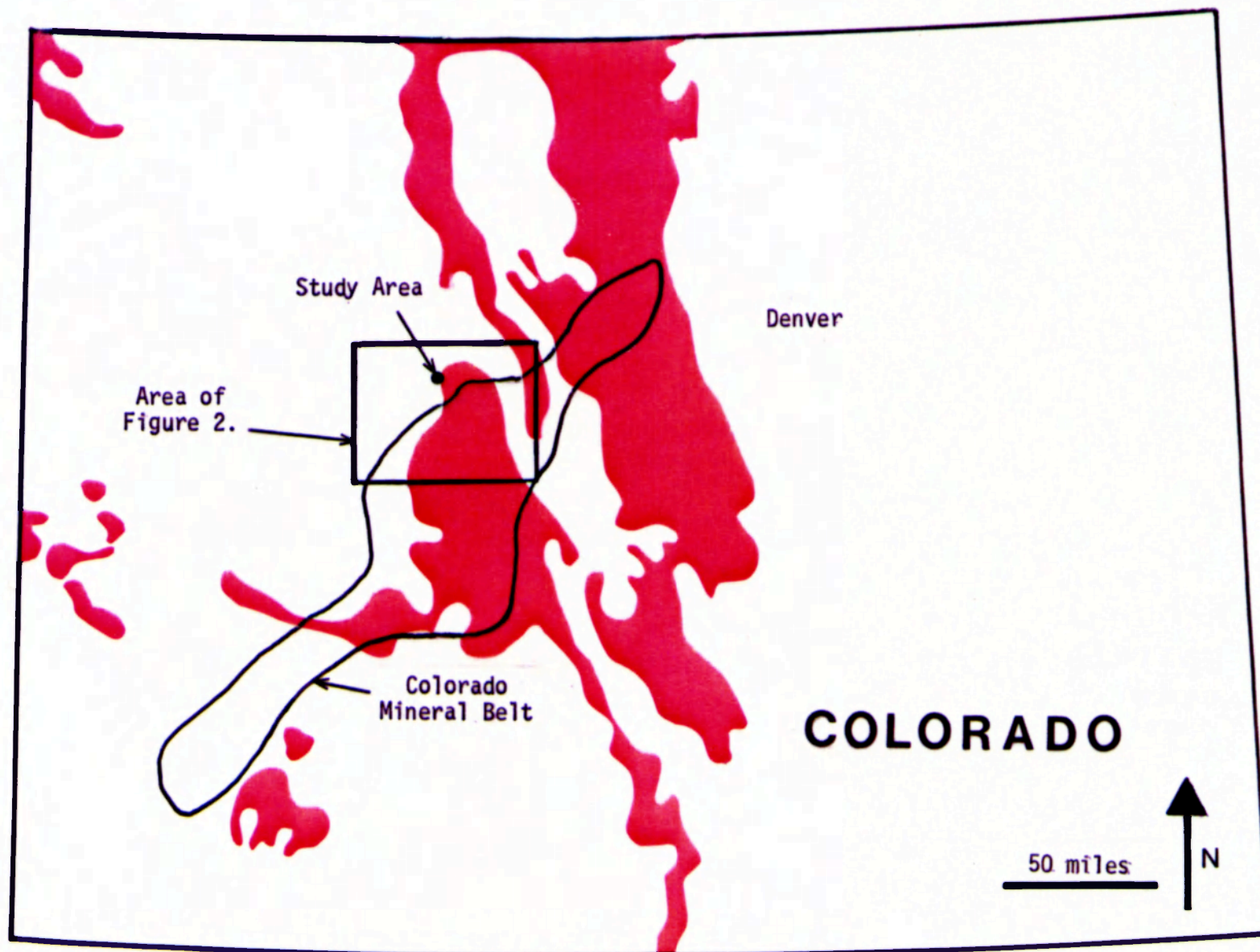
Figure 1. Location of study area in relation to the Colorado Mineral Belt and exposed Precambrian basement (shown in red).
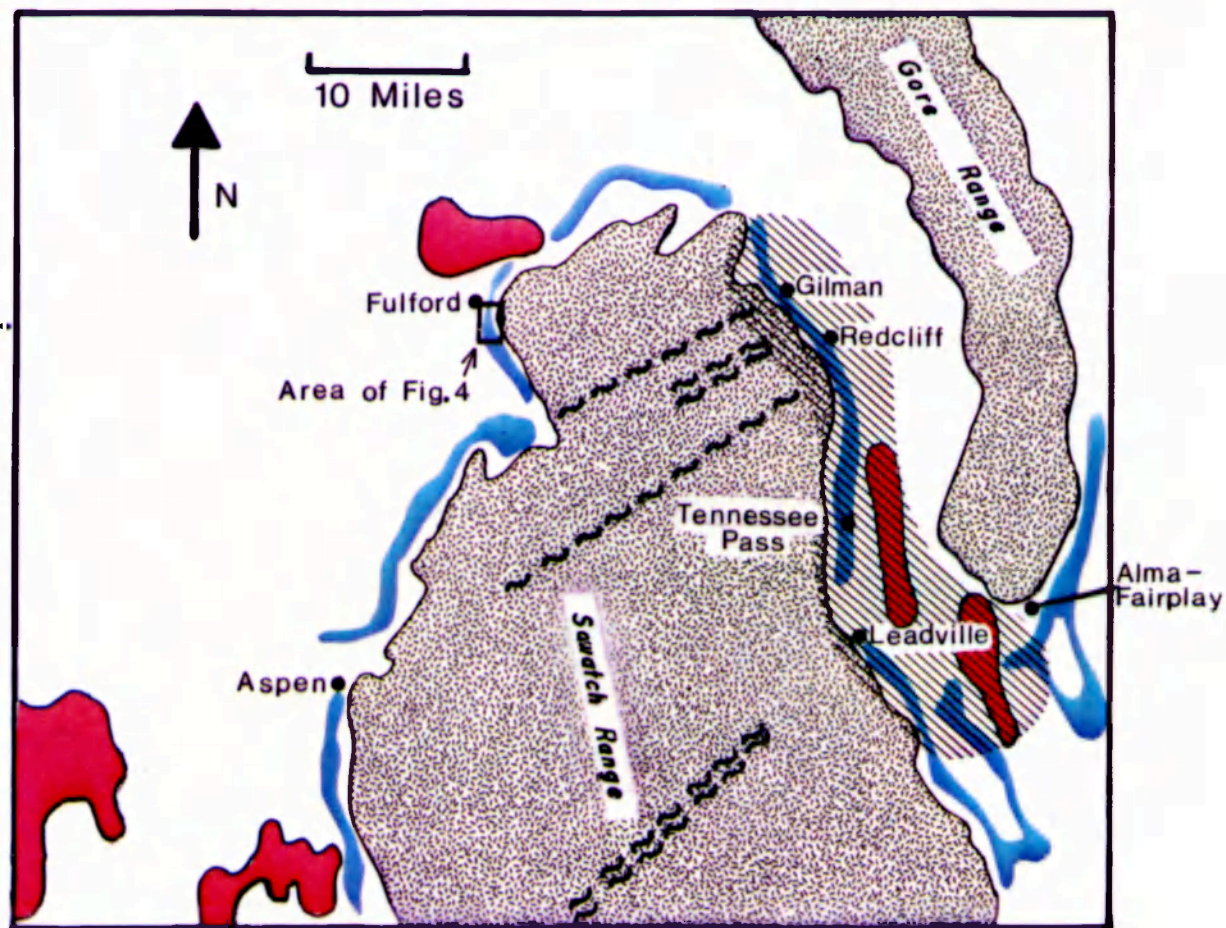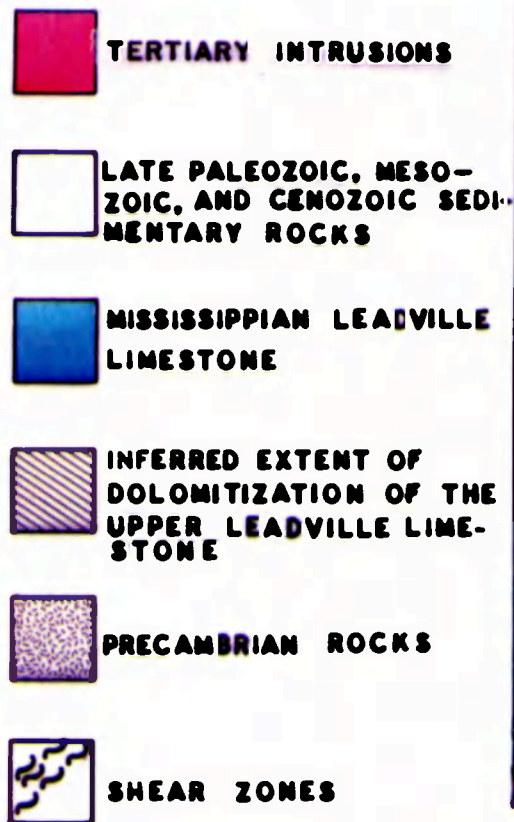
Figure 2. General geology of the northern Sawatch Range, and locaton of mining districts where the Mississippian Leadville Limestone is a major ore host. Outlined is the location of Figure 4, Bedrock Geology of Southern Fulford District, Eagle County, Colorado.

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tions of ore minerals occur in the Leadville Limestone. Also, even though the mechanisms of mineralization did operate at least to some extent in the Fulford district, they were not effective in depositing economic concentrations of ore minerals. A comparison of the Fulford district to areas where economic concentrations of ore minerals occur in the Leadville Limestone, with emphasis on the previously mentioned ore controls, may provide some explanation for the resistance of the Leadville Limestone of the Fulford district to replacement mineralization.

LOCATION AND DESCRIPTION OF STUDY AREA

The Fulford district is 18 miles southeast of the city of Eagle, Eagle County, Colorado, on the northwestern slope of the Sawatch Range in the Southern Rocky Mountains physiographic province (Figs. 1 and 2). The area studied within the Fulford district is in sections 25, 35, and 36 in T. 6 S., R. 83 W., Eagle County, Colorado.

The study area is between 9,400 feet and 11,000 feet above sea level and is beneath timberline. East of the area, in the Precambrian core of the range, the topography is characterized by sharp peaks, U-shaped valleys, hanging valleys, and cirques. Within the mapped area, which is underlain by Paleozoic sedimentary rocks and Pleistocene glacial till, the slopes are more gentle, and the valleys are V-shaped and narrower. Outcrops are found mostly on the steep sides of the valleys. Below 11,000 feet, the Fulford district is heavily forested. Most of the conifers are Engleman spruce (Picea engelmanni), alpine fir (Abies lasiocarpa), lodgepole pine (Pinus contorta), and Douglas fir (Pseudotsuga taxifolia). Deciduous varieties are aspen (Populus tremuloides) and willow (Salix). Areas devoid of timber are so conspicuous that they are called parks.

METHODS OF INVESTIGATION

FIELD METHODS

Geologic mapping was at a scale of 1:6,000 on base maps prepared by enlargement of topographic quadrangle maps; the final map was prepared by further photographic enlargement of portions of the Fulford and Crooked Creek Pass 7-1/2 minute topographic quadrangle maps of the United States Geological Survey. Aerial photographs of approximately 1:21,000 scale were used for field location. Where possible, data points were plotted on the photographs and transferred by resection to the base map. Sections were measured to the nearest tenth of a foot and detailed descriptions (Appendix 1) noted in three separate areas. In each area, at least 75 percent of the total Leadville Limestone was exposed. Representative samples of each lithology were collected, and, where the rock contained no macroscopically visible (less than 1 percent) allochemical component, the rock was classified according to Folk (1980, p. 169), otherwise the carbonate classification of Dunham (1962, p. 117) was used. Rock colors were taken from Goddard and others (1948) and bedding characteristics were described according to McKee and Weir (1953). Rock samples for geochemical assay were also collected in areas of mining or prospecting activity.

LABORATORY METHODS

Forty thin sections were prepared from field samples using standard techniques. Each thin section was examined microscopically to identify constituent grains (composition), texture, and mineralogy in order to determine the sedimentological history. Percentages of the constituents were determined by identifying the constituent of each 0.4 by 0.4 mm cell in an approximately 20 by 20 mm grid drawn on each section. Twelve thin sections were stained using a solution of Alizarin Red-S and potassium ferricyanide, as described by

Lindholm and Finkelman (1972). Staining was used: (1) to distinguish between and determine the relative abundance of calcite and dolomite, (2) to distinguish between cements where no textural change occurs, and (3) to reveal evidence indicative of the environment of precipitation of calcite cements. Brief descriptions of thin sections are in Appendix 2 and the data summarized in Tables 1, 2, and 3.

Twenty-eight rock samples collected for geochemical assay were analyzed for copper, lead, zinc, silver, and gold by Cone Geochemical of Denver using atomic absorption techniques. The results of the analyses are in Table 4.

R E G I O N A L   G E O L O G I C   S E T T I N G

STRATIGRAPHY

Precambrian Rocks

The older Precambrian granitoid to gneissic rocks of the Fulford district are estimated to be approximately 1700 m.y. old (Gableman, 1949; Tweto and Lovering, 1977). These are intruded by granite pegmatite associated with a second intrusion of granitic rock 1350 to 1450 m.y. ago (Tweto and Lovering, 1977; Tweto, 1980c).

Paleozoic Rocks

Pre-Pennsylvanian Paleozoic rocks are of special interest as they are the main host rocks of the ore deposits in the mining districts of the area. These rocks form a sequence approximately 500 feet thick that rests unconformably on Precambrian granitic rocks and is overlain by more than 6000 feet of Pennsylvanian rocks (Tweto and Lovering, 1977). The Paleozoic formations occurring in the northern Sawatch Range (Fig. 3) are the Sawatch Quartzite and Peerless Formation (Cambrian), the Manitou Dolomite (Ordovician), the Chaffee Group (Devonian), the Leadville Limestone (Mississippian), the Belden and Minturn formations (Pennsylvanian), and the Maroon Formation (Permian).

Lower MINTURN &
BELDEN FORMATIONS

PENN.

LEADVILLE LIMESTONE

MISS.

CHAFFEE GROUP

DYER DOLOMITE

DEVONIAN

PARTING FORMATION

MANITOU DOLOMITE

ORD.

PEERLESS FORMATION

SAWATCH QUARTZITE
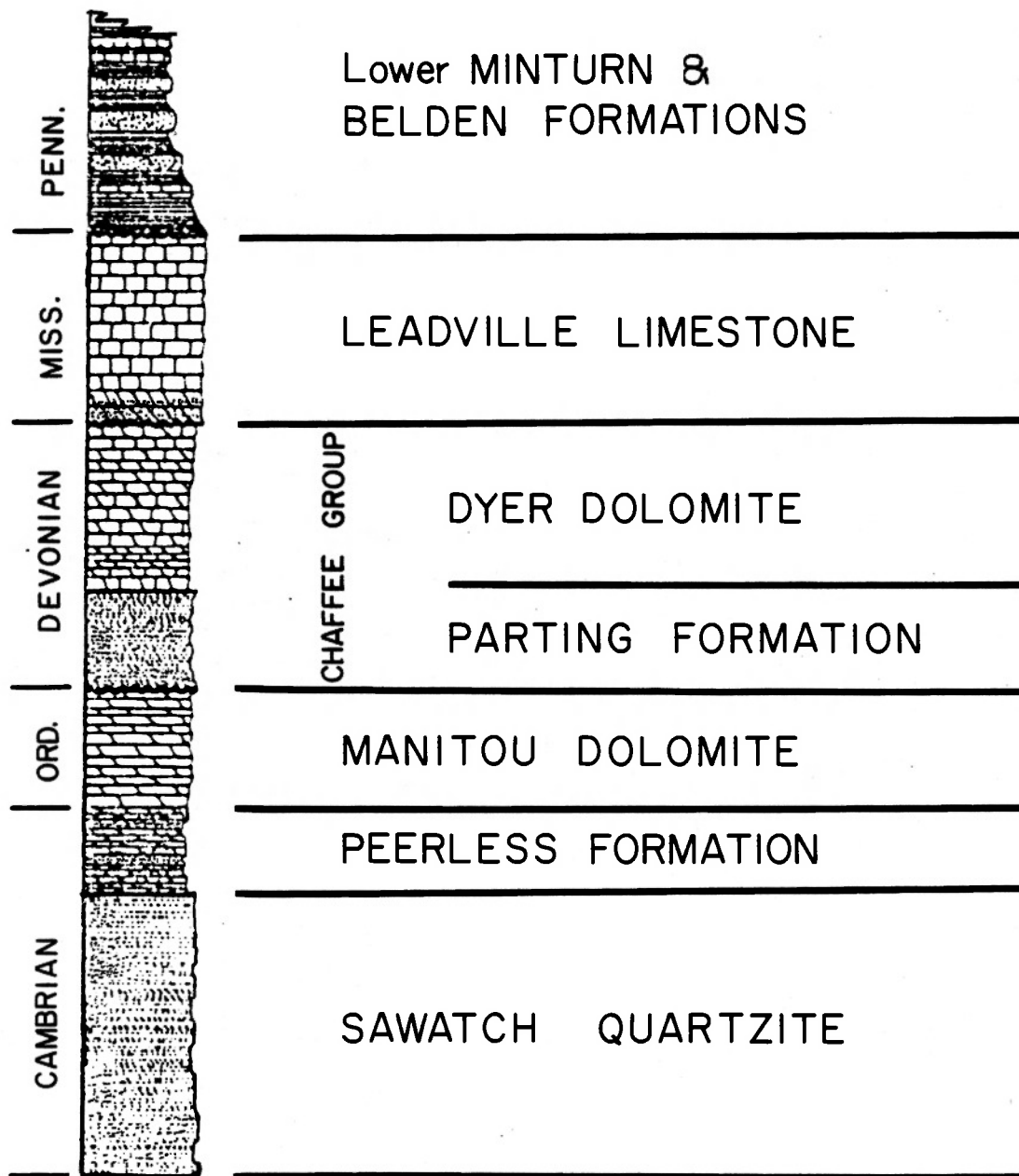
CAMBRIAN

Figure 3. Paleozoic stratigraphy of the northern Sawatch Range
(After Leuck, 1970, p. 5).

However, the Minturn and Maroon formations are not present in the study area.

STRUCTURE

The Sawatch Range consists largely of Precambrian rocks in the core of a huge north-trending anticline 90 miles wide (Fig. 2). On the west flank, the Paleozoic sedimentary rocks form dip slopes that dip westward and northwestward into a broad syncline (Tweto and Sims, 1963).

Although the sedimentary rocks of the northern Sawatch Range are broken by few faults, the underlying Precambrian rocks are broken by numerous faults and shear zones. A major northeast-trending Precambrian shear zone - The Homestake Shear Zone - passes beneath the Aspen, Leadville and Gilman districts (Fig. 2) and to the southeast of the Fulford district (Tweto and Sims, 1963; Lovering and others, 1978). The Homestake Shear Zone and other shear zones of the Southern Rocky Mountains form the boundaries for a mosaic of fault blocks created by brittle deformation of the Precambrian basement rocks during orogenic periods in late Precambrian time. During the Paleozoic and again during Laramide orogeny, crustal stress was released by movement along the shear zones and faults. (See Weimer, 1980). Accompanying movement during Cambrian to Devonian time was the emergence of the Front Range Highland (Ross and Tweto, 1980); it and the Sawatch uplift were slightly positive during Mississippian time (DeVoto, 1980).

The present Sawatch Range was created by Laramide orogeny in late Campanian time (approximately 72 m.y.b.p.). Also associated with Laramide orogeny was igneous activity that was almost entirely restricted to the area of the Colorado Mineral Belt. (See Tweto, 1980b).

PRE-PERMIAN ROCKS OF THE FULFORD AREA

The bedrock geology of the Fulford district, the locations of the measured sections, and the areas where the rocks were mapped in detail are in Figure 4. Prospects, mines, sampling sites and detail of the Leadville Limestone and older Paleozoic rocks are in Figures 5 and 6. Detailed descriptions of the measured sections are in Appendix 1.

CAMBRIAN SYSTEM

The Sawatch Quartzite consists of uniform, medium- to thick-bedded, quartzite. The quartzite is very resistant and forms cliffs or ledges in stream valleys; however, on dip slopes it breaks down to angular blocks. The Sawatch Quartzite constitutes a significant ore zone in the Gilman district, though subordinate to the Leadville Limestone. Replacement and fracture or cavity-filling ore deposits in the Sawatch supplied most of the gold and a large part of the copper produced in the Gilman district (Lovering and others, 1978). In the Fulford district, the Sawatch Quartzite is approximately 250 feet thick (Leuck, 1970) and contains gold-copper-quartz veins that accounted for much of the early production from the district (Gableman, 1949).

The Peerless Formation is a series of thin-bedded sandy dolomites, dolomitic sandstones, and dolomitic shales. The Peerless is commonly glauconitic and locally ferruginous and chloritic (Tweto and Lovering, 1977). In the Fulford district, the Peerless is approximately 35 feet thick (Leuck, 1970) and does not contain any ore minerals.

ORDOVICIAN SYSTEM

In the Sawatch Range, the Ordovician System is represented by the Manitou Dolomite, Harding Sandstone and Fremont Limestone. Of these, the Manitou is the most extensive, is 40-60 feet thick, and consists of thin-bedded, sandy

dolomite with beds of sandstone and quartzite. Only the Manitou occurs in the Fulford district, where it crops out as a dolomite approximately 60 feet thick (Leuck, 1970). The Manitou is widespread in the mineral belt south of Gilman and is an important host rock for ore deposits at Leadville (Tweto, 1968).

DEVONIAN SYSTEM

The Chaffee Formation was first proposed by Kirk (1931) and divided into two members, the Parting Quartzite Member and the Dyer Dolomite Member. Later, Tweto and Lovering (1977) redefined the Chaffee Formation as the Chaffee Group and the Parting Quartzite Member and Dyer Dolomite Member became the Parting Formation and Dyer Dolomite, respectively. The Parting Formation consists of approximately 50 feet of quartzite and quartzite conglomerate. In the Fulford district, the Parting is exposed in the Jackpot Mine where it is approximately 80 feet thick. The Dyer Dolomite, which is a minor ore host in the Gilman district and a major ore host in the Leadville district (Tweto, 1968), is well-exposed in the three measured sections of the mapped area (Figs. 4, 5, 6, and Appendix 1). The rocks of the Dyer Dolomite are uniform throughout the study area and consist of thin-bedded, dark-gray to black (N3-N1), dense, brittle, micrite. The upper contact of the Dyer Dolomite is marked by the change from thin-bedded micrite to the sandstone and breccia of the Gilman Sandstone (Fig. 7). The entire Dyer Dolomite is well-exposed in Nolan Canyon and is approximately 100 feet thick.

MISSISSIPPIAN SYSTEM

Emmons (1882) originally used the term "Leadville Limestone" synonymously with the term "Blue Limestone" for strata that lie between the Parting Quartzite and the Pennsylvanian of central Colorado (Fig. 8). Kirk (1931) suggested that the term "Leadville Limestone" be restricted to that portion of the original Blue Limestone above the Chaffee Group. The Leadville Limestone

Figure 4. Bedrock geology of study area.

EXPLANATION

PENN.	**Pb**	**Belden Formation**

Leadville Limestone

MISSISSIPPIAN	**Mlc**	**Castle Butte Member**
	Mlr	**Redcliff Member**
	Mlg	**Gilman Sandstone Member**

UPPER DEVONIAN	**Dd**	**Dyer Dolomite**
LOWER DEV. to CAMBRIAN	**DЄr**	**Lower Devonian to Cambrian rocks**

>>>> Measured section

X Prospect pit

>—Adit & drift

>—(Inaccessible)

◰ Shaft

② Sample location

Outline of visible outcrop

Contact—dashed where approximate

Figure 5.   Outcrop geology of northern Fulford area.

250 ft
76 m

14

EXPLANATION

TERTIARY ?	**Tlp**	Latite porphyry
PENN.	**Pb**	Belden Formation
MISSISSIPPIAN	**Mlc**	Leadville Limestone Castle Butte Member
	Mlr	Redcliff Member
	Mlg	Gilman Sandstone Member
UPPER DEVONIAN	**Dd**	Dyer Dolomite
LOWER DEV. to CAMBRIAN	**D€r**	Lower Devonian to Cambrian rocks

>>> Measured section

x Prospect pit

>— Adit & drift

>|— (Inaccessible)

② Sample location

Outline of visible outcrop

Contact—dashed where approximate

Zone of contact metamorphism

Figure 6. Outcrop geology of southern Fulford area.

9800

9600

Mlc

Mlc

ℙb

Mlc

Tlp

Mlc

FULFORD
CAVE

Mlr

ℙb

Mlc

Mlr

Mlg

10400

Dd

ℙb

D-€r

Dd

Brush Creek

ℙb

Mlc

Mlg

Mlr

250 ft
76 m
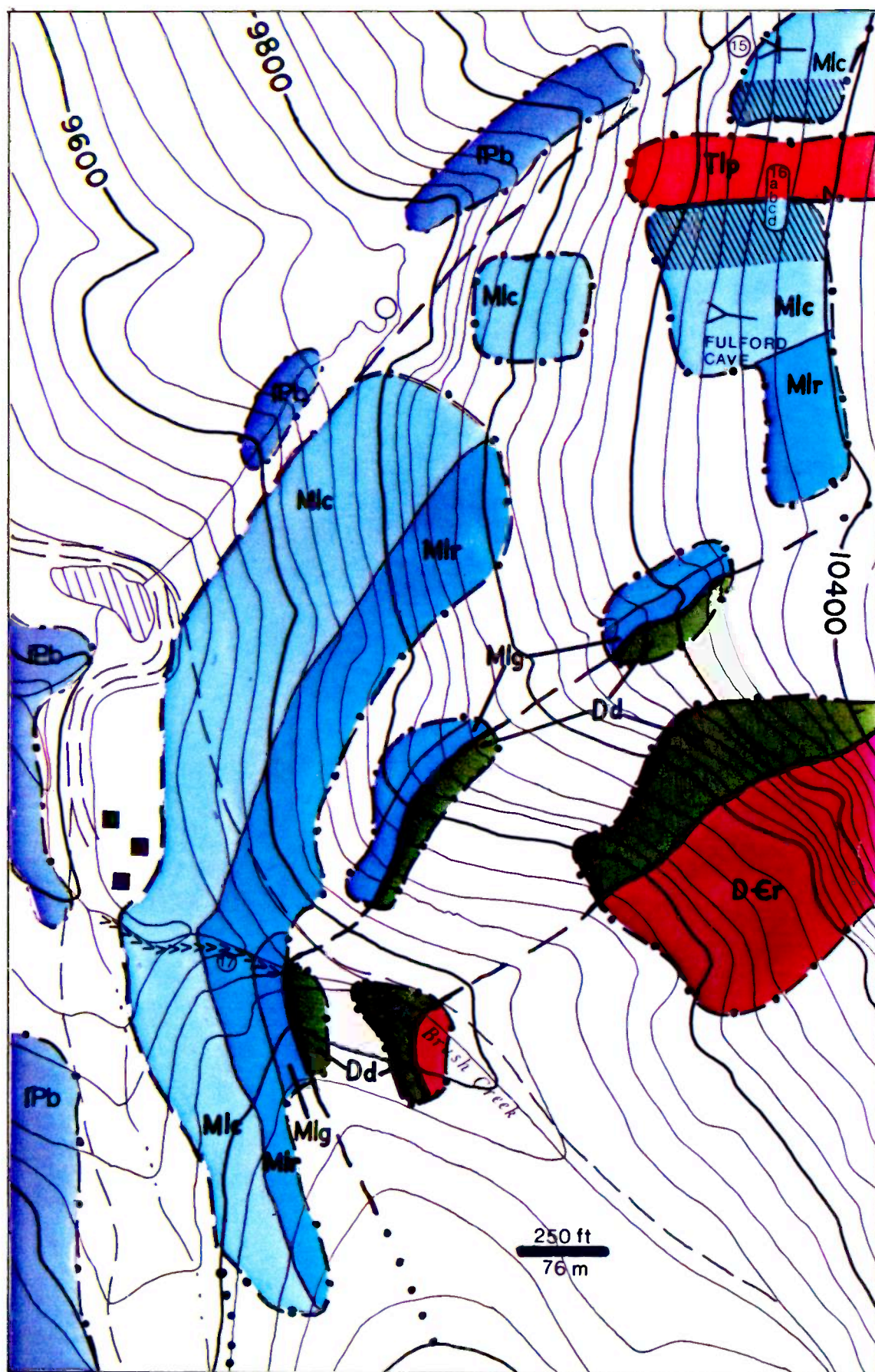
Figure 7. Contact between the thin-bedded micrites of the upper
Dyer Dolomite "Dd" and the lowermost sandy micrite of the
Gilman Sandstone Member "Mlg". View is of the south wall of the
canyon in East Brush Creek.

EMMONS 1882	KIRK 1931	BANKS 1967	NADEAU 1971
PENNSYLVANIAN - BELDEN SHALE			

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        EMMONS        KIRK           BANKS              NADEAU
        1882          1931           1967               1971

              PENNSYLVANIAN - BELDEN SHALE

                                        U
                                        p
                                        p
        B     L  L     L  L|    e       L  L    Castle
        L     E  I     E  I|    r       E  I    Butte
        U     A  M     A  M|   ___      A  M    Member
        E     D  E     D  E|    M       D  E
              V  S     V  S|    i       V  S | Redcliff
        L     I  T     I  T|    d       I  T | Member
        I     L  O     L  O|    d       L  O
        M     L  N     L  N|    l       L  N
        E     E  E     E  E|    e       E  E
        S                      ___
        T                       L           | Gilman
        O                       o           | Sandstone
        N                       w           | Member
        E                       e
                                r

                        DEVONIAN
                        DYER DOLOMITE
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Figure 8. Stratigraphic nomenclature of the Mississippian Leadville Limestone.

is of economic interest because it is the principal host rock of ore deposits at Gilman, Leadville, and Aspen, and many smaller mining districts in the Sawatch and Mosquito ranges. The strata of the Leadville Limestone, as defined by Nadeau (1971), may be divided into three members: a basal member consisting of quartz sandstone, micrite, dolomicrite, and dolomicrite breccia; a middle member consisting of cherty micrite and dolomite; and an upper member consisting of thick-bedded allochemical limestone. The three members of the Leadville Limestone are readily identified in the field; however, the correlation of individual units from one section to another within each member is difficult.

Gilman Sandstone Member

The basal member of the Leadville Limestone was designated the Gilman Sandstone Member by Tweto (1949), and is not an important host rock of ore deposits. Throughout the mapped area, the Gilman Sandstone consists of: (1) a basal quartz sandstone or sandy dolomicrite, (2) a medial sandy dolomicrite breccia, and (3) an upper quartz sandstone or sandy dolomicrite. The member contains intense dissolution features near ore bodies (Lovering and others, 1978), features not observed in the Gilman Sandstone of the Fulford district. In all sections, the contact between the Gilman and Redcliff members is discordant as the uppermost Gilman units have sandstone-filled scour channels.

In the mapped area, the Gilman is poorly exposed. The member generally weathers to a slope more stable than the other members and so is covered by more vegetation. The Gilman is best observed in the section exposed in the small canyon of East Brush Creek (Fig. 8). The member is exposed for 1000 feet along strike on either side of the creek before being covered by vegetation to the north and glacial ground moraine to the south (Fig. 5). In the canyon of Nolan Creek, the Gilman is well-exposed in the canyon walls but is less visible

on the canyon floor. To the south of Nolan Canyon, the Gilman is exposed only in small patches. However, north of the canyon, parts of the member are exposed for more than 1000 feet along strike from Nolan Canyon to the Jackpot Mine (Fig. 4). The Jackpot Mine exposure is on the hillside that is the north wall of a valley modified by a valley glacier that occupied the area of Nolan Creek. The south wall of this valley is the ridge that extends west from Craig Peak. Nolan Canyon is in the center of this valley (Fig. 4). The entire Gilman Member is well exposed in the outcrop above the Jackpot Mine but is concealed beneath the heavy forest cover north of the mine.

East Brush Creek Section.-- In the East Brush Creek section (Table 1 and Appendix 1), the basal sandstone is absent and the lower Gilman consists of a dark gray (N4), sandy micrite that is 1-9 feet thick and weathers to a yellowish gray (5Y8/3). Above the basal unit is a thick-bedded, sandy dolomicrite breccia. In this section, the breccia is 5.3 to 8.5 feet thick and contains several 1- foot thick sandstone lenses (Fig. 9) that are white to very light gray (N9-N7) and laterally are less than 10 feet long. Toward the top of the breccia unit, sandstone becomes more abundant and occupies scour channels at the Gilman-Redcliff contact. Secondary dolomite also occurs in pods that are approximately 5 feet thick, are of different lengths, and are discordant to bedding. The pods are most visible in the lower part of the member.

Nolan Canyon Section.-- In Nolan Canyon (Table 2 and Appendix 1), the basal Gilman consists of a 4- to 6- inch thick, dark gray to black (N1-N3), dense, calcareous, quartz sandstone. The sandstone was observed only in the canyon walls and could not be followed for any mappable distance; however, the unit is also exposed on the Craig Peak Ridge (Fig. 5, sample site 14). Above the sandstone is a medium-bedded unit composed of interbedded sandy dolomicrite and sandy dolomicrite breccia that is 18.4 feet thick and continues north from the canyon for approximately 600 feet along strike. On the north side of the
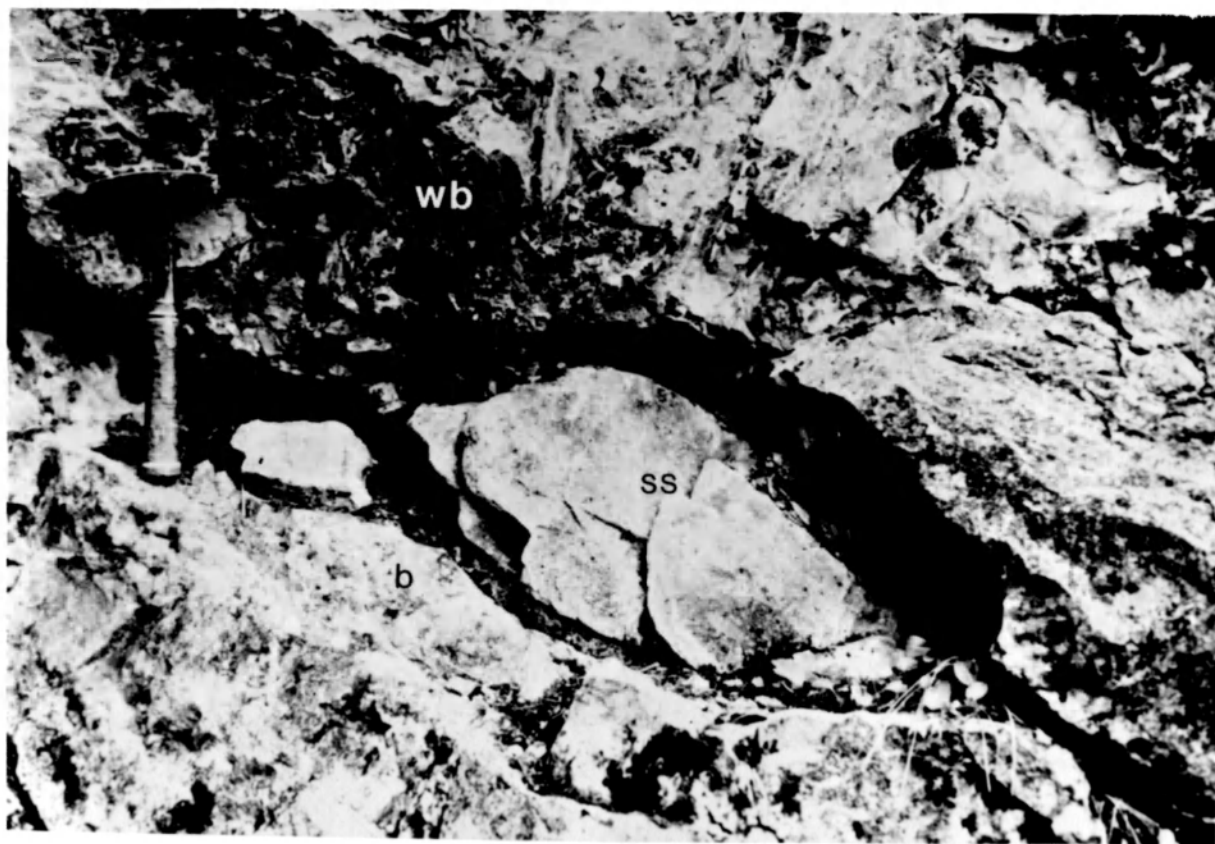
Figure 9. Sandstone lens "ss" of the upper dolomicrite breccia "b" beneath the Waxy bed "wb" exposed in East Brush Creek.

Conglomeratic sandstone of the Molas Formation

Intraclastic-oolitic grainstone

Oolitic grainstone

Skeletal-oolitic grainstone

Skeletal-peloidal packstone

Sandy-micrite breccia (Pink breccia)

Pelmicrite

Cherty micrite

Dolomicrite (Waxy bed)

Quartz sandstone

Sandy-dolomicrite breccia

Sandy micrite/sandy dolomicrite
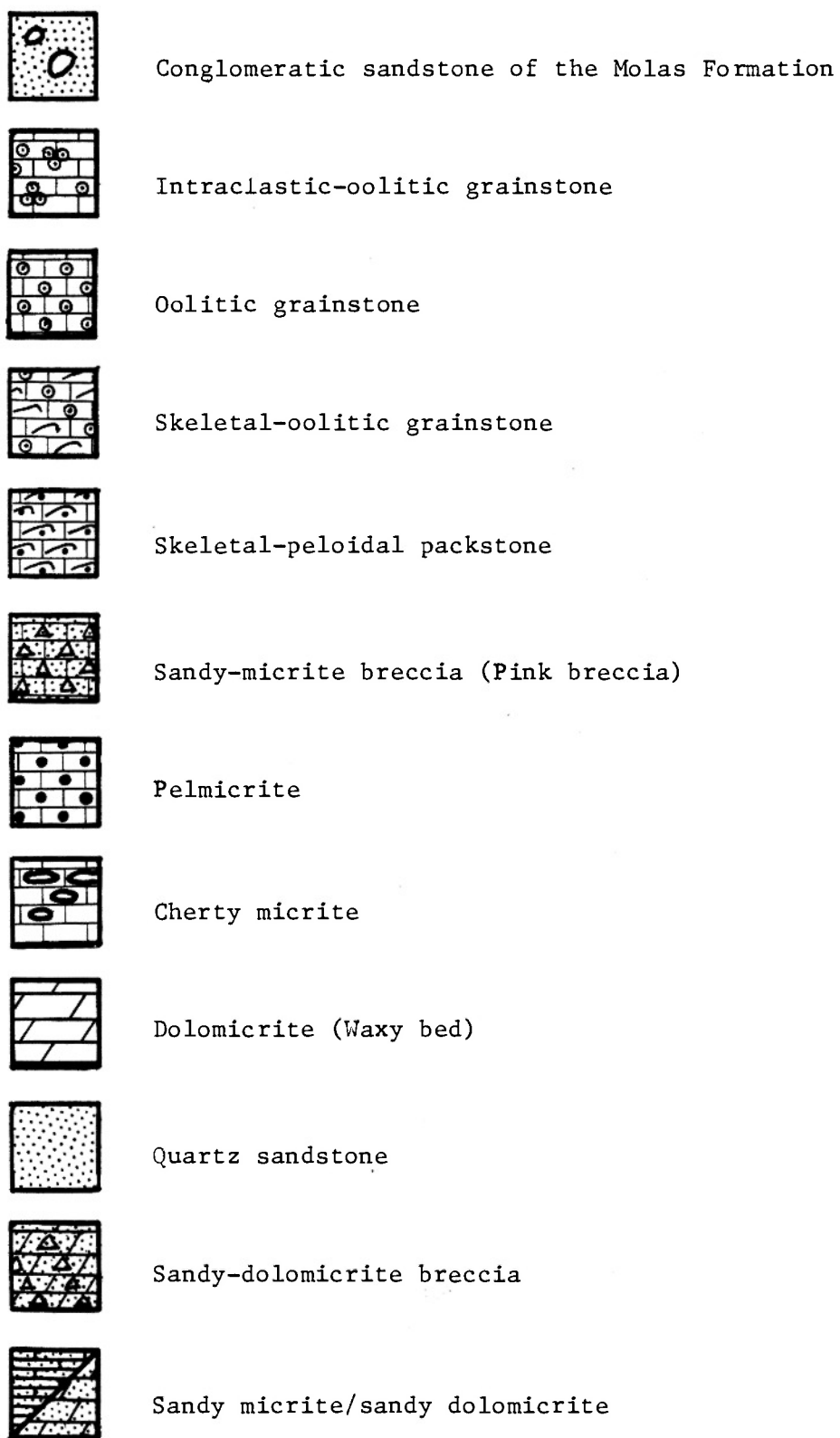
Figure 10. Lithologic symbols used in Tables 1, 2, and 3.

Table 1. Petrographic composition of Leadville Limestone at East Brush Creek, Fulford district. Abundances of components reported as volume percent and sizes reported in millimeters. FeO determined by staining with potassium ferricyanide as described by Lindholm and Finkelman, 1972.

SAMPLE #	FRAMEWORK COMPONENTS											MATRIX COMPONENTS				
	breccia fragments	oolites (size)	peloids (size)	SKELETAL COMPONENT					quartz sand (size)	microcline feldspar	muscovite	micrite	dolomicrite	CEMENTS (%FeO)		
				crinoid	echinoid	foram	ostracod	other						calcite spar mosaic	syntaxial overgrowths	drusy calcite
BCSC		76.3 (.3-.8)		2.1	0.9			0.3						19.4 (1.5-3.0)	0.6 (0-1.5)	0.4 (0)
MRX-7A3		65.7 (.2-1)		8.1	2.1	0.7	0.3	0.3						19.1 (1.5-2.0)	1.7 (1.5-2.0)	0.4 (0)
MRX-6A			72.6 (.2-.3)	8.9	1.1	1.4		0.6				13.8				
MRX-5A	77								12 (0.5)			5		5 % prismatic calcite cement		
MRX-4A			86									5		8		
MRX-3A									4 (0.6)				96			
MRX-2A2									66.2 (.2-.7)	15.2	<0.5		18.6			
MRX-2A1	51.4								15.4 (.1-.8)	3.9	0.6		28.7			
MRX-1A							<0.1		33.9 (.2-.3)	7.3	0.5	58.3				

Table 2. Petrographic composition of Leadville Limestone at Nolan Canyon, Fulford district. Abundances of components reported as volume percent and sizes reported in millimeters. FeO determined by staining with potassium ferricyanide as described by Lindholm and Finkelman, 1972.

Castle Butte Member

pink breccia

Redcliff Member

waxy bed

Gilman Sandstone Member

SAMPLE #	FRAMEWORK COMPONENTS												MATRIX COMPONENTS					
	breccia fragments (intraclasts)	oolites (size)	peloids (size)	SKELETAL COMPONENT				quartz sand (size)	micro-cline	musco-vite	micrite	dolo-micrite	CEMENTS (%FeO)				
				crinoid	echinoid	foram	other						calcite spar mosaic	syntaxial overgrowths	drusy calcite	quartz overgrowths	dolo-mite
BHX-23	(55)	25 (.5-.8)		2.6	0.9								14.9 (0-3.0)	0.5 (0)	0.5 (0)	0.7 % geopetal silt	
MRX-5-6		64.9 (.2-1)		7.7	1.8	0.6	0.5						21.6 (1.5-2.0)	2.0 (1.5-2.0)	0.7 (1.5-2)		
MRX-6C			74.1 (.2-.4)	8.7	1.6	1.0	0.5				12.0		2.0 (1.0)				
PB-C	75							18 (.5-1)			5		2 % prismatic calcite cement				
MRX-RC			86								98.7		1 % microspar				
MRX-WC								3 (.06)				96.6					
MRX-5C								68.4 (.2-.7)	3.8	<0.5		27.8					
MRX-2C	62.1							11.2 (.1-.8)	3.2	<0.5		23.2					
MRX-4C								44.7 (.2-.6)				54.3					
MRX-1C								74.6 (.2-.3)	<0.5							6.1	18.2

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canyon, part of the interbedded unit is above a mineralized vein that occurs in the upper Dyer Dolomite. That part of the Gilman over the vein has been silicified and is a moderate to dark yellowish-brown (10YR6/6), jasperoid, chert breccia. The alteration can be followed along strike for approximately 30 feet north from the canyon and is not more than 10 feet wide on the outcrop. Above the interbedded unit is a 4.6 to 6.9 feet thick, dolomitic sandstone that is lithologically similar to the sandstone lenses in the East Brush Creek section. This unit, on the Craig Peak Ridge south of Nolan Creek, is exposed along strike throughout the mapped area north of Nolan Creek.

Jackpot Mine Section.-- The Gilman Sandstone exposed near the Jackpot Mine is similar to that exposed in the East Brush Creek section. In the Jackpot section (Table 3 and Appendix 1), the basal Gilman is a thin-bedded, light to medium gray (N6-N7), sandy dolomicrite that is 9.8 feet thick and contains small (2-5 inches thick) sand lenses. The sandy dolomicrite crops out in the hillside above the Jackpot Mine but is not exposed north or south of the area.

Overlying the sandy dolomicrite is a 7.4 feet thick sandy, dolomicrite breccia similar to the breccia of the East Brush Creek section, but containing no sandstone lenses. Above the breccia is a sandy dolomicrite that is 9.8 to 11.5 feet thick and contains small stringers of quartz-sand grains. The stringers become lenses at the upper contact of the unit and occupy scour channels on the upper Gilman surface.

Redcliff Member

The middle member of the Leadville Limestone, the Redcliff Member, named for exposures near Redcliff, Colorado, and defined by Nadeau (1971), is the most lithologically consistent of the three members, throughout the study area consisting almost entirely of micrite and dolomicrite. The basal unit of the Redcliff Member rests discordantly on the Gilman Sandstone and consists of a
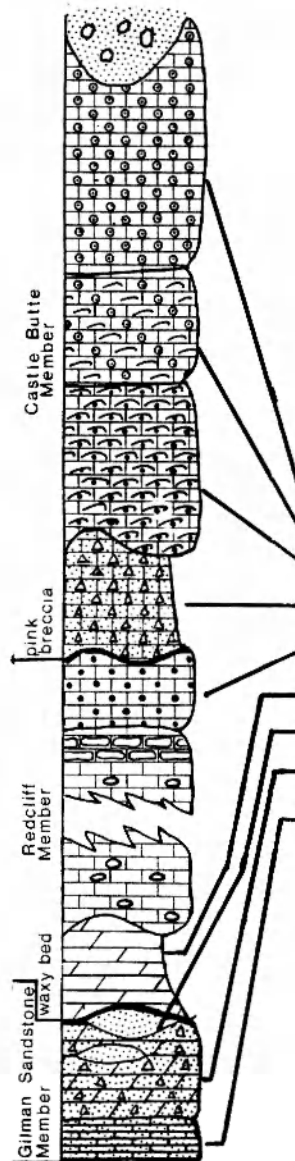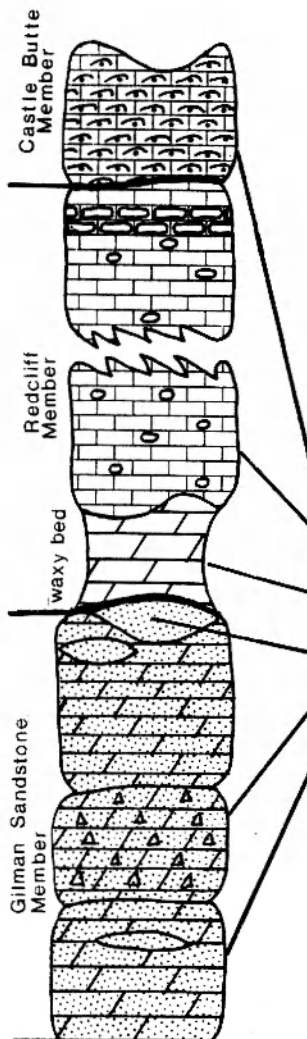
Table 3. Petrographic composition of Leadville Limestone at Jackpot Mine, Fulford district. Abundances of components reported as volume percent and sizes reported in millimeters. FeO determined by staining with potassium ferricyanide as described by Lindholm and Finkelman, 1972.

SAMPLE #	FRAMEWORK COMPONENTS											MATRIX COMPONENTS	
	breccia fragments	peloids (size)	SKELETAL COMPONENT					quartz sand (size)	microcline feldspar	musco-vite	micrite	dolomi-crite
			crinoid	echinoid	foram	ostracod	other					
MRX-6B		73.2 (.2-.4)	9.3	1.2	1.2		0.5				14.4	
MRX-RB											100	
MRX-WB								2.2 (.06)			97.6	
MRX-4B								69.8 (0.5)	0.8	<0.5		29.4
MRX-2B	64.2							11.2 (0.6)	3.0	<0.5	5	21.3
MRX-3B								46.9 (0.6)				53.1

Castle Butte Member

Redcliff Member

waxy bed

Gilman Sandstone Member

very fine-grained, dense dolomicrite that has been traced from the White River

Plateau to the Sangre de Cristo Mountains (Engel and others, 1958; Banks, 1967;

Tweto and Lovering, 1977). This unit is dense even in larger mining districts

where all associated rocks are altered or replaced due to secondary

dolomitization. Because of its waxy luster, this unit is referred to as the

"Waxy bed" (Engel and others, 1958; Banks, 1967; Nadeau, 1971). In the

mineralized districts, the Redcliff above the Waxy bed consists of fine-grained

secondary dolomite. However, in the Fulford district, the upper Redcliff is

undolomitized and unaltered.

The Redcliff is lithologically very consistent throughout the study area.

The basal Waxy bed consists of a yellowish-gray (5Y8/1) to medium gray (N6)

dolomicrite. Above the Waxy bed, the Redcliff is a thick-bedded, medium dark

to medium light gray (N4-N6) micrite with pelmicrite overlying the micrite in

one section. The Redcliff also contains abundant nodular and bedded black

chert. In the mapped area, the Redcliff Member generally forms well-exposed

cliff faces where it is cut by stream valleys. The lowermost unit of this

member, the Waxy bed, forms a characteristic hackly, reentrant exposure at the

base of these cliffs. The Redcliff also forms part of the dip slope on the

flanks of New York Mountain and Craig Peak.

In the southern part of the mapped area, the Redcliff is well-exposed

(Fig. 6). South of East Brush Creek, the Redcliff forms part of the canyon

wall. North of East Brush Creek, the Redcliff exposure is discontinuous for

approximately 2300 feet along strike, after which it becomes covered completely

by vegetation.

In Nolan Canyon, the Redcliff forms cliff exposures in the canyon wall and

south of the canyon, the Redcliff is exposed mainly as part of the dip slope

(Fig. 5). This exposure continues south from the Nolan Canyon section for

approximately 1500 feet to the Craig Peak Ridge, where the Redcliff forms

another cliff exposure. North of Nolan Canyon, the Redcliff is exposed discontinuously, as part of the dip slope, throughout most of the area between the Nolan Canyon section and the Jackpot Mine section.

East Brush Creek Section.-- In the East Brush Creek section (Table 1 and Appendix 1), the basal Waxy bed is 4.4 to 5.1 feet thick owing to the discordant upper and lower contacts. The upper foot of the unit contains 1-inch thick stringers of bedded chert that extend for approximately 3-4 feet laterally. Due to its characteristic reentrant exposure, the Waxy bed is not exposed on the surface north or south of the East Brush Creek section. Above the Waxy bed in this section, the Redcliff is a 33.4 feet thick, very thick-bedded micrite. Nodular chert is scattered throughout the unit, the nodules resembling grapefruit in size and shape. Above the micrite is a 5.0 to 6.4 feet thick pelmicrite.

Nolan Canyon Section.-- In Nolan Canyon (Table 2 and Appendix 1), the Waxy bed is exposed only on the south wall of the canyon and is 2.6 to 4.6 feet thick. The upper Redcliff there is a 49.2 feet thick, very thick-bedded micrite that forms a cliff constituting most of the southern wall of the canyon. Unlike the Waxy bed, the upper Redcliff is exposed north and south of Nolan Canyon as part of the dip slope. This outcrop occurs at an elevation of approximately 10,250 feet on the flank of New York Mountain and is approxiamtely 160 feet wide (Fig. 5).

Jackpot Mine Section.-- At the Jackpot Mine section (Table 3, and Appendix 1), the Redcliff Member is exposed above the mine on the hillside. There, the Waxy bed is 4.1 to 5.6 feet thick. Throughout the Waxy bed are broken layers of black chert that are laterally continuous for 3 to 5 feet. The upper surface of the Waxy bed exhibits 0.5 to 2 feet fc relief. Above the Waxy bed, the Redcliff is 47.6 feet thick and consists of micrite. In the upper six feet, there are abundant black chert layers that are 3 to 4 inches thick and

laterally discontinuous.

Castle Butte Member

The uppermost member of the Leadville Limestone is named the Castle Butte Member for exposures at Castle Butte on Aspen Mountain (Nadeau, 1971). The Castle Butte Member is separated from the Redcliff Member by a brecciated and slightly sandy and shaly micrite. The term, "Pink breccia", is used at the Gilman Mine to identify this unit, which has been identified in many areas of the northern Sawatch Range (Banks, 1967; Nadeau, 1971; Jarvis, 1972; DeVoto and Maslyn, 1977;), and in the Aspen district, the Pink breccia is the principal host rock of Pb-Ag-Zn deposits. In the mining districts on the eastern flank of the Sawatch Range, the Castle Butte consists of medium- to coarse-grained, recrystallized dolomite and is the major host rock of the ore deposits. The ore deposits are related to solution features, breccia-filled caves, and soil zones related to karst topography that developed on top of the Castle Butte Member in Late Mississippian time (DeVoto and Maslyn, 1977).

The Castle Butte Member is lithologically more varied than the Redcliff Member. The basic Castle Butte stratigraphy within the study area is as follows: (1) a basal, sandy micritic breccia (Pink breccia), (2) a skeletal-pelletal packstone, (3) a skeletal-oolitic grainstone, and (4) an upper oolitic grainstone. Locally, an intraclastic-oolitic facies occurs in the upper Castle Butte.

Near the Fulford Cave (Fig. 6), the Castle Butte (the only member exposed north of the cave) has been secondarily altered to a coarsely crystalline limestone (marble). This alteration occurs over an area of approximately 3.5 acres that surrounds a small intrusion of igneous rock. The dike-like intrusion is approximately 800 feet long, 150 to 200 feet wide, and consists of hornblende latite porphyry (Fig. 6). Other secondary crystalline carbonates

occur in the Castle Butte as dolomite pods that replace the limestone.

The Castle Butte Member is exposed throughout the mapped area in cliff exposures and dip slopes. The top of the Castle Butte Member marks a distinct change in slope along the western flank of New York Mountain as the overlying Pennsylvanian sedimentary rocks do not form the resistant dip slopes or cliff exposures. The Castle Butte Member forms dip slopes in the southern part of the mapped area (Fig. 11). South of East Brush Creek, the Castle Butte outcrop is about 250 feet wide and extends south from the creek for approximately 1300 feet. North of East Brush Creek, on the west flank of Craig Peak, the Castle Butte Member outcrop is 250 to 1000 feet wide and extends north for approximately 3000 feet (Fig. 6). The Castle Butte Member is also exposed in the canyon wall of East Brush Creek Canyon.

In Nolan Canyon, the Castle Butte Member forms cliff exposures in the canyon wall. South of the canyon for 1000 feet, the member forms dip slopes approximately 250 feet wide (Fig. 5). From Nolan Canyon north to the Jackpot Mine section, a distance of approximately 1500 feet, the member is discontinuously exposed (Fig. 5). From the Jackpot section northward, the Castle Butte Member is not exposed due to the forest cover and only the lowermost part of the member is exposed in the Jackpot section.

East Brush Creek Section.-- In the East Brush Creek section (Table 1 and Appendix 1), the basal Castle Butte Member, the Pink breccia, consists of angular and ellipsoidal clasts of upper Redcliff and lower Castle Butte rock in a matrix of sandy and clayey micrite. In the East Brush Creek section, the Pink breccia is 10.1-11.8 feet in thickness and is exposed only in the canyon wall; it could not be observed on the surface for any mappable distance. Above the Pink breccia is 15.3 feet of thick, skeletal-pelletal packstone. Overlying the packstone are a skeletal-oolitic grainstone that is 8.2 feet thick, and an oolitic grainstone, 21.0 to 22.5 feet thick. The oolitic grainstone forms the

Figure 11. Oblique aerial view of the southern Fulford area. Shown is the East Brush Creek drainage (from upper left to lower center) and the dip slopes formed by the upper Leadville Limestone "Ml" and outcrop of the Belden Formation "IPb".

majority of the cliff exposure in East Brush Creek and the dip slope in the southern part of the mapped area (Figs. 6 and 11). Isolated syringoporid coral colonies were observed in each of the three uppermost Castle Butte units at East Brush Creek. Secondary dolomite is also in the upper Castle Butte in East Brush Creek where it replaces the limestone in pods that are discordant to bedding. The pods are approximately six feet wide with a thickness ranging from 2 feet to greater than 3 feet.

Nolan Canyon Section.-- In this section (Table 2 and Appendix 1), the Pink breccia is 2.1 to 3.2 feet in thickness, is similar to the Pink breccia of East Brush Creek, and forms a small indentation near the top of the cliff exposure. Above the Pink breccia is a skeletal-pelletal packstone that is 16.4 feet thick in the cliff exposure. The packstone is similar to the packstone of the East Brush Creek section. Overlying the packstone is a skeletal-oolitic grainstone. The grainstone ranges in exposed thickness due to the heavy forest cover, but is generally between 19.7 and 21.3 feet thick. South of Nolan Canyon the grainstone unit grades into an intraclastic-oolitic grainstone that is exposed over an area of approximately 1.5 acres between Nolan Canyon and the Craig Peak Ridge (Fig. 5).

Jackpot Mine Section.-- At the Jackpot Mine (Table 3 and Appendix 1), the Pink breccia is absent and the Redcliff-Castle Butte contact is marked by an abrupt change from micrite to 4.9 feet of skeletal-pelletal packstone. This is the same facies as that above the Pink breccia in the Nolan Canyon and the East Brush Creek sections.

<div align="center">MOLAS FORMATION</div>

The Leadville Limestone was eroded unevenly before deposition of the overlying Pennsylvanian sedimentary rocks. Chemical weathering of the limestone during this erosional period produced a karst surface and also produced a residuum of clay and silt. This layer of regolith, where recognizable as a

thin stratigraphic unit, is designated the Molas Formation (Powers, 1969). The Molas Formation is not recognizable in the Fulford district except in isolated occurrences where sandstone fills channels cut into the upper Castle Butte Member, as on the dip slope 250 feet south of East Brush Creek (Fig. 6). There, the Molas occurs as a fine-grained, conglomeratic sandstone lens 6.4 feet thick and approximately 8 feet wide (Fig. 12).

PENNSYLVANIAN SYSTEM

Shale and limestone strata above the Leadville Limestone were originally called the Weber Shale by Emmons (1882). In 1942, Brill proposed the name, Battle Mountain Formation, for the Weber Shale and overlying Maroon Formation. He then distinguished the former Weber Shale as the Belden Shale Member of the Battle Mountain Formation. The Belden Shale was later designated the Belden Formation by Brill (1952). The Belden Formation is poorly exposed in the Fulford district. The Belden does not form part of the dip slopes in the area, so the lower contact of the formation occurs where the dip slopes of Leadville Limestone plunge beneath the surface. The Belden Formation is exposed in prospect pits and in mine dumps in and around Adelaide Park, northwest of Nolan Canyon (Fig. 5). The formation is also exposed along East Brush Creek just below the beaver pond near Fulford Cave (Fig. 6). Throughout the mapped area, the Belden Formation consists of dark gray to black (N3-N1), carbonaceous shale in beds 2.5 feet thick, interbedded with 1-foot thick, dense, black (N1), algal micrite, and is estimated to be 250 feet thick.

Figure 12. Conglomeratic sandstone of the Molas Formation exposed south of East Brush Creek. Fragments are of Leadville Limestone.

P E T R O G R A P H Y
O F T H E
L E A D V I L L E   L I M E S T O N E

GILMAN SANDSTONE MEMBER

Basal Sandstone

The basal sandstone in Nolan Canyon is composed mostly of fine to medium sand-sized quartz grains cemented by dolomite and quartz (Table 2 and Appendix 2). The quartz grains are rounded to well-rounded; a few have been replaced by dolomite. Quartz cement occurs as indigenous overgrowths around the rounded nuclei, and was probably the early binding cement with dolomite later filling the pore spaces. The sandstone also contains less than 0.5 volume percent unweathered detrital microcline.

Sandy Micrite and Sandy Dolomicrite

The sandy carbonate units of the Gilman Member consist of quartz sand grains in fine-grained carbonate (dolomicrite or micrite) matrix. The Jackpot Mine and the Nolan Canyon sections of these units are similar petrographically (Tables 2 and 3, and Appendix 2), consisting of approximately 45 percent quartz sand grains in a dolomicrite matrix. The East Brush Creek section, however, is calcitic not dolomitic; the quartz sand grains occur in thin (1-5 mm) stringers oriented parallel to bedding. In addition, the East Brush Creek section contains approximately 7 percent unweathered, detrital microcline feldspar. A few ostracode carapaces were also observed in the units from all sections.

Sandy Dolomicrite Breccia

The breccia units are similar petrographically and consist of fragments of Dyer Dolomite, chert, dolomicrite, and quartz sand grains, all in a dolomicritic matrix (Tables 1, 2, and 3). The breccias also contain unweathered microcline feldspar grains that increase in abundance from the

Jackpot Mine section to the East Brush Creek section (north to south). The abundance of quartz sand grains also increases from north to south (Tables 1, 2, and 3).

In the Nolan Canyon Section, parts of the breccia unit have been silicified near a mineralized vein. Where silicified, all the fragments are composed of chert, but the matrix is coarser-grained chalcedonic quartz and is also heavily iron-stained.

Interbedded Sandstone Lenses and Upper Sandstone

The interbedded sandstone lenses in the East Brush Creek and Jackpot Mine sections and the upper sandstone unit at Nolan Canyon are similar, being composed of quartz sand grains, unweathered microcline feldspar, and traces of muscovite, cemented by microcrystalline dolomite. An increase in the amount of microcline also occurs from north to south as in the lower Gilman units (Tables 1,2, and 3).

REDCLIFF MEMBER

Waxy bed

The basal Redcliff, the Waxy bed, consists of dense, laminated microcrystalline dolomite grains that are approximately .003 mm in diameter. Laminae of coarse silt-sized quartz grains occur, although these are not abundant (Tables 1, 2, and 3). Although scattered bores occur, generally throughout the Fulford district the Waxy bed is a nonfossiliferous, monotonous dolomicrite.

Upper Redcliff

Above the Waxy bed, the upper Redcliff is composed mostly of microcrystalline calcite grains that are less than 0.01 mm with an average size of from 0.004 to 0.006 mm. The upper Redcliff is the same throughout the study

area except in the East Brush Creek section where the upper six feet are pelletal micrite that has been neomorphosed to peloid-bearing crystalline limestone (Table 1). This rock consists of densely packed, relict peloids composed of equidimensional calcite grains 0.02mm in diameter. Euhedral, authigenic quartz crystals also occur in this unit and range from 0.05 to 0.5 mm in diameter.

CASTLE BUTTE MEMBER

Pink Breccia

The lowermost Castle Butte, the Pink breccia, is composed of fragments of Redcliff and Castle Butte rock in a matrix of micrite, quartz-sand, silt, and organic matter. The breccia fragments are angular and ellipsoidal, range in size from 0.25 cm to more than 2.5 cm, and consist of skeletal-peloidal packstone from the overlying Castle Butte Member and micrite from the underlying Redcliff Member. The fragments are coated by dark organic material and surrounded by a matrix of fine sand- and silt-sized quartz grains. Some prismatic calcite cement occurs in voids between the fragments and matrix.

Skeletal-Peloidal Packstone

Above the Pink breccia, the Castle Butte Member is a packstone composed of pellets and skeletal debris in a micritic matrix. The packstone is similar in all three sections of the study area and consists of pellets with crinoid columnals, foraminiferal tests, and echinoid fragments as minor components (Tables 1, 2, and 3). Interparticle space is occupied by nonferroan micrite which has, in the East Brush Creek and Nolan Canyon sections, been partly recrystallized to sparry calcite (spar). No pore-filling calcite spar is observed in the packstone at the Jackpot Mine section.

Skeletal-Oolitic Grainstone

Above the packstone, the Castle Butte Member is a grainstone containing oolites and skeletal debris. The petrographic composition of the grainstone is similar throughout the study area, with oolites and crinoid columnals as the major framework components, and echinoid fragments, foraminiferal tests, ostracode shell fragments, and other skeletal fragments as minor components (Tables 1, 2, and 3).

The grainstone has three types of cement: sparry calcite mosaic, syntaxial overgrowths (rim cement) on echinoderm fragments, and drusy calcite crusts on particles. Sparry calcite is volumetrically the most abundant pore-filling cement, with syntaxial rim cement and drusy crusts the second and least abundant, respectively. The cements are similar in both sections where oolitic-grainstone occurs (Tables 2, and 3).

Stained thin sections of the skeletal-oolitic grainstone reveal that all framework components and drusy calcite crusts are composed of nonferroan calcite. However, a darkening of the stain indicates that all pore-filling calcite mosaic cement is ferroan calcite, containing approximately 1.5-2.0 percent FeO. Even the syntaxial rim cement is ferroan calcite, but the echinoderm fragments retain their original nonferroan composition.

Upper Oolitic Grainstone and Intraclastic-Oolitic Grainstone

The vertical transition from skeletal-oolitic grainstone to upper oolitic grainstone is marked by a decrease in skeletal debris and an associated increase in oolites (Tables 1, 2, and 3). The oolites range in size from 0.36 to 0.80 mm, have nuclei of crinoid fragments, are encrusted by calcite, and show little development of radial fabric. The skeletal debris that does occur consists of crinoid columnals with syntaxial overgrowths; sparry calcite mosaic accounts for most of the pore-filling cement. Staining of thin sections

indicates that all framework constituents and drusy calcite crusts are composed of nonferroan calcite. However, all pore-filling cement, including syntaxial rim cement, is ferroan calcite containing approximately 2 percent FeO.

The grainstone at Nolan Canyon is different from that at East Brush Creek in that at Nolan Canyon it contains intraclasts which compose more than half of the rock and range in size from 1.0 mm to more than 2.0 cm (Table 2). Within the intraclasts are oolites that are coated with an isopachous rim cement of acicular calcite crystals that are 0.065 mm long (Fig. 13). The remaining framework of the grainstone is compositionally similar to the oolitic grainstone at East Brush Creek, except for the pore-filling cements. In addition to sparry calcite mosaic, syntaxial rim cement, and drusy crusts, the Nolan Canyon unit contains a cement consisting of calcite crystals approximately 0.01 mm long (Fig. 14). The geopetal structure of this cement indicates that it is penecontemporaneous with precipitation of mosaic cement and postdates precipitation of the drusy crusts.

Staining indicates that all framework constituents, including the intraclasts, are composed of nonferroan calcite. The mosaic of sparry calcite cement is mostly ferroan calcite with different percentages of FeO occurring in discrete zones. The change in FeO appears to be crystallographically controlled because the earliest mosaic cement is nonferroan and shows the characteristic dog-tooth shape against pore space (c-axis perpendicular to the wall of pore space). The next generation of cement, though optically continuous with the first, contains approximately 1.0 to 1.5 percent FeO. The FeO content increases, as seen by a darkening of the stain, in discrete zones within single crystals toward the center of the pore space, the maximum FeO content reaching approximately 2.5 to 3.0 percent (Fig. 15).
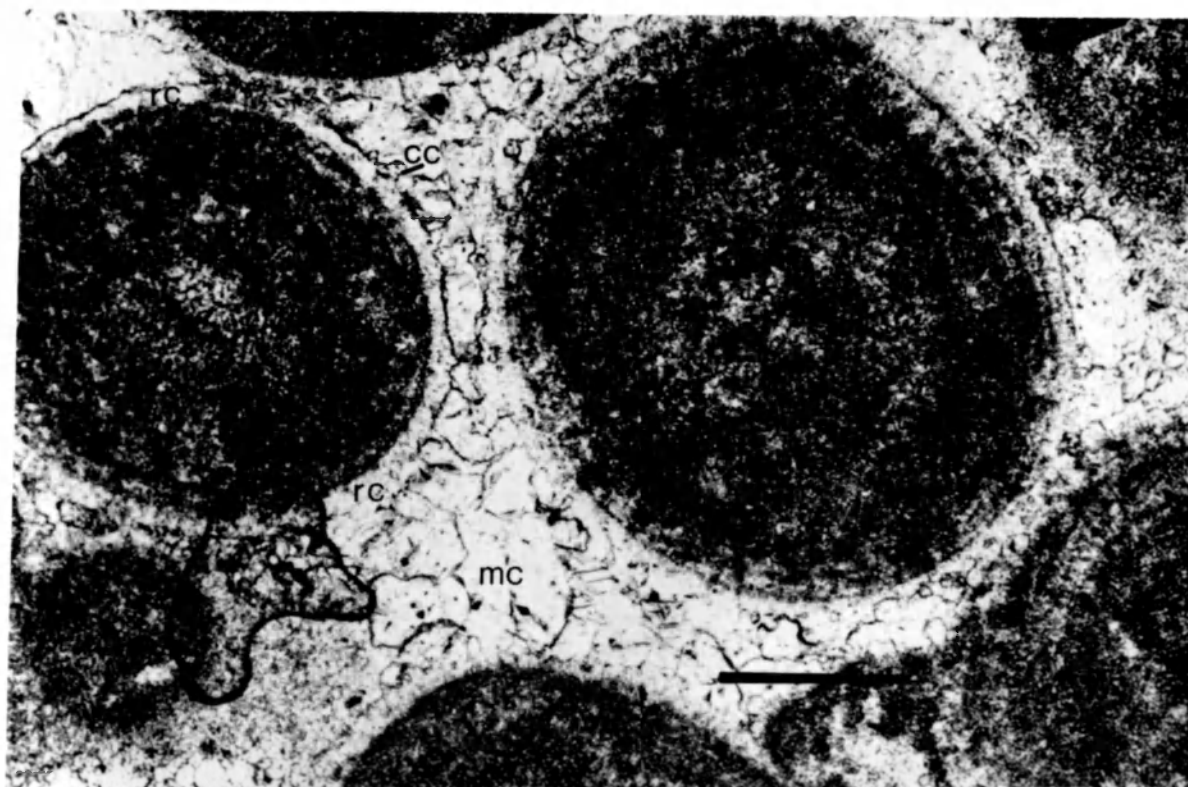
Figure 13.   Photomicrograph of oolites in intraclasts of the intraclastic-
             oolitic grainstone exposed at the Nolan Canyon section. Note the
             isopachous rim cement "rc", the drusy calcite crusts "cc", and the
             calcite mosaic cement "mc".   Scale is 1 millimeter.

Figure 14.   Photomicrograph of "crystal silt" (see "a" near center of view)
and syntaxial rim cement "b" in the intraclastic-oolitic grain-
stone exposed at Nolan Canyon.   Scale is 1 millimeter.

Figure 15. Photomicrograph of stained cements in the intraclastic-oolitic grainstone exposed at Nolan Canyon. Heavy outline designates crystal boundaries. Allochems "a" and early pore-filling cement "b" are iron-free, but later generations of cement "c,d" contain progressively more ferroan iron, as shown by the darker stain. Scale is 1 millimeter.

E C O N O M I C   G E O L O G Y

INTRODUCTION

The Fulford district was established by prospectors overflowing from the Leadville and Aspen districts and owed its short life to small gold-copper-quartz veins in Precambrian igneous rocks and in overlying Cambrian rocks. Small amounts of gold, silver, and copper were also found in Ordovician and Devonian rocks and in the Mississippian Leadville Limestone. According to Wolle (1949, p. 257), prospectors mined substantial gold just east of the Fulford district as early as 1849. However, the first mine was located within the Fulford district in 1887. The first issue of the Fulford newspaper, the Fulford Signal, published April 14, 1893, gave glorified accounts of many discoveries of lead, gold, and silver ore. Several discoveries were in the "Blue Lime" (Leadville Limestone). That some production was realized from the mines of the district is evidenced by the remains of stamp mills that operated in the area.

MINERALIZATION IN THE FULFORD DISTRICT

The concentrations of copper, lead and zinc in the Leadville Limestone are relatively constant, except in actual ore. Engel and Engel (1957) reported concentrations of copper, lead and zinc to be 3, 3, and 10 ppm, respectively, and Banks (1967) reported similar values for both the Leadville Limestone and the limestone of the Dyer Dolomite. These values are the same for unaltered limestone, dolomitized limestone, and limestone near ore (Engel and Engel, 1957, Banks, 1967). The concentration of these elements is also similar to the average concentrations of 4 ppm copper, 9 ppm lead and 20 ppm zinc stated by Turekian and Wedepohl (1961) as an average for carbonate rocks.

The results of geochemical analyses of samples from the Fulford district are in Table 4. Samples were collected in and around areas of prospecting and

mining activity and visible secondary mineralization; therefore, samples are lacking from the middle member where no prospecting, mining activity, or secondary mineralization was located.

In the Fulford district, unaltered, unmineralized Leadville contains 7 ppm copper, 1 ppm lead, and 11 ppm zinc (Table 4, sample 11). These values are taken as background concentrations in the Leadville Limestone of the Fulford area. In the unmineralized samples, the concentration of silver is 1.9 ppm and that of gold is less than 0.02 ppm. Thes values, therefore, are considered as background for silver and gold in Leadville Limestone of the Fulford district; concentrations significantly greater than background are considered anomalous.

Several abandoned mine workings and prospect pits in the Belden Formation, Leadville Limestone, and Dyer Dolomite are scattered throughout the mapped area. The greatest density of prospecting evidence and mining activity occurs in the northern part of the map area (Fig. 5); much less activity occurred in the southern part of the map area. Only one prospect is within the 1/4-square mile southern area shown in Figure 6, whereas 13 prospects or mines are within the northern area shown in Figure 5, one-half the area of Figure 6.

The largest mining operation in the study area was the Jackpot Mine (Fig. 5, sample site 13). The mine tunnel, on the hill above Nolan Canyon, extends eastward into the hillside for approximately 250 feet. The tunnel entrance is in the lower Gilman Sandstone near the Mississippian and Devonian contact. The tunnel was driven to develop gold-copper ore that occurs in a northwest-trending vein deposit (Gableman, 1949). The mineralized vein, as exposed in the tunnel, cuts through the sedimentary rocks from the Manitou Dolomite to the Dyer Dolomite but does not extend into the Leadville Limestone; however, Gilman Sandstone exposed near the mine portal contains anomalous quantities of copper (29 ppm), lead (28 ppm), and zinc (110 ppm) and slightly anomalous gold (0.26 ppm).

Table 4. Concentration of trace metals (in ppm ±10 percent) in samples collected in the Fulford district. Samples are located at their approximate stratigraphic position. Analyses were by Cone Geochemical of Denver, Colorado. For location of samples see Figures 5 and 6.

Member	Sample # & Location	Cu	Pb	Zn	Ag	Au	NOTES
Belden Shale	1. Adelaide Park	21	6	23	1.6	<.02	Dump Sample
Belden Shale	2. "	4	<1	10	2.0	<.02	Dump Sample
Belden Shale	3. Near Adel. Pk.	7	3	29	2.3	<.02	Large Prospect pit
Castle Butte Member	4a. Adelaide Park	56	5	27	3.4	<.02	Prospect (outcrop)
Castle Butte Member	b. "	136	23	103	5.1	<.02	Prospect (outcrop)
Castle Butte Member	15. Near cave	5	<1	11	2.0	0.14	Dump Sample
Castle Butte Member	5a. Adelaide Mine	7	<1	28	2.2	<.02	Oxidized outcrop
Castle Butte Member	b. "	240	44	600	3.0	1.20	Dump Sample
Castle Butte Member	6. Above Adel. Mine	4	<1	20	1.8	<.02	Unoxidized Outcrop
Redcliff Member	16a. Near porphyry	4	57	7	2.2	<.02	Marble near dike
Redcliff Member	b. dike north of	5	<1	12	1.8	<.02	Marble away from dike
Redcliff Member	c. Fulford Cave.	4	<1	7	2.0	<.02	Unaltered outcrop
Redcliff Member	7. Merry Widow Mine	93	47	84	2.3	0.11	Dump Sample
Gilman Sandstone Member	13. Jack Pot Mine	29	28	110	1.9	0.26	Outcrop near portal
Gilman Sandstone Member	9. S. of Nolan Canyon	18	27	112	2.1	<.02	Prospect (outcrop)
Gilman Sandstone Member	10. "	57	154	195	2.1	1.27	Prospect (outcrop)
Gilman Sandstone Member	14a. Craig Pk. Ridge	9	<1	15	1.7	<.02	Prospect (outcrop)
Gilman Sandstone Member	17. E. Brush Creek	14	3700	1340	3.4	<.02	Outcrop in creek
Dyer Dolomite	8. Nolan Canyon	49	51	130	2.5	0.29	Prospect (outcrop)
Dyer Dolomite	14b. Craig Pk. Ridge	5	<1	10	2.0	<.02	Prospect (outcrop)
Dyer Dolomite	12. Alabama Mine	1.3%	5	13	1.1	<.02	Dump sample of quartzite
Dyer Dolomite	16d. same as 16a.	14	72	70	1.1	<.02	Latite porphyry dike

Another mine tunnel, approximately 200 feet vertically below the Jackpot Mine, was driven into the Castle Butte Member (Fig. 5, sample site 12). The tunnel is caved and probably is the Alabama Mine described by Gableman (1949, p. 163). He stated that the tunnel extends eastward for approximately 400 feet and was driven in an attempt to intersect the Jackpot vein at depth. Apparently only a small quantity of mineable ore was found, with the ore minerals being gold and chalcopyrite (Gableman, 1949, p. 163). Samples of quartzite from the dump contain visible chalcopyrite and malachite, contain near background amounts of lead, zinc, silver, and gold, but contain a highly anomalous amount of copper (1.3 percent, Table 4, sample 12). No Leadville Limestone was observed in the mine dump; however, Leadville Limestone around the tunnel portal is fresh and shows no traces of mineralization.

The prospects in Adelaide Park (Fig. 5 sample sites 1, 2, and 4) are small pits approximately 7 feet in diameter, 3 to 4 feet deep, and dug into the algal limestone and shale of the Belden Formation. Sample site four contains oxidized copper minerals (malachite and azurite) and limonite pseudomorphs after chalcopyrite. Sample site three consists of a large prospect pit approximately 15 feet in diameter and 6 feet deep. Although located near the contact of the Pennsylvanian and Mississippian rocks, the pit contained only black shale and algal limestone of the Belden Formation; no traces of mineralization were observed.

Prospects and mines become more concentrated southeast of Adelaide Park near Nolan Canyon; one of the few productive mines of the area is at the mouth of Nolan Canyon (Fig. 5, sample site 5). The mine consists of a collapsed tunnel that was driven northeast along strike of the Leadville Limestone, following a narrow, oxidized ore zone. Samples of oxidized, limonitic rock in the mine dump contain visible traces of oxidized copper minerals and chalcopyrite and contain extremely anomalous concentrations of all metals

assayed, especially gold and zinc at 1.20 and 600 ppm, respectively (Table 4, sample 5b). However, the Castle Butte Member in outcrop adjacent to the mineralized vein contains near background amounts of all metals, as does Castle Butte from outcrop above the mine (Table 4, samples 5a and 6). This mine was located and described by Gableman (1949) as the Adelaide Mine. The Fulford Signal, April 14, 1893, reported that shipments of ore from the Adelaide contained 15 oz/ton silver and 15 percent copper. The newspaper report made no mention of gold; however, Gableman (1949, p. 162) mentioned gold and chalcopyrite as the most abundant ore minerals.

Upstream from the Adelaide Mine a small wooden frame marks the entrance to another caved tunnel (Fig. 5 sample site 7). The tunnel apparently runs due east from its entrance which is in the Gilman Sandstone Member of the Leadville Limestone. Probably, the tunnel was driven to intersect any vein that might have been responsible for the silicified Gilman breccia, as the projection of the tunnel would pass directly beneath the outcrop of the silicified breccia. According to Gableman (1949), the tunnel is the Merry Widow Mine; no further information about the mine could be obtained. Samples of oxidized, limonitic rock from the dump at the mine portal do not contain any visible ore minerals; however, they are anomalously high in copper, lead and zinc (93, 47, and 84 ppm respectively) and slightly anomalous in gold (0.11 ppm, Table 4, sample 7).

Farther upstream from the Merry Widow Mine, in the Dyer Dolomite, an area of oxidized rock occurs on the north wall of Nolan Canyon below the surface outcrop of the silicified Gilman breccia. Amid the oxidized rock on the canyon wall is a small prospect (Fig. 5 sample site 8) in the Dyer Dolomite just below the contact of the Dyer and Gilman. No visible traces of mineralization are present; however, samples of the oxidized outcrop contain values of copper, lead, zinc, silver, and gold similar to the anomalously high values of sample seven (Table 4, sample 8).

On the south wall of Nolan Canyon the rocks show no oxidation or alteration. Several small caves are in the cliff exposure of Leadville Limestone, and they were reported by the Fulford Signal to contain much sulfide mineralization. Examination of the caves, however, did not reveal any mineralization or alteration.

South of Nolan Canyon (Fig. 5 sample sites 9, 10), two small prospects expose limonitic jasperoid rock similar to that exposed in Nolan Canyon. The prospects are small pits in the lower Gilman Sandstone, are approximately 3.5 feet in diameter, and are 2 feet in depth. The only trace of mineralization visible in the prospects is limonite pseudomorphs after chalcopyrite, but Gilman Sandstone from the prospects is anomalously high in copper, lead, and zinc (Table 4, samples 9 and 10). Sample 10 contains higher concentrations of these metals than sample 9 and also contains the highest concentration of gold (1.27 ppm) of any sample; the silver content of both prospects is near background.

Farther south, approximately 500 feet along strike, another prospect in the form of a tunnel was driven into the upper Castle Butte Member (Fig. 5, sample site 11). The tunnel extends southward approximately 35 feet into the outcrop. No mineralization, alteration, or oxidation occurs throughout the tunnel, or in the surrounding outcrop.

At the southern extent of the exposure of Leadville Limestone in the northern map area, there are two more small prospects (Fig. 5, sample sites 14a and 14b). The prospects are small pits 6 feet in diameter and 3 feet deep. The prospect pit at sample site 14a is in the lower Gilman Sandstone, and the prospect pit at sample site 14b is in the upper Dyer Dolomite. Neither prospect contains traces of mineralization or alteration, and samples of outcrop from the prospects contain only background concentrations of the assay metals (Table 4, samples 14a and 14b).

The single prospect in the southern map area is a tunnel driven into the upper Castle Butte Member, on the western flank of Craig Peak near the Fulford Cave (Fig. 6, sample site 15). The tunnel is caved and a small dump lies at the entrance. The Leadville Limestone around the portal and in the dump is unaltered and unmineralized and contains only background quantities of copper, lead, zinc, and silver with a slightly anomalous gold concentration of 0.14 ppm (Table 4, sample 15). South of the prospect, approximately 200 feet along strike, the Leadville Limestone has been contact metamorphosed to a medium- to coarse-grained marble by a dike of latite porphyry (Fig. 5, sample site 16). No prospects are in the marble or in the porphyry (Fig. 5, sample site 16), and no mineralization is visible. The concentration of metals in the metamorphosed Leadville Limestone near the igneous intrusion is near background except for a slightly anomalous concentration of lead (57 ppm) in the sample nearest the intrusion (Table 4, samples 16a, b, c, d). Although no other prospects are in the southern mapped area, sphalerite and galena occur in the dolomite pods of the Gilman Sandstone Member at East Brush Creek (Fig. 5, sample site 17). Also, unaltered micrite nearby contains small veinlets of calcite with visible sphalerite and galena. A sample of the mineralized Gilman Sandstone contains 3700 ppm lead and 1340 ppm zinc (Table 4, sample 17), the highest concentration of lead and zinc of any sample. The sample also contains an anomalous amount of silver; copper is only slightly above background.

D I S C U S S I O N

ENVIRONMENTS OF DEPOSITION
AND
EARLY DIAGENESIS

Late Mississippian Paleogeography of Central Colorado

The area roughly coincident with much of the Front Range and Wet

Mountains was a major emergent area affecting sedimentation during

Mississippian time (DeVoto, 1980). The Uncompahgre Uplift in southwest

Colorado also affected sedimentation during parts of Mississippian time

(Chronic, 1979). The approximate position of the Uncompahgre and Ancestral

Front Range uplifts in relation to the Fulford, Aspen, Gilman, and Leadville

districts is shown in Figure 16.

During Early Mississippian (Kinderhookian) time the sea began

transgressing from the west over all of Colorado west of the Front Range; the

Uncompahgre uplift was not emergent until Late Mississippian (Chronic, 1979)

and was probably covered by Mississippian strata that were eroded prior to

Pennsylvanian sedimentation (DeVoto, 1980). Vertical uplift of the Uncompahgre

and Front Range areas accelerated in Late Mississippian as "Colorado rose above

the sea and became a lowland" on which a karst surface formed (Chronic, 1979,

p. V6); however, DeVoto (1980, p. 57) pointed out that "local and regional

tectonic activity" influenced the karst development.

General Model of
Deposition in Epeiric Seas

The seas that spread over the interior of North America at one or more

times in all of the Paleozoic periods were epeiric seas (seas that spread over

the central part of continents), as distinguished from the Tertiary seas of the

Atlantic, Gulf, and Pacific coasts, which were marginal seas (seas that lap up

on continental margins). Shaw (1964) and Irwin (1965) explained in detail the
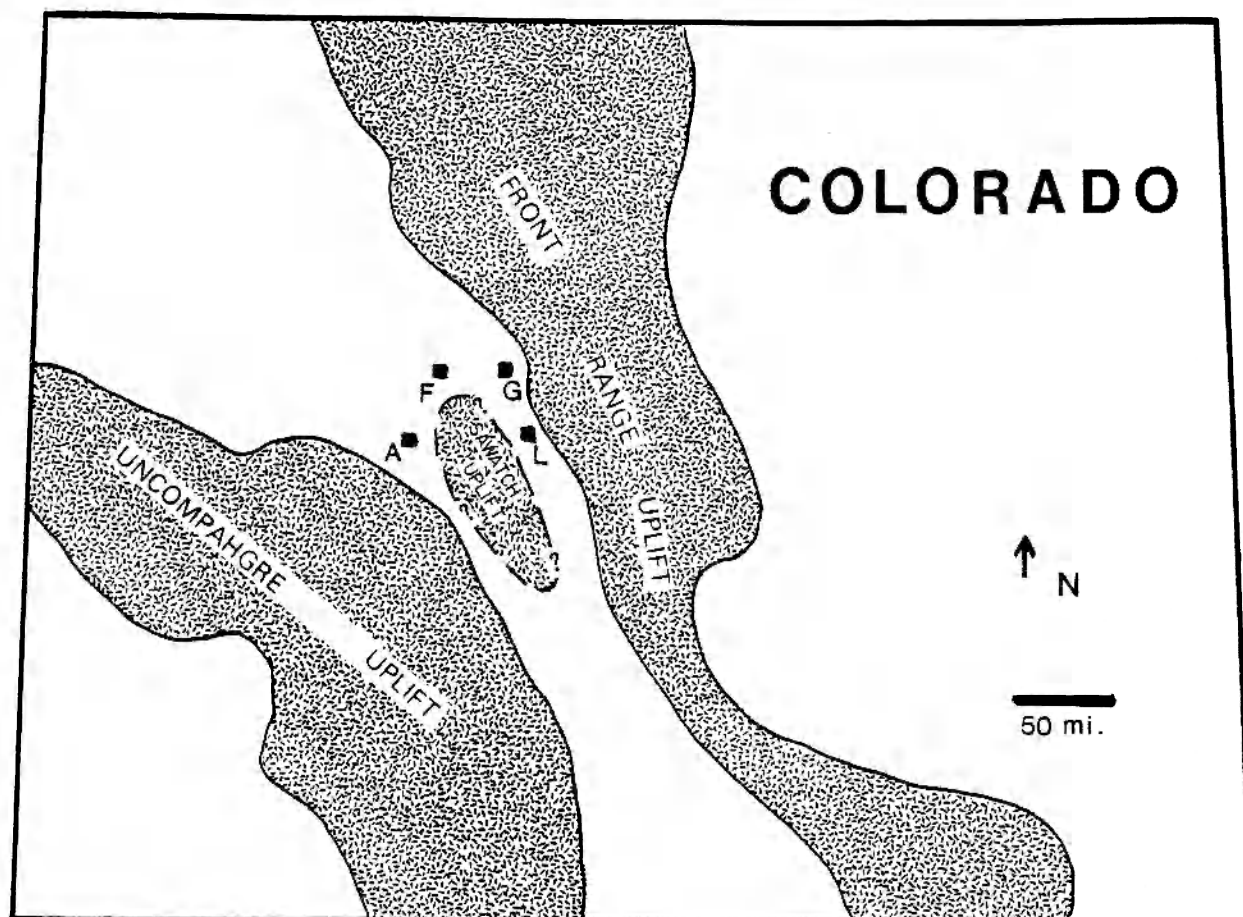
Figure 16. Sub-Pennsylvanian geology of Colorado. Patterned areas outline major uplifts at the end of Mississippian sedimentation. Located are the Leadville "L", Aspen "A", Gilman "G", and Fulford "F" mining districts (After DeVoto, 1983).

type of sedimentary deposits that would form within a shallow epicontinental

(epeiric) sea; they emphasized that such seas would have depositional slopes on

the average of 0.1 to 0.3 feet per mile and would extend seaward for hundreds

or even thousands of miles. Shaw and Irwin concluded that given such

widespread, shallow seas with such low depositional slopes, a necessary

consequence would be the development of different sedimentary environments

oriented parallel to the strand line. These environments, or zones, of

sedimentation and the relative energies of each are pictured in Figure 17.

From the deduced environments, Shaw (1964, p. 30, 31) described the

general rock types to be deposited laterally from the strand line seaward in an

epeiric sea:

> 1. Bittern salts of various types more
> soluble than sodium chloride. 2. Halite.
> 3. Anhydrite or gypsum, or both. 4. Fine-
> grained syngenetic dolomite [with or
> without the addition of terrigenous
> clastics]. 5. Fine-grained limestones....
> 6. Transitional limestones...pellet muds
> common locally. 7. Limestones indicative
> of...mechanically active environments,
> such as oolitic and fossil-fragmental...rocks....

Because the rock types are deposited laterally to one another, they

cannot occur in vertical succession without a migration of the depositional

environments. Therefore, in a transgression the near-shore sediments (1

through 4, above) will be overlain by offshore sediments and in regression, the

opposite.

Leadville Limestone of the Fulford Area

The carbonate lithologies previously described for the Leadville

Limestone of the Fulford district occur in a vertical sequence similar to units

4 through 7 described by Shaw (1964, p. 30, 31). Therefore, the Mississippian

sequence observed in the Fulford district is interpreted to be the result of

clear-water (carbonate) deposition in the transgressing Mississippian epeiric
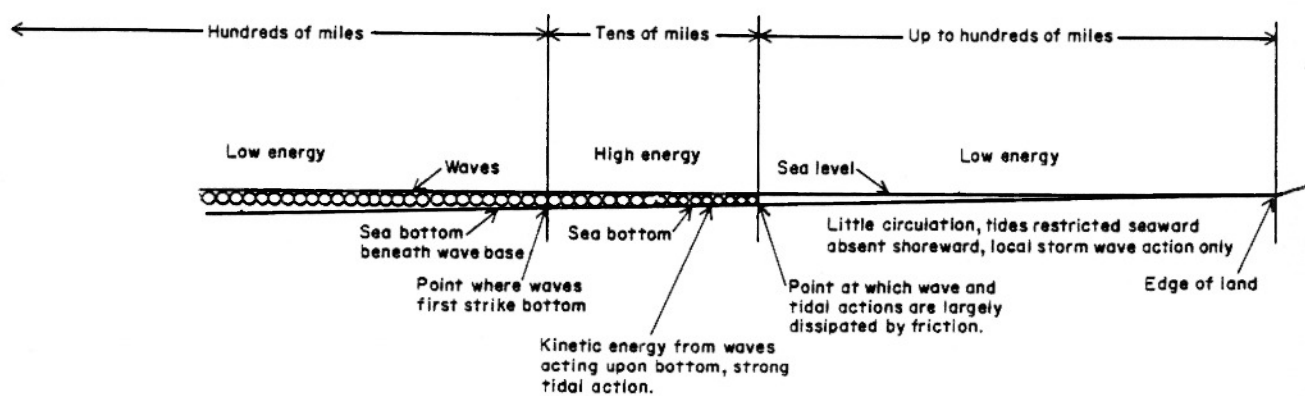
Figure 17. Theoretical energy zones that may develop in epeiric seas (From Matthews, 1974, p. 337).

sea.

The clastic lithologies of the Gilman Member are not discussed specifically in the models of Shaw and Irwin; however Shaw (1964, p. 70, 44) concluded that an epeiric sea will constantly try to impose the characteristic lithologies upon the site of deposition regardless of the amount of terrigenous input, and further, that "it would be inevitable to find something [clastic] at the base of a [transgressive] section unless the old land had been swept completely bare ...". Based on this statement, and the distribution of quartz sand grains and microcline in the Gilman Sandstone Member of the Fulford district, the Precambrian core of the Sawatch Range must have been at least partly exposed during deposition of the Gilman Sandstone and is interpreted to be the source for unweathered feldspar. A similar interpretation is made by Nadeau (1971, p. 22) for feldspar grains in the Gilman Sandstone of other areas in the northern Sawatch Range. The lower Paleozoic quartzites exposed on the flanks of the emergent Sawatch Uplift are considered by Nadeau (1972) and others (Conley, 1964; Wittstrom, 1979) to have provided the majority of the quartz sand grains. In addition, in order to provide a nearby source for the increased abundance of unweathered microline in the southern part of the Fulford district, the most extensive emergence of the Sawatch area during Gilman deposition was probably located south of the Fulford district, toward Aspen (Fig. 2).

The decrease in quartz sand and disappearance of microcline grains in the Redcliff Member indicates the complete submergence of the Sawatch Uplift at the end of Gilman deposition; the environment of deposition remained located in the same shoreward low-energy zone (Fig. 17), as indicated by the continued deposition of fine-grained dolomite (Waxy bed). The micrite of the Redcliff above the Waxy bed represents the eastward (shoreward) shifting of higher-energy regimes as transgression continued. The vertical progression from

micrite to pelletal micrite to skeletal-pelletal packstone to skeletal-oolitic grainstone and finally to oolitic grainstone represents the continued increase in depositional energies as the energy zones illustrated in Figure 17 shifted eastward (shoreward) during the Mississippian trangression.

Environments of Cementation
and
Stabilization

The majority of pore-filling cement in the Castle Butte Member is sparry calcite mosaic cement with minor syntaxial rim cement and drusy calcite crusts. All three types of cement are indicative of precipitation in the freshwater zone, either phreatic or vadose (Land, 1970, p. 184; Folk and Land, 1975, p. 66). In all units of the upper Castle Butte Member (Tables 1, 2, and 3), there is an increase in the FeO content of the cement from 0 percent in the early drusy and syntaxial cements to as much as 3 percent in the later calcite mosaic cement. Neal (1969) concluded that precipitation of ferroan calcite results from the influx of ground water when the sediment is in the vadose zone. Therefore, the pattern of nonferroan to ferroan calcite cement seen in the Castle Butte Member provides further evidence of cementation in the vadose and fresh-water phreatic zones. Also, according to Wagner and Matthews (1982) and Folk and Land (1975), the form of carbonate usually precipitated in these environments is low-Mg calcite, and according to Land (1970), the rate of stabilization to low-Mg calcite is extremely fast in these environments. Therefore, because the Castle Butte Member is shown to have been cemented in these environments, the components were probably stabilized to low-Mg calcite and the pore spaces cemented early in the rock's history.

KARST ACTIVITY

The post-Leadville, pre-Belden solution activity was related to uplift of the northern Sawatch Range in the Mississippian, and the accompanying retreat of the sea across the area (DeVoto, 1980; Tweto, 1980a). Two types of karst features resulted from this solution activity: (1) breccia created by intrastratal karst solution within the upper Leadville Limestone at or near the Redcliff-Castle Butte contact (the Pink breccia), and (2) breccia-filled sinkholes, solution-collapse breccias, and other cross-cutting karst features extending downward from the upper Leadville surface. The cross-cutting features are abundant in some areas (as in the Aspen, Leadville, and Gilman districts), whereas in other areas none are observed (as in the Fulford district). The occurrence of the Pink breccia in the Fulford district probably resulted from bedding-plane solution along the unconformity suggested by Nadeau (1972) to exist between the Redcliff Member (Kinderhookian) and the Castle Butte Member (Osagean). The occurrence of intrastratal karst and small, sandstone-filled scour channels on the upper Castle Butte surface may indicate that the Fulford district is marginal to an area of more extensive karst activity. In areas of extensive karst activity, paleovalleys developed on the Mississippian landscape; DeVoto (1982, 1983) has shown a direct relationship between the paleovalleys and major ore districts. The lack of cross-cutting karst features in the Fulford district indicates that perhaps, locally, solution activity was not effective in solutioning the Leadville Limestone.

One explanation for the ineffectiveness of solution activity in the Fulford area is the lack of permeability for circulation of ground water. As suggested earlier, the bulk of the porosity in the upper Leadville Limestone was occluded by cementation with low-Mg calcite very early in the rock's history. Therefore, the resistance of low-Mg calcite to dissolution (Matthews, 1968, p. 1110; Bathurst, 1971, p. 425; Al-aasm and Veizer, 1982, p. 1101; and

Sibley, 1982, p. 1087) may have been an important factor in preserving the Leadville Limestone of the Fulford district. However, conclusive evidence of the original composition of the upper Leadville Limestone in the karst areas is not available.

The permeability necessary for fluid circulation and subsequent dissolution of carbonate rocks can also be provided by fracture porosity (Posada, 1973, p. 60). Posada stated that "differential movement along fractures and joints," caused by tidal forces and seasonal and diurnal changes, "both inhibits cementation and increases the hydraulic [permeability] of the joints." There was no large-scale fracturing of the Leadville Limestone in the Fulford district, and, attendantly, cross-cutting solution features were not developed. However, in the areas where the development of karst features in the Leadville Limestone has been extensive (Leadville, Gilman, and Aspen districts), northeasterly-trending fractures and faults in the Leadville Limestone developed in response to the reactivation of Precambrian structures (Radabough and others, 1968). These fracture systems could have controlled the development of cross-cutting karst solution features in those areas. Such Precambrian structures are not present beneath the Fulford area (Tweto and Sims, 1963).

Finally, the Front Range Highland was the major positive element influencing the northern Sawatch area in the Late Mississippian (Tweto, 1980a). The Leadville Limestone of the Leadville and Gilman areas was in close proximity to the Front Range Highland (Fig. 16) as the sea began to regress late in Mississippian time. The highlands could have acted as a recharge area where surface water was collected and directed through fracture porosity down the regional dip, with dissolution proceeding outward from the upland region and being greatest in and adjacent to the paleo-upland region and decreasing downdip. The Fulford district could have been too far from the upland recharge

area to have been affected by the solution activity, even if permeable rocks were available. Or, the slightly positive Sawatch Uplift may have acted as a barrier to the flow of water within the aquifer system from the highland to the Fulford district, while not being uplifted enough to act as a freshwater-recharge area.

From the preceding discussion it is concluded that karst activity and the development of cross-cutting karst features in the Leadville Limestone were probably controlled by paleotopography and by reactivation of Precambrian structures. Further, if the Fulford district is proximal to a paleovalley created by the karst activity, there is the possibility of major ore deposits in an area adjacent to the Fulford district.

SECONDARY DOLOMITIZATION

As previously noted, secondary dolomitization of the Leadville Limestone is rare in the Fulford district. On the eastern flank of the Sawatch Range, the Leadville above the Waxy bed has been secondarily dolomitized throughout the 40-mile width of the mineral belt (Lovering and others, 1978). According to Nadeau (1972) the upper micritic Redcliff Member has been altered to fine-grained dolomite and the particulate Castle Butte Member altered to coarse-grained dolomite. Thus, grain-size relations are maintained from primary to secondary textures suggesting an early diagenetic origin for the dolomite. The secondary dolomite in the Leadville of the Fulford district is all coarsely crystalline and occurs in small pods in all members. Since the secondary dolomite in the Fulford district does not reflect the grain size of the original rock, it formed differently from that of the Leadville-Gilman area. Pods of coarsely-crystalline dolomite, similar in size and distribution to those of the Fulford area, were reported by Conley (1964) in the Leadville of the White River Plateau and suggested by Engel and others (1958) to be of an

hydrothermal origin. Therefore, the dolomite pods of the Fulford district were probably the result of incipient hydrothermal activity.

Engel and Engel (1957) and Lovering and others (1978) agreed that the secondary dolomite created by early diagenetic action resulted from causes and processes other than later mineralization, and that the two events were separated in time by at least several million years. Several authors (Posada, 1973; DeVoto and Maslyn, 1977; DeVoto, 1982) suggested that the secondary dolomite was produced by the susurface mixing of marine and fresh water, which is the "dorag model" of Badiozamani (1973).

The Leadville Limestone was subaerially exposed next to the Ancestral Front Range Highland at the beginning of regression of the Mississippian sea (Fig. 16); therefore, freshwater lenses must have developed beneath the exposed Leadville Limestone. Such an environment would have also provided a freshwater recharge for the karst activity that created the large cross-cutting solution features in the Leadville Limestone of the Leadville-Gilman area, and Posada (1973) and DeVoto (1982) suggested that the two processes (dolomitization and karsting) did occur somewhat concurrently.

Regression during dorag dolomitization causes the zone of mixing to migrate downdip and effect dolomitization as long as regression is slow enough to allow sufficient time for dolomitization (Badiozamani, 1973; Sibley, 1980; Morrow, 1982a). The above environment of dolomitization would result in an increase in dolomitization of updip rocks, that is, as the paleohighland is approached (Schmidt, 1965; Sibley, 1980; Morrow, 1982b). The Fulford district was down-dip from the Ancestral Front Range Highland (Fig. 16) and may have been too distant from the paleohighland to have been affected by the proposed dolomitization model.

From the above discussion, it is concluded that the major control of dorag dolomitization in the upper Leadville Limestone was paleotopography, the

Fulford area being too far downdip from the paleoshoreline to be affected.

MINERALIZATION AND ECONOMIC GEOLOGY

In those mining districts of Colorado in which ore production comes primarily from replacement deposits in pre-Pennsylvanian Paleozoic sedimentary rocks, the Misssissippian Leadville Limestone is the most important ore host. A comparison of these districts with the Fulford district should identify certain features that occur in the major mining districts, but not in the Fulford district, and thereby provide an indication of the controls of mineralization in the Leadville Limestone. A comparison among the mining districts and the Fulford area in terms of the presence or absence of features suggested to be related to replacement mineralization in the Leadville Limestone is in Table 5.

In the Aspen district, ore has come principally from solution features in the upper Leadville Limestone, most notably from the Pink breccia and from cross-cutting karst features in the oolitic grainstone lithologies of the upper Castle Butte Member (Nadeau, 1971; Devoto, 1982). Although the Leadville Limestone at Aspen has been affected by Laramide faulting, folding, and intrusive activity, Nadeau (1971) suggested that these phenomena only provided pathways for mineralizing fluids that entered, and replaced with ore, the porous and permeable solution features and grainstone lithologies. Although dolomitization is associated with the mineralization at Aspen, an early diagenetic (dorag) dolomitization event is not recognized as on the eastern flank of the Sawatch Range. The differences and similarities between the Aspen and Fulford districts are outlined in Table 5.

In the Leadville district, the control of ore is clearly related to the karst surface on top of the Leadville Limestone and to Tertiary intrusive activity (Tweto, 1968). The most extensive and productive ore bodies occur in

Table 5. Comparison of features related to mineralization, Fulford and other mining districts (an "X" indicates presence of feature, data summarized from Tweto, 1968; Nadeau, 1971; Lovering and others, 1978; and DeVoto, 1982).

DISTRICT NAME	large-scale cross-cutting karst features	replacement mineralization	early dolomitization episode	Pink breccia	Underlying Precambrian shear zones	Amount of Laramide structurtal and intrusive activity	Original lithology of upper Leadville Ls.
LEADVILLE	X	X	X		X	abundant	oolitic grainstone
GILMAN	X	X	X	X	X	present though not abundant	oolitic grainstone
ASPEN	X	X		X	X	abundant	oolitic grainstone
FULFORD				X		present though not abundant	oolitic grainstone

the upper Leadville Limestone just beneath the Mississippian-Pennsylvanian unconformity in what Tweto (1968, p. 710) described as an "interval of porous and permeable Leadville". According to Nadeau (1971), although no relict textures could be observed, this interval corresponds stratigraphically to nearby horizons interpreted to be oolitic and crinoidal grainstone; however, there was also development of channelways and breccia zones related to limestone dissolution at this horizon (Devoto and Maslyn, 1977). The Leadville district has been greatly affected by Laramide or younger intrusive activity and by faulting, and although much faulting was post-ore, many faults were also active prior to mineralization. Again, as in the Aspen district, faulting and intrusive activity appear to have served only as mechanisms for the access of mineralizing fluids to porous and permeable horizons. Little similarity exists between the Leadville and Fulford districts, as shown by the comparison in Table 5.

In the Gilman district, the long, irregular, pipe-like ore bodies occur in northeast-trending, breccia-filled solution features in the Castle Butte Member and were obviously controlled by paleokarst activity on the top of the Leadville (Lovering and others, 1978). In contrast to the Leadville district, the Gilman district contains only a few minor faults; the only intrusive rock is a porphyry sill, which is definitely pre-ore (Lovering and others, 1978), in the lower Belden Formation. Nadeau (1971) interpreted, from relict textures, that the upper Castle Butte near ore zones was composed predominantly of grainstone lithologies. As shown in Table 5, the Fulford and Gilman districts share many features; however, the most obvious difference is the Precambrian shear zone underlying the Gilman area.

Certain features have been identified that occur in the major mining districts but not in the Fulford district (Table 5); these features are large cross-cutting karst breccias and Precambrian shear zones underlying the areas.

It is suggested that these features were among the major controls of replacement mineralization in the Leadville Limestone and that the absence of these features in the Fulford district resulted in greatly reduced ore mineralization there.

C O N C L U S I O N S

From geologic reconnaissance of the Fulford area and examination of the Mississsippian Leadville Limestone of the area, the following conclusions are reached:

1. The vertical sequence of lithologies in the Leadville Limestone of the Fulford district correlates with the lateral sequence of units deposited in shallow, epeiric sea as described by Shaw (1964) and Irwin (1965) and so represents deposition by a transgressive, epeiric sea.

2. The primary pore space in the Castle Butte Member was cemented largely with ferroan calcite spar (up to 3 percent FeO) which indicates the influence of meteoric water and suggests that cementation occurred in the fresh-water phreatic and vadose zones.

3. The environment of stabilization and cementation of the Castle Butte Member suggests that the bulk of the pore-filling cement was deposited as ferroan low-Mg calcite.

4. The Leadville Limestone of the Fulford district was resistant to karst-solution activity owing to the lack of fracture porosity and permeability and to the isolation of the area from an area of fresh-water recharge. Also, the stability of the ferroan low-Mg calcite components may have aided in the resistance to dissolution.

5. The upper Leadville Limestone of the Fulford district was not diagenetically dolomitized, as on the eastern flank of the Sawatch Range, due to the Fulford area's greater distance from the Ancestral Front Range Highland.

6. Although metals were introduced to the Fulford area, and to a small degree to the Leadville Limestone, significant replacement mineralization did not occur as in the Aspen, Leadville, and Gilman districts.

7. The lack of replacement mineralization in the Leadville Limestone of the Fulford area is related to certain features that occur in the major mining districts, but not in the Fulford area; these features are large cross-cutting karst features in the Leadville Limestone and shear zones in the Precambrian rocks.

8. If, as suggested by the occurrence of the Pink breccia and sandstone of the Molas Formation, there exists an area of more extensive karst development near the Fulford district, major replacement mineralization could also exist in that area.

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APPENDIX 1

MEASURED SECTIONS

Section No. 1
(East Brush Creek Section)

(Location: Cliff exposures on East Brush Creek approximately 500 feet
upstream from Fulford Cave campground, exposure on
southwest side of creek; center of section line,
sects. 35 and 36, T. 6 S., R. 83 W., Eagle County, Colorado.
Attitude of beds: N10 E/36 NW.)

	Thickness	
	feet	meters

Pennsylvanian Belden Formation:
Black shale interbedded with one-foot thick, algal
limestone.

Mississippian Leadville Limestone:
Castle Butte Member:

9. Oolitic grainstone, light to medium light
gray (N7-N6), thick-bedded; abundant oo-
lites; a few crinoid fragments; forms part
of cliff exposure and dip slope............21.0-22.5   6.4-6.9

8. Skeletal-oolitic grainstone, medium light
gray (N6), thick-bedded; grains include
crinoid and echinoid fragments, oolites and
other skeletal debris; single colony of
syringoporid coral; forms parts of
cliff exposure and dip slope.....................8.2   2.5

7. Skeletal-peloidal grainstone, medium gray
(N5), thick-bedded; grains include crinoid
fragments and echinoid spine fragments and
peloids; single colony of syringoporid
coral; forms parts of cliff expo-
sure and dip slope................................15.3   4.7

6. Breccia (Pink breccia), medium-bedded;
angular fragments of units 5 and 7; sandy,
shaly, micrite matrix; irregular relief on
upper and lower contacts...................10.1-11.8   3.1-3.6

Redcliff Member:

5. Pelletal micrite, medium light gray (N6),
medium-bedded, highly fractured; abundant
layered and nodular chert; irregular relief
on upper contact................................5.0-6.4   1.5-2.0

4. Micrite, medium light to medium dark gray
(N6-N4), thick-bedded; abundant nodular
black chert; forms cliff exposure..............33.4   10.2

3. Dolomicrite (Waxy bed), yellowish gray (5 Y
   8/11) to medium gray (N6), thick-bedded;
   fragmented layers of chert 1-inch thick
   in upper foot of unit; hackly reentrant
   exposure at base of cliff; upper contact
   has 0.5 to 2.0 feet of relief................4.4-5.1   1.3-1.6

Gilman Sandstone Member:
   2. Breccia, light to medium light gray (N7-
      N6), thick-bedded; angular fragments of
      Dyer Dolomite, Gilman Sandstone, and chert;
      sandy dolomicritic matrix; abundance of
      one-foot thick sandstone lenses, lenses
      more abundant toward upper contact; upper
      contact has relief.........................5.3-8.5   1.6-2.6

   1. Micrite, medium light gray (N6) fresh,
      yellowish gray (5Y8/3) weathered, medium-
      bedded, sandy; fine-grained quartz sand
      occurs in stringers one to two inches thick.....1.9   0.6

Devonian Dyer Dolomite:
   Micrite, dark gray to black (N3-N1), thin-bedded, brittle.

Section No. 2
(Nolan Canyon Section)

(Location: Cliff exposure in canyon of Nolan Creek, 0.4 mi. upstream
         from road at town of Fulford; cliff exposure on south side
         of creek; N1/2, sect. 25, T. 6 S., R. 83 W.,
         Eagle County, Colorado. Attitude of beds: N37 E/ 34 NW.)

	Thickness	
	feet	meters

Mississippian Leadville Limestone:
   Castle Butte Member:

Covered

   8. Skeletal-oolitic grainstone, medium gray
      (N5), thick-bedded; abundance of ooliths
      and crinoid fragments; forms upper part of
      cliff exposure and most of dip slope; upper
      contact covered by forest..................19.7-21.3   6.0-6.5

7. Skeletal-pelletal packstone, medium light
gray, (N6), thick-bedded; abundance of
pellets and crinoid fragments, a few
echinoid and other skeletal fragments;
forms part of cliff exposure and dip slope......16.4   5.0

6. Breccia (Pink breccia), medium-bedded,
angular fragments of units 5 and 7; sandy
shaly matrix; forms reentrant exposure in
cliff; relief on lower contact...............2.1-3.2   0.6-1.0

Redcliff Member:
    5. Micrite, medium to medium dark gray (N5-
N4), thick- to very thick-bedded, nodular
chert scattered throughout, layered chert
abundant near top; forms part of cliff expo-
sure and dip slope; numerous caves in cliff.....49.2   15.0

4. Dolomicrite (Waxy bed), medium to medium
dark gray (N5-N4), medium-to thick-bedded;
abundance of layers of fragmented black
chert 1-inch thick; hackly reentrant
exposure at base of cliff; upper and lower
contacts exhibit 0.5 to 2.5 feet of
relief......................................2.6-4.6   0.8-1.4

Gilman Sandstone Member:
    3. Sandstone, light to very light gray (N7-
N8), thick-bedded, fine- to medium-grained
quartz sand grains; dolomitic; relief on
upper contact...............................4.6-6.9   1.4-2.1

2. Sandy dolomicrite, medium dark gray (N4),
medium-bedded, abundance of sand grains;
unit is interbedded with sandy dolomicrite
breccia containing fragments of Dyer
Dolomite, beds of each approximately 0.3 to
1.0 feet thick..............................18.4   5.6

1. Sandstone, dark gray to black (N3-N1), fine-
to medium-grained quartz sand grains;
calcareous..................................0.3-0.5   0.1-0.2

Devonian Dyer Dolomite:
   Micrite, dark gray (N3), thin-bedded, brittle.

Section No. 3
(Jackpot Mine Section)

(Location: Cliff exposure on hillside above the Jackpot Mine;
NW1/4, NE1/4, NE1/4, sect. 25, T. 6 S., R. 83 W.,
Eagle County, Colorado. Attitude of beds; N30 E/42 NW.)

	Thickness	
	feet	meters

Mississippian Leadville Limestone:
    Castle Butte Member:

                        Covered

6. Skeletal-pelletal packstone, medium to me-
   dium light gray (N5-N6), thick-bedded;
   contains abundance of peloids and crinoid
   fragments with a few echinoid fragments;
   several horn corals weathered in positive
   relief; forms uppermost part of cliff
   exposure..16.4   5.0

Redcliff Member:
5. Micrite, light to medium dark gray (N7-N4),
   thick-bedded; abundance of nodular chert
   throughout unit; layered chert 1 to 2
   inches thick in upper 6 feet; forms prom-
   inent cliff exposure and part of dip
   slope...47.6   14.5

4. Dolomicrite (Waxy bed), medium to medium
   dark gray (N7-N4), medium-bedded; fragment-
   ed layers of black chert; hackly reentrant
   exposure at base of cliff; varied relief
   on upper and lower contacts...................4.1-5.6   1.3-1.7

Gilman Sandstone Member:
3. Dolomicrite, light to medium light gray
   (N7-N6), medium-bedded; fine- to medium-sand
   grains of quartz in lenses and stringers 4-
   inches thick and up to 3 feet long; upper
   contact has relief with many sandstone
   lenses..9.8-11.5   3.0-3.5

2. Breccia, light to medium light gray (N7-
   N6), thick-bedded; angular fragments of
   Dyer Dolomite and lower Leadville
   Limestone, matrix dolomicrite
   to sandy dolomicrite............................7.4   2.3

    1. Dolomicrite, light to medium gray (N7-N5),
       thin-bedded; sandy; fine- to medium-sand
       grains of quartz in lenses 2 to 5 inches thick...9.8   3.0

Devonian Dyer Dolomite:
    Micrite, medium to dark gray (N5-N3), thin-bedded, brittle.

APPENDIX 2

PETROGRAPHIC DESCRIPTIONS
OF
THIN SECTIONS OF
LEADVILLE LIMESTONE

P E T R O G R A P H I C   D E S C R I P T I O N S
O F
T H I N   S E C T I O N S   O F
L E A D V I L L E   L I M E S T O N E

GILMAN SANDSTONE MEMBER

Sample No.

Basal Sandstone

MRX-1C   The basal sandstone in Nolan Canyon is composed of fine to medium sand-sized quartz grains (0.18 to 0.30 mm) which make up 75 percent of the rock by volume. The remainder of the rock consists of dolomite and quartz cement in a 4 to 1 ratio. The quartz grains are mostly single grains with slightly undulose extinction; approximately 2 percent of the grains are composite grains. All quartz grains are rounded to well-rounded. Dolomite cement replaces 5 percent of the quartz grains; quartz cement occurs as indigenous overgrowths around rounded nuclei. Detrital microcline feldspar makes up less than 0.5 percent of the rock.

Sandy Dolomicrite and Sandy Micrite

MRX-1A   The sandy micrite at East Brush Creek consists of quartz sand grains in thin (1 to 5 mm) stringers oriented parallel to bedding and separated by micrite. The quartz grains compose 65 percent of the rock, are medium sand-sized (0.2 to 0.3 mm), rounded to well-rounded, and have slightly undulose extinction. Detrital microcline feldspar makes up 7 percent by volume of the rock. Elongate, detrital flakes of muscovite mica, approximately 0.09 mm long, occur in the micrite in an abundance of 0.5 percent.

MRX-4C   The sandy dolomicrite at Nolan Canyon is composed of 44.7 percent fine to coarse sand-sized quartz grains (0.18 to 0.60 mm) in a matrix of microcrystalline dolomite (dolomicrite). The majority (73 percent) of the quartz grains are subangular to angular and the rest are subrounded to rounded.

MRX-3B   At Jackpot Mine the sandy dolomicrite is composed of 46.9 percent fine to coarse sand-sized quartz grains (0.15 to 0.70 mm) in a dolomicrite matrix. As in the Nolan Canyon unit, 75 percent of the quartz grains are angular to subangular and the rest are subrounded to rounded.

Sandy Dolomicrite Breccia

MRX-2A1   The breccia unit at East Brush Creek contains 51.4 percent fragments that range in size from less than 1 cm to 15 cm. The fragments consist of Dyer Dolomite, chert, and dolomicrite. The remainder of the rock consists of 15.4 percent silt- to coarse-sand sized quartz grains (0.03 to 0.8 mm) and 28.7 percent dolomicrite. The quartz grains range from subangular to well-rounded. Unweathered, detrital microcline feldspar makes up 3.9 percent and muscovite mica 0.6 percent of the rock.

MRX-2C
The breccia unit at Nolan Canyon contains 62.1 percent fragments that range in size from 1 cm to 15 cm and consist of Dyer Dolomite, chert, and dolomicrite. The remainder of the rock consists of 11.2 percent silt to coarse sand-sized quartz grains and 23.2 percent dolomicrite. The quartz grains are subangular to well-rounded. Unweathered microcline feldspar comprises 3.2 percent and muscovite mica less than 0.5 percent of the rock.

MRX-2B
The breccia unit at Jackpot Mine contains 64.2 percent fragments that range in size from 1 cm to 15 cm. The remainder of the rock is 11.2 percent silt to coarse sand-sized quartz grains and 21.3 percent dolomicrite. The quartz grains are subangular to well-rounded. Unweathered microcline feldspar makes up 3.0 percent and muscovite mica less than 0.5 percent of the rock.

Interbedded Sandstone Lenses and Upper Sandstone

MRX-2A2
The sandstone lenses at East Brush Creek are composed of quartz sand grains and detrital feldspar cemented by dolomicrite. The quartz grains make up 66.2 percent of the rock, are fine to coarse sand-sized (0.18 to 0.65 mm), and subangular to well-rounded. Unweathered microcline feldspar is 15 percent of the rock, muscovite mica is less than 0.5 percent, and the remainder (18.6 percent) is dolomicrite cement.

MRX-2C
The upper sandstone unit at Nolan Canyon is composed of 68.4 percent fine to coarse sand-sized quartz grains (0.18 to 0.65 mm) that are subrounded to well-rounded. Unweathered microcline feldspar is 3.8 percent of the rock, muscovite mica is less than 0.5 percent, and the remainder (27.8 percent) is dolomicrite cement.

MRX-4B
The sandstone lenses at Jackpot Mine are composed of 69.8 percent fine to coarse sand-sized quartz grains (0.18 to 0.65 mm) that are subrounded to well-rounded. Unweathered microcline feldspar is 0.80 percent of the rock, muscovite mica is less than 0.5 percent, and the remainder (29.4 percent) is dolomicrite cement.

REDCLIFF MEMBER

Waxy Bed

MRX-3A
The Waxy bed at East Brush Creek consists of laminated dolomicrite approximately 0.003 mm in size. The dolomicrite makes up 96 percent of the rock. The remainder of the rock consists of silt-sized quartz grains (0.06 mm) in thin laminations. Some evidence of boring or bioturbation was observed.

MRX-WC
The Waxy bed at Nolan Canyon consists of laminated dolomicrite approximately 0.003 mm in size. The dolomicrite makes up 96.6 percent of the rock. The remainder of the rock consists of silt-sized quartz grains (0.06 mm) in thin laminations.

MRX-WB
The Waxy bed at Jackpot Mine consists of laminated dolomicrite approximately 0.003 mm in size. The dolomicrite makes up 97.6 percent of the rock. The remainder of the rock consists of silt-sized quartz grains (0.06 mm) in thin laminations.

Upper Redcliff Member

MRX-4A   The upper six feet of the Redcliff Member at East Brush Creek consists of densely packed, relict peloids composed of equidimensional calcite grains 0.02 mm in size. The peloids make up 86 percent of the rock. The remainder of the rock consists of 5 percent microcrystalline calcite (micrite) and 8 percent calcite spar.

MRX-RC   The upper Redcliff Member at Nolan Canyon is composed almost entirely of micrite. The calcite grains are all less than 0.01 mm and most are less than 0.006 mm in size. The micrite makes up 98.7 percent of the rock with approximately 1 percent microspar.

MRX-RB   The upper Redcliff Member at Jackpot Mine is composed entirely of micrite. The calcite grains are all less than 0.01 mm and most are less than 0.006 mm in size. The micrite makes up 100 percent of the rock; no microspar was observed in thin seciton .

CASTLE BUTTE MEMBER

Pink breccia

MRX-5A   The Pink breccia at East Brush Creek is composed of fragments of micrite from the Redcliff Member and skeletal-peloidal packstone from the overlying Castle Butte Member. The fragments make up 77 percent of the rock and range in size from 0.25 cm to more than 2.0 cm. The rock also contains 12 percent coarse silt-sized (0.05 to 0.08 mm) quartz grains that are angular to well-rounded. Calcite occurs as micrite between the fragments and makes up 5 percent of the rock. Approximately 5 percent of the rock consists of prismatic calcite crystals extending perpendicular to the walls of some of the fragments.

PB-C   The Pink breccia at Nolan Canyon is composed of fragments of micrite from the Redcliff Member and skeletal-peloidal packstone from the overlying Castle Butte Member. The fragments make up 75 percent of the rock and range in size from 0.25 cm to more than 2.5 cm. The rock also contains 18 percent coarse silt-sized (0.05 to 0.08 mm) to very fine sand-sized quartz grains that are angular to well-rounded. Calcite occurs as micrite between the fragments and makes up 5 percent of the rock. Approximately 2 percent of the rock consists of prismatic calcite crystals extending perpendicular to the walls of some of the fragments.

Skeletal-Peloidal Packstone

MRX-6A   At East Brush Creek the skeletal-peloidal packstone consists mostly of peloids that range in size from 0.15 to 0.30 mm and make up 72.6 percent of the rock. Skeletal material consists mostly of crinoid columnals, echinoid fragments, and forminiferal tests. The crinoid columnals are 0.3 to 0.5 mm in size and make up 8.9 percent of the rock. The echinoid fragments constitute 1.1 percent of the rock and are approximately 0.5 mm in size. The foraminiferal tests are approximately 0.3 mm in size and are 1.4 percent of the rock. The remaining skeletal component (0.6 percent of the rock) is unidentifiable. The interparticle space is occupied by nonferroan micrite which is 13.8 percent of the rock. Approximately 1 percent of the rock is sparry calcite mosaic cement.

MRX-6C   At Nolan Canyon the skeletal-peloidal packstone consists mostly
of peloids that range in size from .15 to .40 mm and make up 74.1
percent of the rock. Skeletal material consists mostly of crinoid
columnals, echinoid fragments, and forminiferal tests. The crinoid
columnals are 0.3 to 0.5 mm in size and make up 8.7 percent of the
rock. The echinoid fragments constitute 1.6 percent of the rock and
are approximately 0.5 mm in size. The foraminiferal tests are
approximately 0.3 mm in size and are 1.0 percent of the rock. The
remaining skeletal component (0.5 percent of the rock) is
unidentifiable. The interparticle space is occupied by nonferroan
micrite which is 12.0 percent of the rock. Approximately 2 percent
of the rock is sparry calcite mosaic cement.

MRX-6B   At the Jackpot Mine the skeletal-peloidal packstone consists
mostly of peloids that range in size from .15 to .40 mm and make up
73.2 percent of the rock. Skeletal material consists mostly of
crinoid columnals, echinoid fragments, and forminiferal tests. The
crinoid columnals are 0.3 to 0.5 mm in size and make up 9.3 percent
of the rock. The echinoid fragments constitute 1.2 percent of the
rock and are approximately 0.5 mm in size. The foraminiferal tests
are approximately 0.3 mm in size and are 1.2 percent of the rock.
The remaining skeletal component (0.5 percent of the rock) is
unidentifiable. The interparticle space is occupied by nonferroan
micrite which is 14.4 percent of the rock.

Skeletal-Oolitic Grainstone

MRX-7A3   The skeletal-oolitic grainstone at East Brush Creek contains
oolites which range in size from .18 to 1.0 mm and are 65.7 percent
of the rock. The oolites have nuclei of skeletal fragments and
concentric coatings with little development of radial texture. The
skeletal component consists of crinoid columnals, echinoid
fragments, foraminiferal tests, and ostracode shell fragments. The
crinoid columnals make up 8.1 percent of the rock and range from 0.3
to 1.0 mm in size. The echinoid fragments are 0.6 mm in size and
make up 2.1 percent of the rock. The remaining skeletal components
(foraminiferal tests, ostracode shell fragments, and unidentifiable
fragments) make up 0.7 percent, 0.3 percent, and 0.3 percent of the
rock respectively. Sparry calcite mosaic cement contains 1.5 to 2.0
percent FeO and is 19.1 percent of the rock. Syntaxial overgrowths
contain 1.5 to 2.0 percent FeO and are 1.7 percent of the rock.
Drusy calcite crusts on framework components contain 0 percent FeO
and are 0.4 percent of the rock.

MRX-5-6   The skeletal-oolitic grainstone at Nolan Canyon contains
oolites which range in size from .2 to 1.0 mm and are 64.9 percent
of the rock. The oolites have nuclei of skeletal fragments and
concentric coatings with little development of radial texture. The
skeletal component consists of crinoid columnals, echinoid
fragments, foraminiferal tests, and ostracode shell fragments. The
crinoid columnals make up 7.7 percent of the rock and range from 0.3
to 1.0 mm in size. The echinoid fragments are 0.6 mm in size and
make up 1.8 percent of the rock. The remaining skeletal components
(foraminiferal tests, ostracode shell fragments, and unidentifiable
fragments) make up 0.6 percent, 0.2 percent, and 0.5 percent of the
rock respectively. Sparry calcite mosaic cement contains 1.5 to 2.0
percent FeO and is 21.6 percent of the rock. Syntaxial overgrowths
contain 1.5 to 2.0 percent FeO and are 2.2 percent of the rock.

Drusy calcite crusts on framework components contain 0 percent FeO and are 0.5 percent of the rock.

Upper Oolitic Grainstone

BCSC   The oolitic grainstone at East Brush Creek is composed of 76.3 percent oolites, 2.1 percent crinoid columnals, 0.9 percent echinoid fragments, and 0.3 percent unidentifiable skeletal fragments. The oolites range in size from .36 to .80 mm, have nuclei of echinoderm fragments, and show little development of radial fabric. Sparry calcite mosaic cement is 19.4 percent of the rock and contains 1.5 to 3.0 percent FeO. Syntaxial overgrowths on echinoderm fragments range from 0.0 to 1.5 percent FeO and make up 0.6 percent of the rock. Drusy calcite crusts on many framework components are 0.4 percent of the rock and contain no FeO.

Intraclastic-Oolitic Grainstone

RMX-23   The grainstone at Nolan Canyon is composed of intraclasts that range in size from 1.0 mm to more than 2.0 cm and make up 55 percent of the rock. The intraclasts are composed of 75 percent oolites, 23 percent calcite cement, and 2 percent echinoderm fragments. The oolites, as well as the echinoderm fragments, have a coating of isopachus rim cement .065 mm thick. The remainder of the rock consists of oolites which range in size from 0.5 to 0.8 mm and are 25 percent of the rock, crinoid columnals which are 2.6 percent of the rock, and echinoid fragments which are 0.9 percent of the rock. Sparry calcite mosaic cement is 14.9 percent of the rock and exhibits a zonal variation in FeO content. The variation appears to be crystallographically controlled with the earliest cement being nonferroan calcite and showing the characteristic dog-tooth shape against pore space. The next generation of mosaic cement, though opticaly continuous with the first, contains 1.0 to 1.5 percent FeO and the FeO content increases in discrete zones with the maximum content reaching 2.5 to 3.0 percent FeO. Syntaxial overgrowths on skeletal fragments are 0.5 percent of the rock and are mostly non-ferroan calcite. Drusy calcite crusts on framework components are 0.3 percent of the rock and are nonferroan calcite. Approximately 0.7 percent of the rock is calcite crystals 0.01 mm in size that resemble silt resulting from internal sedimentation. Geopetal evidence shows this "crystal silt" to be penecontemporaneous with mosaic cement and to postdate drusy calcite crusts.

RECONNAISSANCE GEOLOGY OF THE
MISSISSIPPIAN LEADVILLE LIMESTONE
AND IMPLICATIONS FOR MINERALIZATION CONTROLS,
FULFORD MINING DISTRICT, EAGLE COUNTY, COLORADO

by

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ABSTRACT

The Mississippian Leadville Limestone is the major ore host for Cu-Pb-Zn-Ag mineralization in the Leadville, Aspen, and Gilman mining districts on the flanks of the Sawatch Range in northwest-central Colorado. The Fulford district is on the west flank of the Sawatch Range directly opposite the productive Gilman district and within a relatively unmineralized area. Although the mechanisms of mineralization did operate at least to some extent in the Fulford district, they were not effective in depositing economic concentrations of ore minerals.

This reconnaissance geologic study compares the Fulford district to areas where economic concentrations of ore minerals occur in the Leadville Limestone with emphasis given to those features and processes that seemed to have been the major controls of mineralization in the major mining districts: (1) karst solution features, (2) Tertiary igneous and hydrothermal activity, (3) sedimentological, stratigraphic, and diagenetic features of the Leadville Limestone, and (4) Laramide tectonic activity.

The Paleozoic rocks of the Fulford district were mapped in general, and the Leadville Limestone was mapped in detail. Three measured sections within the mapped area include the three defined members of the Leadville Limestone. The lowermost member, the Gilman Sandstone Member, consists of a basal sandstone or basal sandy dolomicrite, a medial sandy dolomicrite breccia, and an upper sandstone or sandy dolomicrite with sandstone lenses occupying scour channels on the uppermost surface. The middle member, the Redcliff Member, is a cherty micrite with a basal unit composed of dense dolomicrite. The uppermost member, the Castle Butte Member (the most important member as an ore host in mining areas), consists of skeletal-pelletal packstone which is overlain by an oolitic grainstone or an intraclastic-oolitic grainstone. In two of the measured sections the lowermost Castle Butte unit consists of a sandy and clayey micrite breccia (termed the "Pink breccia").

The Leadville Limestone of the Fulford district was not subjected to

dolomitization, intrusion and karst solution on as large a scale as in other mining districts and so retains most of its primary sedimentological features. Secondary dolomite created by early, diagenetic dolomitization does occur as on the east flank of the Sawatch Range; however, secondary dolomitization in the Fulford district is restricted to small pods of coarsely crystalline dolomite created by incipient hydrothermal activity. Intrusive activity in the study area was restricted to the emplacement of a small dike of latite porphyry around which the Leadville Limestone has been recrystallized, but not otherwise altered or mineralized. Karst activity in the district was not successful in creating large, cross-cutting dissolution features; however, an intraformational karst horizon (the "Pink breccia" of mining areas) was recognized within the Leadville Limestone. Also, conglomeratic sandstone of the Molas Formation occurs on the exposed uppermost surface of the limestone.

Petrographic examination revealed that the uppermost member of the Leadville Limestone in the study area was stabilized and cemented in the fresh-water phreatic and vadose zones and that the bulk of pore-filling cement was deposited as ferroan (up to 3 percent FeO) low-Mg calcite spar. The stability of the ferroan low-Mg calcite constituents may have inhibited karst dissolution of the limestone as well as diagenetic dolomitization.

Features that occur in the major mining districts but not in the Fulford district are large, cross-cutting karst features in the Leadville Limestone and shear zones in the underlying Precambrian rocks. The absence of these features is considered to be the major factor controlling the lack of replacement mineralization in the Fulford district. However, the occurrence of the Pink breccia and Molas Formation indicates the possibility of replacement mineralization nearby.