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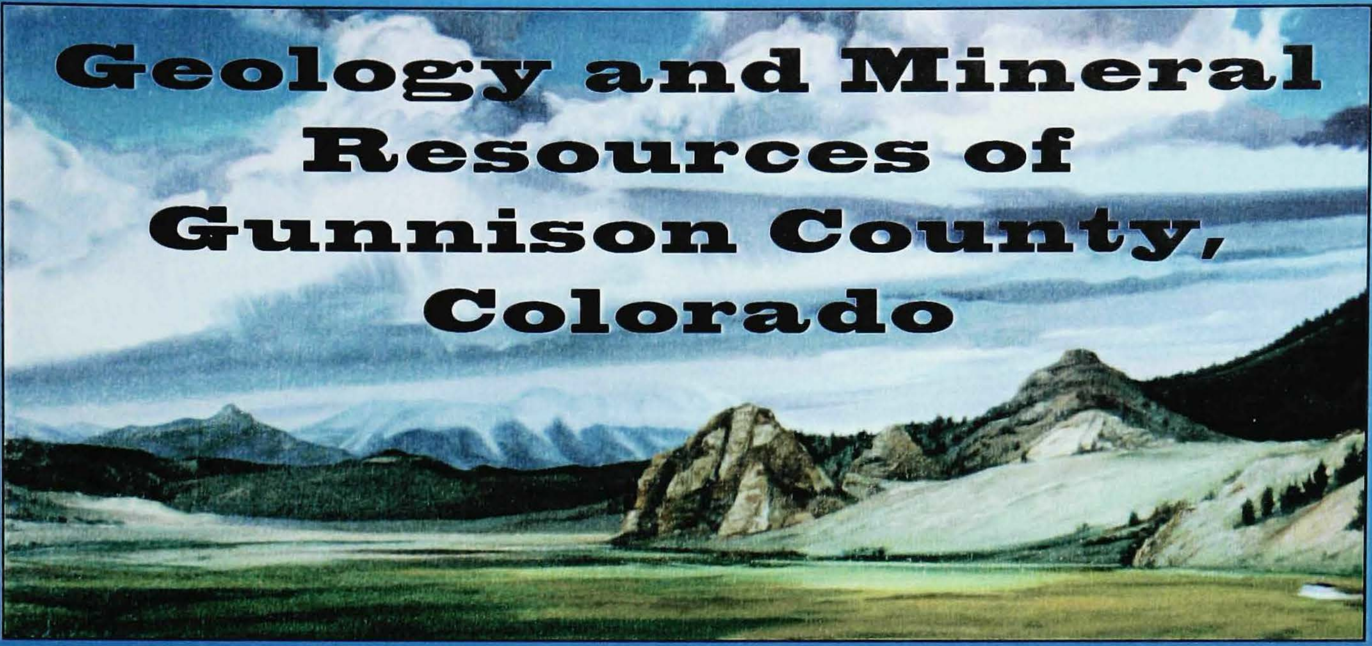
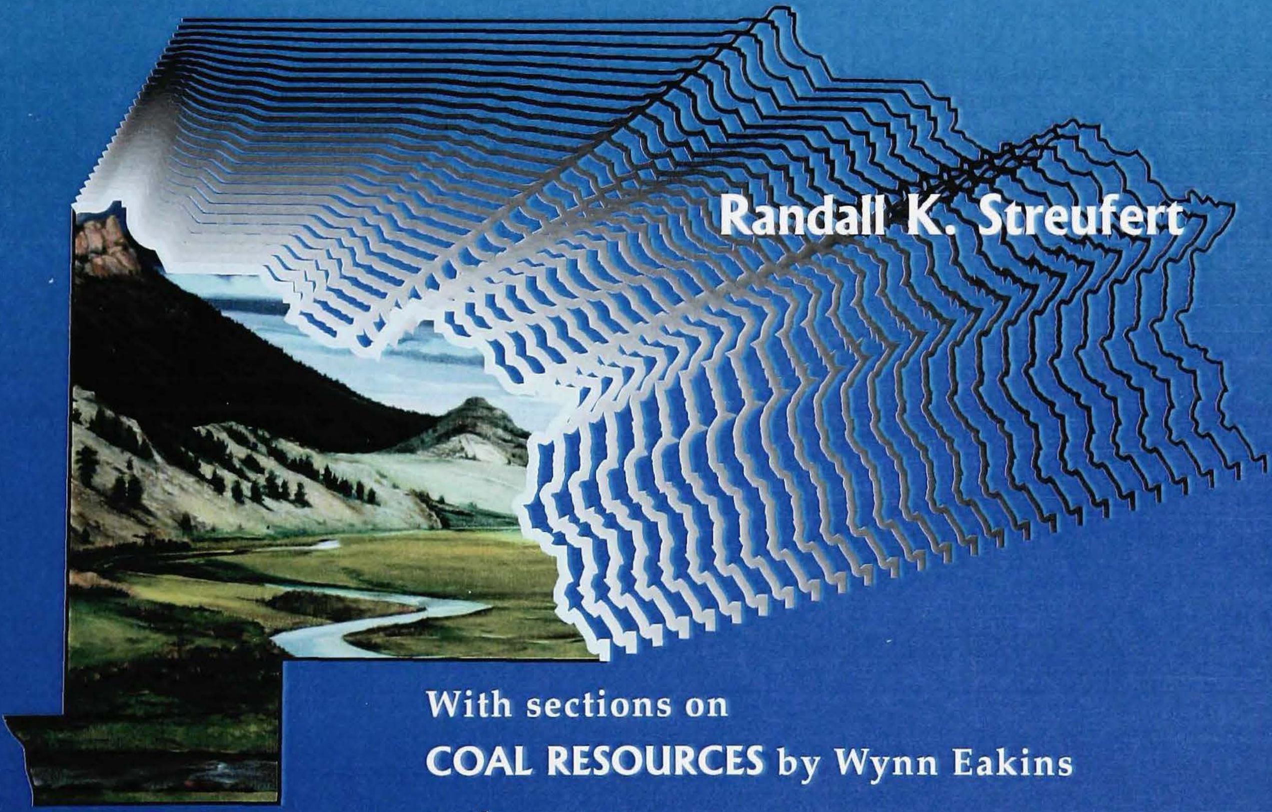


Geology and Mineral Resources of Gunnison County, Colorado



Randall K. Streufert

With sections on
COAL RESOURCES by Wynn Eakins
and
PETROLEUM RESOURCES by H. Thomas Hemborg

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
1999

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CONTENTS

FIGURES

TABLES

PLATE

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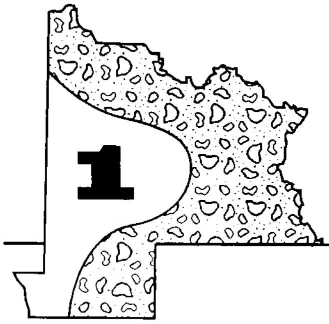


1

Geologic Setting

INTRODUCTION

Gunnison County is located in central and southwestern Colorado in an area of diverse geology. Precambrian through Tertiary rocks occur throughout the county and have undergone different stages of development. The divisions of these tectonic and depositional provinces are shown in Figure 1. Most of the geologic provinces of Gunnison County contain economically important deposits of minerals or mineral fuels. Plate 1 of this report is a 1:250,000 scale geologic map of Gunnison County that was complied from existing 1 x 2 degree quadrangle geologic maps by the United States Geological Survey.

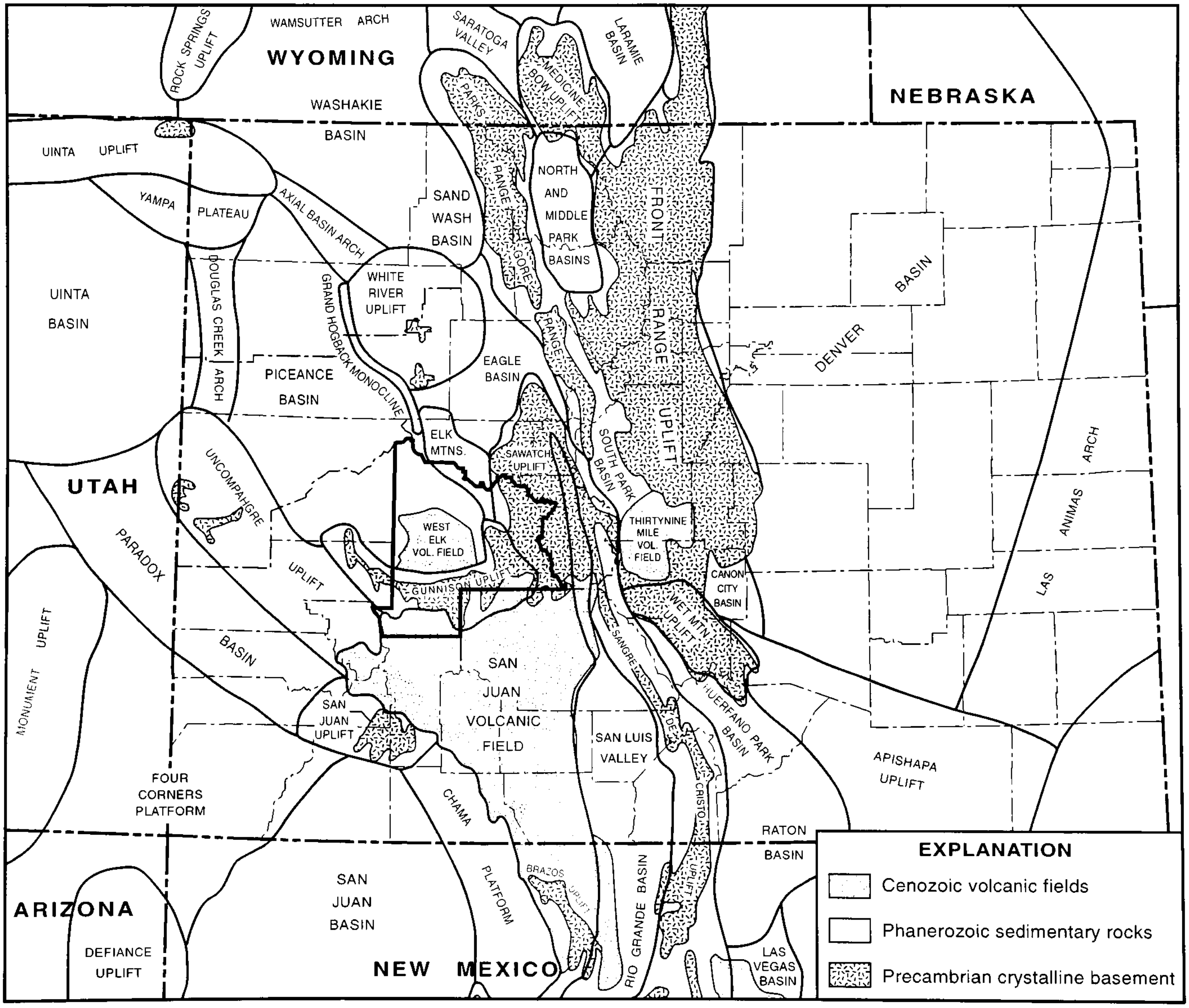


Figure 1. Map showing basic tectonic features of Colorado with Gunnison County in bold outline.

Proterozoic crystalline and Paleozoic sedimentary rocks exposed in eastern Gunnison County are part of the Laramide Sawatch Uplift, a large north–south-trending anticlinal uplift that contains a number of Colorado's tallest peaks. The crest of the Sawatch Uplift is the eastern boundary of Gunnison County which coincides with a large portion of the Continental Divide. This area of exposed Proterozoic and Paleozoic terranes in eastern Gunnison County contains many of the county's productive mining districts, which were worked for precious and base metals from vein and replacement deposits, for uranium from vein deposits, and for rare-earth elements and thorium from pegmatite deposits.

Another large exposed Proterozoic terrane is the Gunnison Uplift in southern Gunnison County. Rocks exposed in the Gunnison Uplift include a suite of metavolcanic rocks containing stratabound massive sulfide deposits (Dubois Greenstone). It is bounded on the south by the Cimarron Fault, a large Laramide dip-slip fault that cuts, and may have localized, a Late Proterozoic and early Cambrian alkalic-carbonatite intrusive complex at Powderhorn (see Powderhorn District, this report). The Gunnison Uplift also exposes the Proterozoic, dominantly metasedimentary Black Canyon Schist (Xb) in the Black Canyon of the Gunnison River (Hansen, 1971). The Gunnison Uplift is a large fault-block highland that locally dips 5 to 10 degrees north-northeast and disappears underneath Mesozoic sedimentary rocks to the northwest (Hedlund and Olson, 1981). The Gunnison Uplift includes numerous mining districts that have been worked for gold and silver, base metals, and minor uranium. The alkalic intrusive complex at Powderhorn contains the largest single resource of titanium in the world.

The Middle Tertiary San Juan volcanic field and the similarly aged West Elk volcanic field cover a great portion of southern and western Gunnison County, respectively, with extrusive and volcaniclastic rocks. Most of southern Gunnison County is covered by thick sheets of Oligocene ash-flow tuff overlying pre-ash-flow andesitic lavas and breccias of the extensive San Juan volcanic field to the south. The West Elk volcanic field northwest of Gunnison forms a deeply dissected, south-sloping volcanic plateau. These volcanic deposits are related to Early to Middle Oligocene granodioritic plutons and laccoliths emplaced in the West Elk Mountains. Associated intermediate-composition volcanoes that erupted locally in the West Elk volcanic field are related in time to the larger San Juan volcanic event to the south (Gaskill and others, 1981; Lipman and others, 1969). Although many of these plutons may have vented, volcanic ejecta is preserved only in the southern part of the West Elk Mountains as the West Elk Breccia. No known economic mineral deposits are associated with the lavas and ash-flow tuffs of the San Juan volcanic field that extend northward into Gunnison County. No known mineralization is associated with the West Elk volcanic field.

The southern edge of the Piceance Basin extends into northern Gunnison County; however, only shallow marine and clastic rocks of Cretaceous and Tertiary age crop out. Tertiary volcanic activity and the emplacement of hypabyssal stocks in the Elk Mountains and Ruby Range locally metamorphosed and altered these Mesozoic and Tertiary sedimentary rocks. At the Mount Emmons molybdenum deposit near Crested Butte, metamorphosed and altered sediments of the Piceance Basin host stockwork molybdenite mineralization. The Piceance Basin is also economically important because of coal production from underground mines (see Coal Resources, this report), and to a lesser extent from the production of oil and gas (see Petroleum Resources, this report).

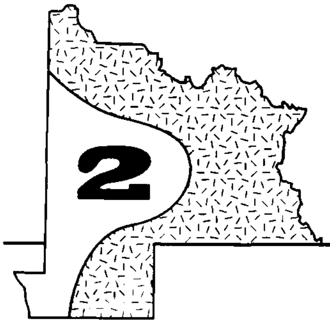
The Elk Mountain Uplift extends into northern Gunnison County (Figure 1). The Elk Mountains are an area of complex Middle through Late Tertiary intrusive activity that overprinted Laramide thrust faulting and related deformation. The predominant Laramide structure is the Elk Mountain Thrust Fault, which extends through the very northern portion of Gunnison County. The Elk Range Thrust is a north vergent structure that transitions into a large drape fold known as the Grand Hogback Monocline just to the northwest of Gunnison County in Pitkin County. The thrust fault places Late Mesozoic rocks over Pennsylvanian–Permian redbeds. The Middle Tertiary Snowmass pluton, and younger Treasure Mountain Dome, are intrusive events that have possibly been focused along and near the trace of this zone of thrust faulting. Important economic mineral deposits are associated with this zone including precious and base metals, molybdenum, tungsten, and dimension stone.

TECTONIC AND GEOMORPHIC HISTORY

Proterozoic rocks in Gunnison County have a varied parentage representing many depositional environments and reflecting varying degrees of metamorphism and deformation. Early and Middle Paleozoic time was characterized by repeated epeirogeny, accompanied in some places by fault movement, and in southern Gunnison County by Cambrian intrusion of alkalic rocks. Many periods of erosion and nondeposition during the Early and Middle Paleozoic are represented by numerous unconformities in the lower and middle Paleozoic section. In Late Paleozoic time depositional patterns changed in response to large uplifts in Colorado comprising the Ancestral Rocky Mountains.

In Gunnison County, the Uncompahgre–San Luis Highland, to the southwest, and to a lesser degree, the Front Range Highland to the northeast, were initially recorded as orogenic sediments in near-source, clastic rocks (The Pennsylvanian Gothic and Minturn Formations). The Uncompahgre and Front Range Uplifts were active and continued to shed sediment into the intervening Central Colorado Trough throughout the remainder of the Paleozoic and into the Triassic. A regional unconformity below the upper Middle Jurassic Entrada Sandstone (the pre-Entrada unconformity) truncates rocks of both the former highlands and the intervening basins. Some of the Mesozoic rocks in Gunnison County are related to the San Juan Basin forming contemporaneously to the southwest. Shallow marine sedimentation during the Cretaceous was widespread and continued until the onset of the Laramide orogeny.

During Laramide time (latest Cretaceous through middle or late Eocene) Colorado was part of a widespread compressional tectonic regime affecting the entire western United States. Reactivation of parts of the Pennsylvanian mountain ranges (Ancestral Rockies), as well as the creation of new highlands, was accompanied by intrusion of porphyritic rocks and formation of precious and base metal deposits. An extensive erosion surface was cut across much of the post-Laramide landscape in Colorado prior to widespread volcanism in the early Oligocene (Tweto, 1980a). Prolific volcanism in southern Colorado during this period, manifested in Gunnison County as the West Elk and San Juan volcanic fields, and as numerous hypabyssal intrusive rocks in the Elk Mountains, continued for about 15 million years into the early Miocene. A pronounced regional uplift across much of the southwestern and parts of the central United States, which most likely occurred 9 to 10 million years ago, initiated a canyon-cutting cycle into the relatively graded Middle to Late Tertiary surface producing much of the landscape geomorphology seen today in western Colorado. This landscape is characterized by river drainages superimposed upon older bedrock structure. Pleistocene glaciation finished the sculpting of much of the mountain topography seen today in Western Colorado including Gunnison County.



2

Precambrian Rocks

INTRODUCTION

Precambrian rocks in Colorado consist of an 1,800 Ma gneissic and shistose complex (Xfh, Xb), and of three ages of granitic rocks including: 1,750 Ma, 1,400 Ma (Yg), and 1,100 Ma. The gnessic and schistose complex was deformed and metamorphosed during at least two episodes. The oldest granitic rocks (Xg) were emplaced late in the second stage at about 1,750 Ma. (Tweto, 1980b). The younger granites (Yg) were emplaced during major movement on pre-existing north-northwest-trending faults. These rocks are on the northern edge of a province of late Early Proterozoic rocks, which includes the southwestern United States and much of Mexico, accreted onto a distinctly older Archean province to the north near the Colorado–Wyoming border. Rock types within this province are diverse, reflecting varied parent material and a wide range of both prograde and retrograde metamorphism and of penetrative deformation (Tweto, 1980b).

In Gunnison County, the 1,800 Ma rocks consist of interlayered felsic and hornblendic gneiss (Xfh), biotitic gneiss and migmatite (Xb), and mafic intrusive rock (Xm). Granitic rocks of the 1,750 Ma suite (Xg) are present in Gunnison County as plutons of granodiorite, quartz monzonite, and as a granodiorite gneiss. The 1,400 Ma granite suite is present as quartz monzonitic stocks (Yg), but also as alkalic and mafic rocks (Yam). No 1,100 Ma granite (Pikes Peak granite) exists in Gunnison County. However, latest Proterozoic to Cambrian alkalic and mafic intrusive rocks (Powderhorn district) are localized along predominantly north-northwest-trending Precambrian faults, many of which were reactivated in the Laramide.

PROTEROZOIC X

The oldest Precambrian rocks (1,800 Ma) in Gunnison County are Proterozoic interlayered felsic and hornblendic gneisses (Xfh) with a predominantly volcanic parentage. These rocks have undergone varying degrees of metamorphism. Rhyolites, basalts, and interlayered graywackes are recognizable in areas of low-grade metamorphism, especially in the southern portion of Gunnison County where a belt of Proterozoic volcanic and volcaniclastic rocks (the Dubois Greenstone; Gunnison gold belt) is exposed.

Because Proterozoic X rocks of the Gunnison Greenstone belt are less metamorphosed at the eastern end of their exposure, many volcanic and volcaniclastic units can be described. These units are both aerial and sub-marine, and include exhalative massive sulfide deposits that contain gold and silver. Biotitic gneisses and migmatite (Xb) containing interlayered hornblende gneiss, calc-silicate rocks, and abundant pegmatite have a sedimentary parentage.

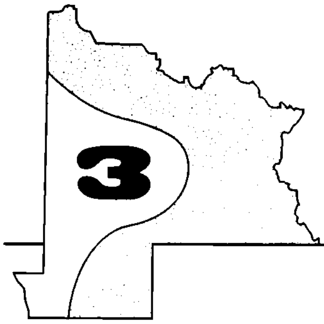
The 1,750 Ma granitic suite (Xg), and some slightly younger rocks, are represented in Gunnison County by the Denny Creek Granodiorite Gneiss, Kroenke Granodiorite, Pitts Meadow Granodiorite, Browns Pass Quartz Monzonite, and other rocks previously mapped as Pikes Peak and Silver Plume granite. The slightly younger Whitepine, Quartz Creek, and Cochetopa granites are 1,670 Ma in age. (B. Bartleson, written commun., 1998). These rocks occur in numerous places in eastern Gunnison County near the Continental Divide and Sawatch Uplift. They also crop out in southern Gunnison County as the Powderhorn Granite, host rock for Cambrian alkalic-carbonatite intrusive rocks (see Powderhorn District, this report). Mafic intrusive rocks (Xm) consisting of gabbro and mafic diorite and monzonite occur in small plutons and dikes in eastern Gunnison County.

PROTEROZOIC Y

Granites and quartz monzonites ranging in age from 1,350 to 1,480 Ma (Yg) are exposed in Precambrian terranes in Gunnison County. These rocks occur in small batholiths and many smaller stocks that lack foliation and are commonly concordant with enclosing gneisses (Tweto, 1980b). They are found in southern Gunnison County near Blue Mesa Reservoir as small outcrops of Vernal Mesa and Curecanti Quartz Monzonite and equivalent rocks. Alkalic and mafic intrusive rocks of 1,400 Ma (Yam) occur in a northwest-trending line of plutons near Cebolla Creek.

PROTEROZOIC YX

Granitic rocks in the vicinity of Spring Creek and Taylor Park (YXg) are undivided owing to problematic ages and areas of complexly mixed X and Y age Proterozoic rocks. Some of these rocks have physical characteristics of the 1,400 Ma granites but have age dates indicating ages of 1,800 Ma.



3

Sedimentary Rocks

PALEOZOIC ERA

CAMBRIAN SYSTEM

The oldest Paleozoic rocks in Gunnison County are Late Cambrian in age and represent a gradual west-to-east transgression of a Cambrian sea upon an eroded, low-relief Precambrian surface. Throughout Gunnison County this interval is represented by a package of quartzose sandstones and conglomerate (Sawatch Quartzite) that gradually thickens to the west and northwest. At the close of the Cambrian the supply of detrital material into this sea diminished, and vast tidal flats were dominated by carbonate formation. In the northern part of Gunnison County (Treasure Mountain area), as well as at Aspen and to the northwest in the Piceance Basin, this interval is represented by dolomite and quartzite (Peerless Formation). Rocks of the Sawatch Quartzite are Dresbachian in age; the Peerless Formation in this area may be in part Franconian age (Lochman-Balk, 1972). On the White River Uplift to the north, dolomite and algal limestone of the Dotsero Formation (Bass and Northrop, 1953) occur between, and are conformable with, the Peerless Formation and overlying rocks of the Early Ordovician Manitou Formation. These very latest Cambrian (Trempealeauan) rocks are entirely absent in Gunnison County owing to an interval of erosion.

SAWATCH QUARTZITE (MꞒr)

The Sawatch Quartzite crops in the eastern portion of Gunnison County as the basal unit in a series of isolated blocks of Paleozoic rock that are fault-bounded by Proterozoic rocks (Plate 1). The unit also outcrops in the northernmost and northeastern portions of the county on Treasure Mountain Dome and in the Elk Mountains, respectively. The Sawatch Quartzite is fairly consistent lithologically across Gunnison County but varies somewhat in thickness. In the area of Treasure Mountain Dome the Sawatch Quartzite is a white to light brownish-gray, medium to very thick, regularly bedded, locally ripple marked, crossbedded, glauconitic, medium-grained quartzite. The basal zone contains upwards of 3 ft (0.9 m) of arkosic quartz pebble to small cobble conglomerate. The unit in this area also contains some thin, sandy shale intervals which have been contact metamorphosed to hornfels by intrusion of the Late Tertiary Granite of Treasure Mountain (Mutschler, 1970; Gaskill and Godwin, 1966a).

In eastern Gunnison County near Fossil Ridge, the Sawatch Quartzite has been broken into three subunits (Lower, Middle, and Upper). In this area a basal conglomerate and medium-grained quartzite package (Lower unit) is overlain by a fine- to medium-grained, poorly sorted sandstone and sandy dolomite (Middle unit), which in turn is overlain by massive, white, cliff-forming, fine- to coarse-grained quartzites of the Upper unit (Zech, 1988).

The Sawatch Quartzite is of variable thickness across Gunnison County, ranging from roughly 100 ft (30 m) near Fossil Ridge, to 350–400 ft (106–122 m) in northernmost Gunnison County near Aspen. The Sawatch Quartzite locally is a favorable host for precious and base metal deposits but production from this interval has been small.

PEERLESS FORMATION (MꞒr)

The Peerless Formation outcrops only in the northern portion of Gunnison County on Treasure Mountain Dome. The unit most likely wedges out in the subsurface to the southeast. It has been completely removed by erosion beneath a pre-Ordovician unconformity where Early Paleozoic rocks again crop out to the east and south of Treasure Mountain Dome in eastern Gunnison County. On the Treasure Mountain Dome, Peerless Formation rocks consist of light- to dark- and greenish-gray, very fine to fine-grained sandstone interbedded with limestone and dolomitic limestone, dark-greenish and purplish-gray shale, and purplish-gray arkosic sandstone, all of which have been contact metamorphosed to quartzite and hornfels that contain serpentine and epidote (Gaskill and Godwin, 1966a). The thickness of this sequence in the Treasure Mountain Dome area is about 90 ft (27 m). The Peerless Formation is ocassionally a favorable host for precious and base metal deposits but has not been a significant producer.

ORDOVICIAN SYSTEM

Ordovician stratigraphy in Gunnison County, and indeed in Colorado in general, is fragmented by several episodes of intra-Ordovician and pre-Devonian erosion. In Gunnison County the Ordovician is represented by three formation, all of which are possibly separated by unconformities. The formations from base to top are the Manitou Dolomite of Canadian age; the Harding Sandstone, which is most likely Rocklandian age; and the Fremont Limestone of Cincinnatian age (Ross and Tweto, 1980). The Manitou Dolomite was subjected to a period of weathering and erosion lasting perhaps as long as 35 million years prior to deposition of the Harding Sandstone and Fremont Limestone (Ross and others, 1978). The Ordovician rocks that are preserved in the stratigraphic record are predominantly dolomite, dolomitic limestone, and minor calcareous clastic rocks which represent periods of marine sedimentation. In Gunnison County these rocks crop out in the eastern mining districts near Fairview Peak and Fossil Ridge, and in the northern portion of the County near the Elk Mountains and on Treasure Mountain Dome. All of the Ordovician formations wedge out south and southwestward of the Elk Mountains beneath unconformities.

MANITOU DOLOMITE (MOr)

The Manitou Dolomite is the most extensive and thickest of the Ordovician formations. Stratigraphic divisions of the Manitou Dolomite of Bass and Northrop (1953), the lower Dead Horse Conglomerate and the upper Tie Gulch Dolomite Member, which are used on the White River Plateau to the north, are not used in Gunnison County. The Lower Ordovician Manitou Dolomite outcrops on the northeast side of the Elk Mountains and in the Treasure Mountain Dome area. The unit also occurs in a belt of exposed Paleozoic rocks in the eastern portion of the county in the vicinity of Fairview Peak and Fossil Ridge. Between Tincup and Pitkin the Manitou Dolomite is a light- to medium-gray dolomite with sparse white chert nodules, and with an average thickness of around 200 ft (61 m). The Manitou is 250 ft (77 m) thick at Aspen (Bryant, 1971), 220 ft (68 m) thick at Cement Creek just south of Crested Butte (McFarlan, 1961), and 240 ft (74 m) thick at Monarch (Robinson, 1961) to the east in Chaffee County. The Manitou Dolomite is an important host rock for precious and base metal deposits.

HARDING SANDSTONE (MOr)

The Harding Sandstone varies in distribution and lithology across its area of occurrence in central Colorado. At Tennessee Pass in Lake County the Harding Sandstone is present only sporadically as channel fillings in, or small erosional remnants on, the Peerless Formation. The thickest known section of Harding Sandstone, 186 ft (57 m), has been described 2.5 mi north of Cotopaxi in the Arkansas River Valley by Sweet (1954). In Gunnison County the Harding Sandstone is a maximum of 5 ft (1.5 m) thick on the Treasure Mountain Dome and is composed of dark-gray to white, fine-grained sandstone, siltstone, and shale, and their metamorphic equivalents, quartzite, hornfels, and argillite (Gaskill and Godwin, 1966a). In exposed lower Paleozoic sections in eastern Gunnison County and on Fossil Ridge, the Harding Sandstone is mottled light-gray and grayish-pink, medium-and coarse-grained, bimodal, well-rounded sandstone to quartzite; it is upwards of 15 ft (5 m) thick (Zech, 1988).

In eastern Gunnison County mining districts (such as Pitkin, Tincup, and Whitepine) the Harding Sandstone is identifiable in the field by abundant heterostraci fish plates surrounded by purple orbicules of phosphatic iron-oxide stain (Fischer, 1978). Although the formation does not generally host significant ore in these districts, it is a good marker bed for Devonian ore zones above.

FREMONT LIMESTONE (MOr)

The Fremont Limestone (Fremont Dolomite) has been described as an erosional remnant of a once extensive group of rocks that represent the most widespread marine submergence to which North America has ever been subjected (Ross, 1976 a,b). The thickest sections described are at Kerber Creek (Burbank, 1932) and at Priest Canyon (Sweet, 1954), both of which are 300 ft (91 m) thick. The unit thins considerably to the south and is a maximum of 85 ft (26 m) thick in Gunnison County. Zech (1988) described 44–49 ft (13–15 m) of Fremont Limestone at Fossil Ridge.

At Fossil Ridge and in eastern Gunnison County mining districts (such as Whitepine, Quartz Creek, Tincup; Figure 3, p. 28) the unit is a brownish-gray, resistant, jagged-weathering, partly fossiliferous and dolomitic limestone with thin-bedded, platy-weathering dolomite beneath (Zech, 1988). On Treasure Mountain Dome the unit is a medium dark gray to white, fine- to medium-grained, very thick, massive- to thin-bedded, limestone and dolomitic limestone, all of which have been metamorphosed to lime-silicate marble (Gaskill and Godwin, 1966a). The Fremont Limestone has not been found at any locality without the Harding Sandstone beneath it (Ross and Tweto, 1980). The Fremont Limestone has produced metaliferous ores in Gunnison County. At the Fairview Mine in the Quartz Creek mining district (Figure 3, p. 28, Table 1), the Fremont Limestone produced silver-lead-zinc ores from the Fairview ore zone.

DEVONIAN SYSTEM

The unconformity at the base of Devonian rocks in central Colorado represents about 100 million years (Campbell, 1981). Missing from this interval are sediments representing any portion of the Silurian, and Early and Middle Devonian time. The likelihood of at least periodic Silurian deposition in Colorado, followed by a period of erosion lasting into the Late Devonian, is indicated by the presence of Middle and Upper Silurian brachiopods contained in limestones recovered from several Devonian kimberlite diatremes in the northern Front Range near the Colorado–Wyoming border (Chronic and others, 1969).

The known and paleontologically documented Devonian system in Colorado northeast of the Uncompahgre Uplift is represented by the lower and middle parts of the Chaffee Group. The upper portions of the Chaffee Group may be Mississippian in age but unconformities and lack of fossils preclude exact age determinations. Despite these stratigraphic uncertainties, the Chaffee Group is generally regarded as Devonian because of genetic similarities between the included formations. The Chaffee Group represents Late Devonian sedimentation in central Colorado. This includes an initial west to east marine transgression that covered a highly eroded older Paleozoic terrain; and a localized minor period of regression occurring in Late Devonian or Early Mississippian time (Campbell, 1981).

CHAFFEE GROUP (MOr)

The Chaffee Group from base to top consists of the Parting Formation, Dyer Dolomite, and the Gilman Sandstone. Documented Upper Devonian rocks are represented by the Parting Formation of Frasnian age and the Dyer Dolomite, the majority of which is Famennian age (Baars, 1972). The Dyer Dolomite is divided into two formal members on the White River Plateau by Campbell (1970a), a lower Broken Rib Member and an upper Coffee Pot Member. Eastward in the Central Colorado Trough the stromatolitic dolomite of the upper Coffee Pot Member thickens at the expense of fossiliferous limestone of the lower Broken Rib Member. This dolomite probably represents the easternmost extent of the Late Devonian transgression and the westward regression of the sea in earliest Mississippian time (Baars and Campbell, 1968). If so, this would indicate the upper formations in the Chaffee Group, the Gilman Sandstone, and the upper part of the Dyer Dolomite may in part be Mississippian in age (Baars, 1972). On the basis of genetic similarities of dolomitic lenses in water-reworked eolian sandstones near Minturn, and on the hypersaline character of carbonates in the Dyer Dolomite, Tweto and Lovering (1977) reassigned the Gilman Sandstone from the Leadville Limestone (Mississippian) to the Chaffee Group. Separated above and below by unconformities and completely lacking in fossils, the Gilman Sandstone may be Upper Devonian or Lower Mississippian.

Rocks of the Chaffee Group crop out in the northern part of Gunnison County in the Elk Mountains and on Treasure Mountain Dome but lack the Gilman Sandstone. A full Chaffee Group section, including the Gilman Sandstone, occurs in eastern Gunnison County in areas of precious and base metal deposits in Paleozoic rocks (Whitepine, Quartz Creek, Tincup, (Figure 3, p. 28, Table 1) and near Fossil Ridge. The Devonian rocks in Gunnison County wedge out and thin to the southwest beneath a pre-Entrada unconformity.

Parting Formation (MOr)

Across Gunnison County, the Parting Formation is variable in lithology and thickness. In the vicinity of Fossil Ridge the unit consists of an upper sequence of sandstone interbedded with dolomite, and thin-bedded limestone and shale. The sandstone is grayish-orange-pink, resistant, coarse- to medium-grained, and poorly sorted. The dolomite is pale orange-weathering, and is resistant to erosion forming a rough surface. This sequence overlies a section of thin-bedded, ripple-laminated, sandy dolomite and coarse-grained sandstone. The lower portion of the unit is notable for very thinly bedded sandstone with some interbedded shale and dolomite with ripple marks, mudcracks, and ocassional salt casts (B. Bartleson, written commun., 1998). The Parting Formation in this area is reported as being 69 ft (21 m) thick (Zech, 1988).

In the Elk Mountains and at Treasure Mountain Dome the unit is white to medium-gray limestone and dolomite with partings and thin beds of greenish-gray shale and siltstone. A thick gray quartzite caps the unit and a dolomite pebble conglomerate is present locally at the base. In this area of Gunnison County the unit is 50–65 ft (15–20 m) thick. Most of the Parting Formation in the Elk Mountains and Treasure Mountain Dome areas has been contact metamorphosed to marble, hornfels, and argillite by Tertiary intrusive rocks (Gaskill and Godwin, 1966a; Mutschler, 1970).

Dyer Dolomite (MOr)

In Gunnison County the Dyer Dolomite lies conformably above the Parting Formation. Exposures of the Dyer Dolomite Member are found in all eastern Gunnison County mining districts (such as Quartz Creek, Whitepine, Tincup), at Fossil Ridge, and in the northern part of the county on Treasure Mountain Dome. On Fossil Ridge the unit consists of a basal sandy limestone overlain by mottled grayish-red, medium-bedded, fossiliferous limestone and dolomitic limestone; the limestone in turn is overlain by medium dark gray and yellowish-weathering limestone and dolomite. The upper limestone and dolomite unit weathers into small, sharp, platy fragments, allowing it to be identified in the field. The Dyer Dolomite on Fossil Ridge is reported by Zech (1988) to be 119–134 ft (36–41 m) thick. In the Quartz Creek mining district the Dyer Dolomite is an important host horizon for precious and base metal deposits.

On Treasure Mountain Dome the Dyer Dolomite is light-gray to white, buff-weathering, fine-grained, locally sandy dolomite and limestone that is somewhat cherty. These rocks have been contact metamorphosed to lime-silicate and serpentine marble. Thickness is 60–100 ft (18–30 m). Replacement type zinc-lead-copper-silver deposits in the Dyer Dolomite occur on Treasure Mountain Dome and in the Crystal River Canyon (Gaskill and Godwin, 1966a).

Gilman Sandstone (MOr)

The Gilman Sandstone occurs in eastern Gunnison County Paleozoic sections but is absent from the Chaffee Group at Treasure Mountain Dome. On Fossil Ridge the Gilman Sandstone consists of yellowish gray weathering, slope-forming, massive sandy dolomite, medium to light gray, medium-grained sandstone, and a medium bluish gray, dolomitic breccia with fragments of dolomite and chert. Total thickness is 14–18 ft (4–5 m) (Zech, 1988). At the Fairview Mine on Terrible Mountain in the Quartz Creek district, the Gilman Sandstone is, in part, a very fine-grained, smooth-weathering, buff colored, micritic dolomite which is referred to locally as the "Buckskin" limestone. These rocks probably acted as a partial aquitard for metal-bearing solutions which created replacement precious and base metal deposits in the underlying Dyer Dolomite.

MISSISSIPPIAN SYSTEM

The Mississippian is represented in the Central Colorado Basin by carbonates of the Leadville Limestone. These rock are Early Mississippian in age (Baars, 1966; DeVoto, 1980a). The Late Mississippian and Early Pennsylvanian in central Colorado was a period of weathering and erosion during which time an extensive karst surface was developed upon Early Mississippian rocks. A residual soil (paleosol) locally preserved on this surface is called the Molas Formation. This reddish-brown to purple regolith has been dated in part as Early Pennsylvanian (Merrill and Winar, 1958).

In the Central Colorado Basin, Early Mississippian rocks are divided into two formal members separated by an unconformity. The basal carbonate in the Leadville Limestone is the Redcliff Member, a predominantly thin-bedded, stromatolitic dolomite mudstone and dolomite breccia (DeVoto, 1980a). These rocks rest unconformably on dolomitic sandstones of the Gilman Sandstone (reassigned by Tweto and Lovering (1977) to the Upper Devonian Chaffee Group). The Kinderhookian-age Redcliff Member is probably in part of Osagean age; however, the formal boundary is placed at an obvious intra-formational unconformity rather than at a change in fossil faunas (DeVoto, 1980b). Osagean rocks of this sequence in central Colorado are designated as the Castle Butte Member. These rocks consist predominantly of pelletal, oolitic, and mixed-skeletal grainstones and packstones (DeVoto, 1980a). The relatively thin, predominantly subtidal Lower Mississippian carbonate sequence in central Colorado, coupled with unconformities that record subaerial erosion, suggest that the Mississippian period was dominated by erosion interrupted by short periods of marine sedimentation (DeVoto, 1980b).

LEADVILLE LIMESTONE (MOr)

The Leadville Limestone outcrops in eastern Gunnison County in areas of exposed Paleozoic terrain, and in the Elk Mountains, where the unit attains its maximum thickness of 275 ft (84 m). Although an upper and lower member are recognizable in Gunnison County, the formal divisions of the formation are not in use. The Leadville Limestone caps part of Fossil Ridge. Here it consists of two units. An upper, dense, light bluish gray to dark gray, massive, very thick bedded limestone contains abundant well-cemented, collapse-breccia-dominant paleokarst; a lower dark-gray unit is fossiliferous, massive limestone, dolomite, and stromatolitic limestone. The Leadville Limestone on Fossil Ridge is 195–210 ft (59–64 m) thick. In this area the Molas Formation was recognized but is included in the overlying Belden Formation (Zech, 1988).

In the Elk Mountains and on Treasure Mountain Dome the Leadville Limestone contains a basal sequence of sandy limestone and dolomite marble, calcareous sandstone, and thin beds of hornfels. These beds are overlain by an upper finely to coarsely crystalline calcite marble with a few beds of cherty and dolomitic marble, and white to medium-bluish-gray, thin-bedded to massive marble and dolomitic marble. The rocks of the Leadville Limestone on Treasure Mountain Dome are at most 275 ft (84 m) thick (Mutschler, 1970). In the Elk Mountains and on Treasure Mountain Dome these rocks have been contact metamorphosed by Tertiary intrusive rocks.

The Molas Formation in this area is as much as 50 ft (15 m) thick. It contains a brownish- or blackish-red, dusky- or grayish-green pebble to boulder residual breccia and conglomerate, argillite, sandy argillite, and argillaceous quartzite. The Molas Formation rests on an irregular karst surface with as much as 40 ft (12 m) of relief (Mutschler, 1970). The Molas Formation has been metamorphosed to hornfels and quartzite on Treasure Mountain Dome (Gaskill and Godwin, 1966a).

Exceptionally pure white marble (Yule Marble) quarried from the Leadville Limestone at Yule Creek has been used in the Tomb of the Unknown Soldier and the Lincoln Memorial in Washington, D.C., as well as in the Arlington National Cemetary in Virginia, and structures in other localities. The Leadville Limestone is also an important ore-producing horizon for precious and base metals in numerous Gunnison County mining districts.

PENNSYLVANIAN AND PERMIAN SYSTEMS

The Pennsylvanian and Permian sections in the Central Colorado Trough record what is probably a 70-million year period of continuous, unbroken sedimentation. This stratigraphic interval is the most continuous section in Gunnison County. At the onset of the Pennsylvanian, and through most of Morrowan time, karst topography continued to develop on exposed Mississippian carbonates of the Leadville Limestone (DeVoto, 1980b). In southwestern Colorado and Gunnison County, deposition of the Molas Formation onto this karst surface probably continued into early Atokan time with some reworking of the upper portions of the formation by marine readvances later in the Atokan (Merrill and Winar, 1958).

During Late Morrowan time, the black shales, carbonates, and other clastic rocks of the Belden Formation began to be deposited over this well developed karst surface. Deposition of these marine shales and limestones predominated into Atokan time but decreased as the Uncompahgre and Front Range Uplifts began to contribute orographic sediments into the basin (Minturn/Gothic Formations and Maroon Formation). The Uncompahgre Uplift to the southwest and the Ancestral Front Range Uplift to the east ultimately contributed more than 13,000 ft (4,000 m) of fluvial and marine sediments to the intervening Central Colorado Trough (Campbell, 1981). The structural and sedimentary history of this basin has been described by Mallory (1972) and DeVoto (1980b).

Pennsylvanian mountain building adjacent to the Central Colorado Trough reached a maximum in the Des Moinesian (Middle Pennsylvanian) (DeVoto, 1980b). This was also the time of maximum marine advance, although nonmarine alluvial-plain and alluvial-fan sediments began to accumulate at the basin margins and around local fault-block uplifts within the basin (DeVoto, 1980b; Streufert and others, 1997a). In the eastern part of the trough (eastern Gunnison County) these basin-margin and localized orographic sediments compose the Middle Pennsylvanian Minturn Formation.

In the south and southwestern parts of the basin, (Gunnison County and Crested Butte–Aspen area), time and stratigraphically equivalent rocks related to orographic influences from the Uncompahgre Uplift, and to the emergence of localized fault blocks, have been designated as the Gothic Formation (Langenheim, 1952; Bartleson, 1972; Bartleson, Bryant, and Mutschler, 1968). Continued mountain building and basin-filling sedimentation in Des Moinesian time in the Central Colorado Trough restricted the seaway in the northern portion of the trough. Here up to 9,000 ft (2,745 m) of evaporitic rocks (Eagle Valley Evaporite) formed in a series of sub-basins collectively known as the Eagle Basin. The Eagle Basin does not extend into Gunnison County.

Complex tectonic styles and sedimentation patterns in the Central Colorado Trough, recorded in interbedded and inter-tonguing marine, non-marine, and transitional rock types characteristic of Des Moinesian time, shifted significantly in Missourian and Virgilian (Late Pennsylvanian) time. Although the basin geometry remained the same, arid-climate, alluvial-fan and braided-river sedimentation were the dominant styles in the Central Colorado Trough for the remainder of the Pennsylvanian and into the Permian (DeVoto, 1980b). This interval of sedimentation is represented by the predominantly coarse- to fine-grained, clastic, subordinate marine, red-bed sequence of the Maroon Formation. The strata of the Maroon Formation formed in mountain-front alluvial fans as poorly sorted, coarse-grained detritus; braided-stream systems; basin-center, low-energy streams, flood-plains, and playa lakes (DeVoto, 1980b). These depositional patterns continued into the Early Permian. By the close of the Paleozoic the Uncompahgre and Ancestral Front Range highlands had been greatly reduced by erosion and the intervening basins mostly filled in. Sedimentation into the Central Colorado Trough continued, after a brief period of erosion, into the Late Permian and Early Triassic periods, represented by redbeds of the State Bridge Formation. These rocks are absent from Gunnison County owing to nondeposition or erosion beneath the pre-Entrada unconformity, or both.

BELDEN FORMATION (ℙb and ℙmb)

The Belden Formation outcrops in northern Gunnison County on Treasure Mountain Dome, on Fossil Ridge, where only 300 ft (91 m) of the formation remain as an erosional remnant, and in the eastern part of the county in areas of exposed Paleozoic sections (Whitepine, Quartz Creek, and Tincup mining districts). On Treasure Mountain Dome the unit consists of light- to dark-gray, sandy and cherty limestone, dolomitic limestone, and dolomite, and gray to greenish-gray calcareous sandy siltstone and minor sandstone interbedded with dark carbonaceous shale (Gaskill and Godwin, 1966a; Mutschler, 1970). In the vicinity of Treasure Mountain Dome these rocks have been metamorphosed to marble and calcium-silicate hornfels and are occasionally productive host rocks for precious and base metal deposits.

GOTHIC FORMATION (ℙm and ℙmb)

Across the northwestern and north-central portions of Gunnison County (Elk Mountains) the Middle Pennsylvanian Gothic Formation consists of predominantly gray, pale-yellow to brown sandstone, conglomerate, and shale with ocassional limestone beds. On 1:250,000-scale geologic maps of Gunnison County (Montrose and Leadville 1 x 2 degree maps) the Gothic Formation of Langenheim (1952) is included as a part of the Minturn Formation. On the geologic map prepared for this report (Plate 1) sediments that occur stratigraphically above the Belden Formation and below the Maroon Formation in the area of the Elk Mountains are designated as Gothic Formation, owing to the fact that the Minturn Formation cannot be defined on the west side of the Central Colorado Trough. These basin-marginal and near-source orographic sediments in northwestern and north-central Gunnison County are more correctly referred to as the Gothic Formation (B. Bartleson, written commun., 1998). On Plate 1 the Gothic Formation is in all cases mapped as a combined unit with the underlying Belden Formation (ℙb and ℙmb).

A coal resources-based 1:100,000-scale geologic map of the Paonia and northern Gunnison County areas (Ellis and others, 1987) includes Gothic Formation that is mapped to the exclusion of Minturn Formation. On this map the Gothic Formation consists predominantly of brownish-gray to reddish-brown arkosic sandstone, siltstone, conglomerate, gray shale, and limestone upturned against and intruded by Middle Tertiary granodioritic rocks of the White Rock pluton, and occurring stratigraphically below the Pennsylvanian/Permian Maroon Formation.

MINTURN FORMATION (ℙm and ℙmb)

The Minturn Formation as originally described on the east side of the Central Colorado Trough consists mostly of arkosic, poorly sorted, basin-margin clastic rocks, but it also contains interbedded limestone beds, in the type localities at Minturn and Pando, Colorado (Tweto and Lovering, 1977; Tweto, 1949). These sediments accumulated just to the west of the emergent Ancestral Front Range highland in both marine, and nonmarine, largely fluviatile, environments (Tweto and Lovering, 1977). To the north of Gunnison County these clastic and subordinate carbonate rocks change facies westward into, and interfinger with, evaporitic rocks of the Eagle Basin. The Minturn Formation only occurs in eastern Gunnison County on the western flank of the Sawatch Uplift, where it is mapped as a combined unit with the underlying Belden Formation (ℙmb) (Plate 1).

MAROON FORMATION (Pℙm)

The redbeds of the Maroon Formation consist of maroon and red to grayish-red sandstone, conglomerate, and mudstone, with minor carbonate beds. The unit is an arkose and is somewhat micaceous. The Maroon Formation attains its maximum thickness of greater than 9,500 ft (2,900 m) in the Elk Mountains just southwest of Aspen (Bryant, 1969). These sediments thin abruptly to the south across northern and central Gunnison County, wedging out between Cement Creek and the Taylor River by a combination of depositional thinning and truncation beneath the pre-Entrada unconformity (Tweto and others, 1976). Sedimentation during latest Pennsylvanian and earliest Permian time, as recorded in the Maroon Formation in the Central Colorado Trough was characterized by stream channel and flood-plain deposits that grade into coastal plain or tidal flat deposits basinward (Tweto and Lovering, 1977).

MESOZOIC ERA

TRIASSIC SYSTEM

Late Paleozoic mountain building begun in the Pennsylvanian gave way by the Middle to Late Permian to an interval of tectonic stability that extended into the Triassic in most parts of Colorado. Lower Triassic sediments may have thinly blanketed southern Colorado only to be subsequently removed by erosion, or they may never have been deposited, as no Lower Triassic rocks have been recognized in Gunnison County. Southwestward-thickening Upper Triassic rocks were deposited in a wedge onto a part of the stable craton in northeastern Colorado. These rocks, however, are absent from much of central Colorado owing to epeirogenic upwarping and ensuing erosion beneath the pre-Entrada unconformity (Maughan, 1980).

JURASSIC SYSTEM

During the Jurassic, although western North America was invaded four times by seas, Colorado was largely exposed and marine conditions were never widespread. In the Early Jurassic the basic framework of a large north–south trending, asymmetrical basin called the Western Interior Basin had been established and successive marine encroachments from both the north and south began. Each of these seas advanced farther into the center of the continent and they joined in the early Late Cretaceous (Berman and others, 1980). Jurassic sediments were deposited along the western margin of the major Jurassic seaway west and northwest of Colorado. Marine shales, sandstones, and limestones grade southwestward and eastward into continental sandstones, redbeds, and varigated, multi-colored shales composing the Jurassic in western Colorado. Jurassic marine deposition occurred only in portions of north-central and northwestern Colorado because Jurassic shorelines were controlled by persistent uplifts to the west (Uncompahgre Uplift), and northeast (Trans-continental Arch). The Jurassic section in western Colorado contains as many as five principal unconformities, as well as a regional unconformity at the contact between the Upper Jurassic Morrison Formation and the Lower Cretaceous Dakota Group (Berman and others, 1980).

The Middle and Upper Jurassic sequences of southern and southwestern Gunnison County are described, in part, by stratigraphic nomenclature carried north from the San Juan Basin. In Gunnison County the Junction Creek Sandstone (Middle Jurassic) is assigned formation status, although in the San Juan Basin it is a member of the Wanakah Formation (Middle and Upper Jurassic), also present in Gunnison County.

The Junction Creek Sandstone extends north of Almont in south-central Gunnison County, where it rests depositionally on Proterozoic crystalline rocks and is overlain by the Morrison Formation. This sandstone may very well be the Entrada Sandstone and needs further study (B. Bartleson, person. commun., 1998). The Wanakah Formation does not extend north or east of the mouth of the Lake Fork of the Gunnison River. The Entrada Sandstone (Middle Jurassic) occurs in northern Gunnison County, thinning to the south and east, and does not occur south of Cement Creek.

ENTRADA SANDSTONE (Jme)

The Entrada Sandstone (Middle Jurassic) was deposited in western Colorado and northern Gunnison County upon a widespread erosion surface (pre-Entrada unconformity) cut across all older formations from Triassic through Proterozoic in age. Triassic sediments may have existed in Gunnison County and may have been possibly removed entirely by this pre-Entrada interval of erosion. Many Paleozoic formations and some Proterozoic terranes show modification, such as beveling of thicknesses and truncations, beneath the pre-Entrada unconformity. An excellent summary of the stratigraphy and of the workers who have published on the Entrada Sandstone and its many equivalents in given by Berman and others (1980).

The Entrada Sandstone is a light-gray to white, pale-orange, and pink, medium- to massive- bedded, usually crossbedded, sandstone or quartzite that is locally conglomeratic at the base. The unit is a maximum 100 ft (30 m) thick in northern Gunnison County, thins to the south, and pinches out at the Taylor River. The Entrada Sandstone is frequently mapped together with the Morrison Formation (Jme) in areas of cover or poor access. It is metamorphosed into quartzite in northern Gunnison County where exposed in the Elk Mountains and on Treasure Mountain Dome, and occasionally hosts precious and base metal sulfide deposits.

JUNCTION CREEK SANDSTONE (Jmw and Jmj)

In southwest Colorado the Junction Creek Sandstone (Middle Jurassic) interfingers with and overlies the Wanakah Formation. The Wanakah, represents the third marine invasion of the Western Interior Basin by Jurassic seas, and overlies the Todilto Limestone and Entrada Sandstone (Berman and others, 1980). The Middle Jurassic in Gunnison County is represented by the Entrada and Junction Creek Sandstones only, and they are not correlative. In the area of the Black Canyon of the Gunnison River the Junction Creek Sandstone is included as part of the Wanakah Formation (included in Jmj and Jmw units on Plate 1). The Junction Creek Sandstone thins to the northeast and pinches out just north of the Taylor River. North of the town of Gunnison in the vicinity of Almont, the Junction Creek Sandstone rests depositionally on Proterozoic granitic and gneissic rocks and is overlain by the Morrison Formation (Ellis and others, 1987). These authors mapped the Junction Creek Sandstone as a separate unit as far north as the Roaring Judy Fish Hatchery, located on the East River 4 mi north of Almont. To the north at Round Mountain, these are mapped together with Cretaceous Dakota Sandstone and Burro Canyon Formations and the Jurassic Morrison Formation. To the north of Round Mountain (5 mi north of Roaring Judy Fish Hatchery), the Junction Creek Sandstone is believed to be absent and Entrada Sandstone is recognized below the Morrison Formation.

The Junction Creek Sandstone is a light-yellowish-gray to white, massive, friable, eolian sandstone which is locally quartzitic. Its maximum thickness in Gunnison County is about 180 ft (55 m) (Ellis and others, 1987).

WANAKAH FORMATION

The Middle and Upper Jurassic Wanakah Formation occurs only in southern and southwestern Gunnison County, mainly in exposures within the upper Black Canyon of the Gunnison River and Blue Mesa Reservoir. In this area the Junction Creek Sandstone

(Middle Jurassic) is included as a member. The Wanakah Formation, except for the Junction Creek Member (Formation), does not extend eastward of the mouth of the Lake Fork of the Gunnison River. The formation contains the following members from top to bottom: 1) interbedded gray mudstone and cherty algal limestone, 2) Junction Creek Sandstone Member, 3) gypsiferous mudstone and sandstone, and 4) the Pony Express Limestone Member. The basal Pony Express Limestone Member is locally absent (Ellis and others, 1987). The maximum thickness of the unit in Gunnison County is less than 300 ft (90 m) (Tweto and others, 1976).

MORRISON FORMATION (Jme)

The Upper Jurassic Morrison Formation in western Colorado is divided into four members: from top to bottom, the Brushy Basin, Westwater Canyon, Recapture, and Salt Wash Members. In Gunnison County only the upper Brushy Basin Member and underlying Salt Wash Member are present (Tweto and others, 1976). Both the Salt Wash and Brushy Basin Members thin eastward (Tweto and others, 1976; Ellis and others, 1987).

The Morrison Formation consists of variegated, predominantly dull green and reddish-brown, claystone, mudstone, and siltstone (Brushy Basin Member), and prominent beds of light-gray sandstone (Salt Wash Member). Locally the unit can contain thin limestone beds and lenticular beds of pebble conglomerate. The maximum thickness of the unit in Gunnison County is probably about 500 ft (152 m) (Tweto and others, 1976).

CRETACEOUS SYSTEM

The Cretaceous rocks of Colorado are important economically because they contain coal, coal-bed methane, and oil and gas resources and as such they have been well studied. The Cretaceous period in the Western Interior Basin was a time of nearly continual deposition of continental sediments in the western portion of the basin, and of marginal marine grading to offshore deposits in the east. A widespread Cretaceous deltaic system located in Wyoming and Utah produced large sediment accumulation and subsidence in western and central Colorado (Berman and others, 1980). Cretaceous rocks range in total thickness from 3,200 ft (976 m) in southeastern Colorado to 11,350 ft (3,460 m) in northwest Colorado (Young, 1970). Cretaceous rocks occur in all structural basins in Colorado and most likely existed above the older rocks now exposed in many of Colorado's present day uplifts from which they have been removed. Coal beds, especially in the Upper Cretaceous Mesaverde Group, are mined in northwestern Colorado and from Gunnison County (see "Coal Resources" chapter, this report). Coal beds in Cretaceous sections formed from consolidation of local organic debris while the much more abundant terrigenous clastic sediments composing the Cretaceous of Colorado originated in the Sevier orogenic belt to the west in present day Utah (Berman and others, 1980) and, to a lesser degree, as material shed off a cratonic source area to the east (MacKenzie and Poole, 1962).

The oldest Cretaceous rocks in Colorado and in Gunnison County are those of the Burro Canyon Formation (Lower Cretaceous), which occurs locally between the Upper Jurassic Morrison Formation and rocks of the Upper Cretaceous Dakota Group. The Burro Canyon and Dakota Group rocks are usually mapped together. Both the Burro Canyon Formation and Dakota Group rocks are dominated by quartz sandstone, with minor shale and conglomerate. The Dakota Group rocks represent the most widespread of all Cretaceous regressive sequences in the Western Interior Basin and are found in many western states and in the internal Provinces of Canada (Berman and others, 1980). The Dakota Group and its depositional environments are hence described by numerous workers. A very good summary and list of references is given in Berman and others (1980). Locally, lack of diagnostic fossils in the Dakota makes exact time correlation difficult within the unit. Rocks of the Burro Canyon Formation and Dakota Group occur in all parts of Gunnison County except the Sawatch Uplift, from which they have been removed by erosion.

The Upper Cretaceous Mancos Shale is composed of minor sandstone, and siltstone, all of marine origin. Sequences of Mancos Shale that are exposed in Gunnison County attain a thickness of 5,000 ft (1,524 m) in the northwestern portion of the county. Mancos Shale is metamorphosed into hornfels in portions of the Elk Mountains and on Treasure Mountain Dome, and it locally hosts precious and base metal sulfide deposits as in Lead King Basin in northern Gunnison County.

The Upper Cretaceous Mesaverde Group occurs extensively in northwestern Gunnison County and contains commercially important coal beds in its lower portions. The Group contains from top to bottom,
1) Ohio Creek Member—conglomeratic sandstone;
2) Barren member–sandstone, shale and uneconomic coal-beds; 3) Coal-bearing member(s)—sandstone, shale, and coal; and 4) Rollins Sandstone Member—quartzose sandstone. The Mesaverde Formation is a maximum of 2,500 ft (762 m) thick in northwestern Gunnison County.

BURRO CANYON FORMATION (Kdb, KJdb, KJdj, KJdw)

The Burro Canyon Formation consists of lenticular beds of light-gray chert-pebble conglomerate and sandstone, and light-gray to green claystone (Tweto and others, 1976). The unit is commonly mapped with the overlying Upper Cretaceous Dakota Sandstone

(Kdb), or it is grouped into larger combined Mesozoic units (KJdm, KJdj, KJdw), including the Dakota Sandstone through the Jurassic Morrison Formation, Junction Creek Sandstone, or Upper Jurassic Wanakah Formation. The Burro Canyon Formation outcrops along either side of the valley near the town of Almont, at the confluence of the East and Taylor Rivers (head of the Gunnison River), where it is combined with the Dakota Sandstone (Kdb). The combined unit is also found in exposed Cretaceous sections upturned against the Middle Tertiary White Rock pluton northeast of Crested Butte. In these exposures the Burro Canyon Formation consists of light-gray sandstone; conglomeratic, chert-pebble sandstone; and light bluish gray to light-green claystone, shale, and siltstone with a maximum thickness of 100 ft (30 m) (Ellis and others, 1987). Although the unit is exposed all along U.S. Highway 50 both east and west of Gunnison, it is missing a few mi south of the highway and is not again recognized until south of the San Juan Mountains (B. Bartleson, written commun., 1998).

DAKOTA SANDSTONE (Kd, Kdb, KJde, KJdj, KJdm, KJdw)

The Dakota Sandstone unconformably overlies the Burro Canyon Formation and consists of light-gray to light-brown resistant sandstone, that is locally carbonaceous, shale, coal beds, and chert-pebble conglomerate (Tweto and others, 1976). Its maximum thickness is 200 ft (60 m). The Dakota Sandstone occurs in outcrops in southeastern Gunnison County, in the Elk Mountains, and along the Gunnison, East and Taylor Rivers. It is commonly either mapped with the Burro Canyon Formation (Kdb), or with other Mesozoic formations (KJdj, KJdw, KJdm, KJde). It is mapped separately in an area of Cretaceous rock upturned against the Middle Tertiary granodioritic White Rock pluton in the Elk Mountains north of Crested Butte (Ellis and others, 1987). In this area the unit consists of light-gray to brown resistant sandstone or quartzite, minor shale, local thin coal beds, and minor chert-pebble conglomerate sandstone lenses at or near the base; its thickness ranges from 40 to 200 ft (12 to 61 m).

Because of its widespread deposition and very resistant nature, the Dakota Sandstone is widely exposed. It is useful in regional structural analyses because strain events are recorded in the brittle resistant quartzites of the unit as fractures and slickensides. In Gunnison County the Dakota Sandstone locally hosts precious and base metal deposits.

MANCOS SHALE (Km)

The Mancos Shale outcrops over large areas in the northwestern portion of Gunnison County and in many places in the Elk Mountains, as well as west and southeast of Gunnison. Many Middle Tertiary laccolith-shaped intrusives of granodiorite are emplaced into thick sequences of Mancos Shale in the West Elk Mountains in northwestern Gunnison County and near Crested Butte along the west flank of the Elk Mountains. Mancos Shale most likely underlies the large area in west-central Gunnison County covered by volcanic and volcaniclastic rocks of the West Elk volcanic field. Scattered outcrops of Mancos Shale in the eastern part of Gunnison County are isolated erosional remnants on the west flank of the Laramide-age Sawatch Uplift.

In the Elk Mountains the Mancos Shale consists of gray to dark gray marine shale with sandstone beds near the top. The unit includes silver-gray siliceous shale of the Lower Cretaceous Mowry Shale Member at the base, the Upper Cretaceous Frontier Sandstone Member, 300 to 400 ft (90 to 122 m) above the base, overlain by calcareous shale equivalent to the Niobrara Formation (Tweto and other, 1978).

The maximum thickness of the Mancos Shale in Gunnison County is greater than 5,000 ft (1,500 m) (Tweto and others, 1976). Contact metamorphosed Mancos Shale is a host for precious and base metal deposits near Treasure Mountain Dome. Hornfels of the Mancos Shale partially host the molybdenite deposit at Mount Emmons near Crested Butte.

MESAVERDE FORMATION GROUP (Kmv)

The Upper Cretaceous Mesaverde Formation outcrops extensively in northern Gunnison County and is important economically because it contains coal resources. The Mesaverde Formation consists of gray to brown sandstone, siltstone, shale, and coal beds, which conformably overlie the Mancos Shale; the units represent a number of marine transgressions that produced rich coal measures. The coal resources of Gunnison County are discussed in the "Coal Resources" chapter. The Formation contains four members, from bottom to top, Rollins Sandstone Member, Coal-bearing member, Barren member, and the Ohio Creek Member. Because of commercially important coal beds in the formation it has been studied by many workers. The maximum thickness of the Mesaverde Formation in northern Gunnison County is 2,300 to 2,500 ft (700 to 762 m) (Ellis and others, 1987; Tweto and others, 1976). These rocks are shown on Plate 1 as the undivided unit Kmv that is used on the Montrose 1 x 2 degree quadrangle (Tweto and others, 1976). In the Leadville 1 x 2 degree quadrangle (Tweto and others, 1978) the unit was split into a lower unit, consisting of sandstone, shale, and lower productive coal-zones, and an upper unit, consisting of sandstone and shale with minor coal. On the geologic map of Gunnison County in this report (Plate 1), a combined unit (Kmv) has been used to maintain consistency.

Rollins Sandstone Member (Kmv)

The Rollins Sandstone Member was assigned to the Mesaverde Formation by Johnson (1948). It is the basal member of the formation occurring immediately above marine rocks of the Mancos Shale. The sandstone is fine grained to very fine grained, tan to light gray, with calcareous to siliceous cement. It is a coarsening upward, wave-dominated, deltaic section: offshore sandstone grades upward to marginal marine sands and then to coastal swamp deposits and coal at the top (B. Bartleson, written commun., 1998). The unit rises stratigraphically about 275 ft (84 m) near the western boundary of Gunnison County and is from 100 to 200 ft (30 to 61 m) thick (Ellis and others, 1987). To the north on the Grand Hogback the unit is recognizable in exposures in Four Mile Creek by iron-staining caused by burning coal beds in the overlying coal-bearing member (Bowie Shale Member of the lower Williams Fork Formation in Cattle Creek quadrangle), and by a carbonate crust on outcrop exposures (Kirkham and others, 1996).

Coal-bearing Member (Kmv)

The coal-bearing member, not formally named in Gunnison County, is a zone containing economically important coal beds that are part of a statewide coal-resource hosted in upper Cretaceous rocks. In the northern portion of Gunnison County the unit contains sandstone interbedded with siltstone, mudstone, shale, and coal and approaches a thickness of 650 ft (198 m) (Ellis and others, 1987).

Barren Member (Kmv)

A package of thin sandstones, mudstones, siltstones, shales, and thin, uneconomic coal beds that comprises the upper Mesaverde Formation above the economic coal zone is not formally described. The unit coincides with the upper Mesaverde (Kmvu) of Tweto and others (1978). Sandstone beds in this sequence, which comprises more than 60 percent of the total sediments of the Mesaverde Formation, tend to be thinner, and more discontinuous. The coal beds are less well developed and are commonly lignitic.

Ohio Creek Member (Kmv)

The Ohio Creek Member was redescribed as being probably Late Creatceous in age and was reassigned as the upper member of the Mesaverde Formation (Gaskill and Godwin, 1963; Johnson and May, 1980). The unit consists of lenticular sandstone, which is locally conglomeratic with abundant chert pebbles, siltstone, and mudstone. The lower contact of the unit with thin clastic beds of the Barren member is gradational and locally conformable. The unit is separated locally from the overlying early Tertiary Wasatch Formation by an unconformity (Ellis and others, 1987).

CENOZOIC ERA

The Cenozoic Era in western Colorado was characterized by two events: the accumulation of orographic sediments (Wasatch Formation) into basins adjacent to newly formed Late Cretaceous- to early Tertiary uplifts (Laramide Orogeny), and widespread middle to late Tertiary volcanism that produced both intrusive and extrusive suites of rocks. The complex Tertiary volcanic history of Gunnison County is described in the following section on Igneous Rocks. Many of the volcanic deposits of Gunnison County include thick sequences of volcaniclastic rocks, some of which are named on Plate 1, such as Oligocene sedimentary deposits, and Miocene boulder gravel. These units will be described below as the youngest sedimentary deposits in Gunnison County but the reader should bear in mind that they are intimately related to the numerous and diverse Tertiary volcanic eruptions.

TERTIARY SYSTEM

Mountain building of the Laramide Orogeny was well underway by the beginning of the Tertiary Period in western Colorado. Eocene and Paleocene sediments of the Wasatch Formation (Tw) collected in the Piceance Basin in response to the erosion of these uplifts. The Eocene Telluride Conglomerate (Ttc) also formed at this time. Middle Tertiary sedimentary deposits are associated with Oligocene volcanic sequences and consist of both volcaniclastic and alluvial sediments (Tos, Tog) within the volcanic rocks. Miocene-age boulder gravel and tuffaceous conglomerate (Tmg) is interbedded with extrusive volcanic and volcaniclastic rocks in the West Elk and Elk Mountains (Tweto and others, 1976).

PALEOCENE AND EOCENE

Wasatch Formation (Two)

The Wasatch Formation consists of variegated claystone and shale with local lenses of sandstone, volcanic sandstone, and basal conglomerate. As shown on Plate 1, the Wasatch Formation has a maximum thickness of 1,800 ft (550 m); it is mapped with the underlying Ohio Creek Formation. The thickness of the Ohio Creek Member shown on Plate 1 is 400 ft (120 m), for a combined thickness for the unit (Two) of 2,200 ft (670 m) (Tweto and others, 1976). The Wasatch Formation, which is distinguished from the underlying Cretaceous Ohio Creek Member on the northern Gunnison County and Paonia Coal map of Ellis and others (1987), has a maximum thickness of 2,000 ft (610 m).

EOCENE

Telluride Conglomerate (Tt)

A few small isolated outcrops of Telluride Conglomerate are found in the southwest corner of Gunnison County near Little Cimarron Creek and Cimarron Creek (Plate 1). These rocks are light-gray to red conglomerate, grit, and sandstone, with lesser quantities of mudstone and shale (Tweto and others, 1976). The maximum thickness of these rocks is about 500 ft (150 m).

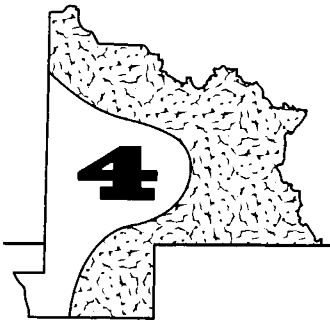
Sedimentary Deposits

Late Eocene gravels, water-laid tuffs, sand, and silt, occupy various stratigraphic positions within the West Elk volcanic sequence, and northwest and southeast of Parlin (Coyote Hill). The deposits probably formed during a late Eocene erosion event. They may be equivalent to Oligocene gravel deposits described by Ellis and others (1987) as coarse gravel and boulders derived from Precambrian rocks mantling Late Eocene pediment surfaces.

MIOCENE

Boulder Gravel and Tuffaceous Conglomeratic Sandstone

Boulder gravel and interbedded tuffaceous conglomeratic sandstone and tuff are derived from sedimentary and plutonic rocks in the Sawatch and Elk Mountain uplifts. The volcanic and volcaniclastic units include rhyolitic pumice tuff, andesitic tuff, and tuffaceous sand and gravel. The Miocene gravels and ash-flow tuffs occur in isolated outcrops on the ridge between Ohio Creek and East River in central Gunnison County (Ellis and others, 1987). These rocks are not described on Plate 1.



4

Igneous Rocks

INTRODUCTION

The igneous rocks of Gunnison County include a single Cambrian alkalic intrusive suite (carbonatite complex) located near Powderhorn, and a widespread and diverse Laramide to Miocene collection of hypabyssal and extrusive rocks. The Cenozoic igneous rocks of Gunnison County can be divided into three distinct suites based on field relationships, isotope dates, and petrochemical data (Mutschler and others, 1981).

The Twin Lakes pluton on Independence Pass (TKi) is the oldest Cenozoic intrusive center in Gunnison County and was intruded during the Laramide Orogeny (Late Cretaceous to Eocene). Only the southern portion of the stock exposed on the western flank of the Sawatch Uplift near Jenkins Mountain and Grizzly Peak is shown on Plate 1. These rocks range in composition from dacitic to rhyolitic.

Middle Tertiary (Oligocene and Miocene) hypabyssal rocks (Tmi), which include granodioritic, quartz monzonitic, and granitic stocks, laccoliths, dikes, sills, and irregular bodies, are abundant in both the Elk and West Elk Mountains, and to a lesser extent in eastern Gunnison County in the Sawatch Uplift. The middle Tertiary was also a time of widespread extrusive volcanism, represented in Gunnison County by Oligocene vent-facies andesitic lavas and breccias (Tpl) from numerous volcanoes in the West Elk volcanic field, and by slightly younger Oligocene ash-flow tuffs (Taf), and inter-ash-flow andesitic lavas and breccias (Tial), from caldera sources in the San Juan Mountains and Sawatch Range.

Late Tertiary (Miocene) igneous rocks are a bimodal assemblage derived from basaltic and rhyolitic magmas which reached a high crustal level and were locally vented (Mutschler and others, 1981). Igneous rocks associated with the late Tertiary period include rhyolitic plugs, sills, laccoliths, and small stocks (Tbr) occurring on Round Mountain and in north-central Gunnison County, lava flows and interbedded tuffs, breccias, and volcanic conglomerates (Tbb) in southern Gunnison County, and the sodic granite stock of Treasure Mountain (Tui) and associated satellite dikes and plugs.

The Cambrian alkalic intrusive suite at Powderhorn and the three distinct periods of Cenozoic intrusion and volcanic activity will be discussed sequentially in the following sections.

PALEOZOIC INTRUSIVE ROCKS (CAMBRIAN)

Powderhorn Carbonatite Complex

The complex of alkalic rocks at Powderhorn contains intrusive bodies of pyroxenite with, in general order of decreasing age, abundant magnetite-ilmenite-perovskite segregations, uncompahgrite, ijolite, nepheline syenite, and a late carbonatite stock (Olson and Hedlund, 1981). The alkalic rocks at Powderhorn were emplaced about 570 Ma into Proterozoic X-age granite (Powderhorn Granite) and metamorphic rocks. A fenite alteration halo of up to 2,000 ft (600 m) wide surrounds the margin of the complex in the Proterozoic wall rock and adjacent to alkalic dikes. Carbonatite dikes, similar in composition to the carbonatite stock, cut all older rock types of the intrusive complex, and the Proterozoic wall rock, especially in the fenitized aureole. These rocks crop out throughout an area of approximately 31 sq km immediately southeast of the town of Powderhorn. Parts of the intrusive complex are covered by ash-flow tuffs, welded tuffs, and colluvium, mostly of Oligocene age, and by alluvium and colluvium of Quaternary age.

The complex is bisected by the Cimarron Fault, a large northwest-trending, dip-slip fault that most likely is Laramide in age. The Cimarron Fault is dowthrown to the southwest such that intrusive rocks of the alkalic complex exposed on the upthrown, or northeast, side of the fault represent a deeper structural level of the complex (Hedlund and Olson, 1975). Erosion since faulting has placed rocks of different levels of the intrusive complex in contact across the fault at the present ground surface. In the present outcrop pattern of the intrusive complex, nearly all of the uncompahgrite, most of the ijolite, and the carbonatite stock lie southeast of the Cimarron Fault, while the pyroxenite with magnetite-ilmenite-perovskite segregations and the nepheline syenite are found northeast of the fault.

The intrusive complex at Powderhorn is a classic example of a carbonatite-nephelinite magmatic igneous association. It is possible that erosion may have removed nephelinitic extrusive volcanic rocks usually associated with similar complexes (Armbrustmacher, 1981).

LARAMIDE INTRUSIVE SUITE (LATE CRETACEOUS TO EOCENE)

Twin Lakes Pluton (TKi)

A large stock of dacitic to rhyolitic granite and porphyry is exposed in northeastern Gunnison County in the vicinity of Jenkins Mountain and Grizzly Peak (Plate 1). The portion of the stock which extends into Gunnison County is a smaller portion of the whole intrusive body which covers an area greater than 100 square mi southeast of Independence Pass. These rocks have intruded Proterozoic granites (Xg) and to a lesser extent Proterozoic metasedimentary rocks (Xb). The Twin Lakes pluton has been dated at 63.8 ± 1.4 Ma from a sample collected north of Lake Pass in Lake County (B. Bryant, person. commun., 1998). These early Laramide rocks are slightly younger than hornblende quartz diorite, quartz porphyry, aplite, and aplite porphyry found in sills and fault-controlled plutons to the north in the Aspen area, which have K-Ar ages of from 67–72 Ma (Bryant, 1979). Rich silver-lead-zinc manto deposits of the Aspen mining district are related to these early Laramide intrusive rocks. It is possible that similar silver-lead-zinc deposits in the Dorcester mining district of Gunnison County (Figure 3, p. 28, Table 1) are in turn related to the quartz-rich, late Laramide intrusive rocks near Jenkins Mountain and Grizzly Peak.

MIDDLE TERTIARY SUITE (OLIGOCENE AND MIOCENE)

Intermediate Hypabyssal Stocks, Laccoliths, Dikes, and Sills (Tmi)

Middle Tertiary intrusive granodioritic rocks are widespread in the western Sawatch Range, Elk Mountains, Ruby Range, and West Elk Mountains (Figure 2) (Mutschler and others, 1981). Small stocks and sills of granodioritic prophyry intrude Proterozoic crystalline rocks and Paleozoic clastic-carbonate sections occurring in most eastern Gunnison County metal mining districts, and they may have provided the thermal energy for the formation of those metal deposits. In the Elk Mountains large stocks of equigranular to porphyritic granodiorite, including the Whiterock pluton and Italian Mountain complexes, were intruded into a thick Phanerozoic section and created extensive zones of contact metamorphism. Valuable mineral deposits occurring in contact aureoles include silver and base metal mineralization in the Elk Mountain mining district (Figure 3, p. 28, Table 1), and deposits of lapis lazuli and sodalite on North Italian Mountain.

A northeast-trending zone of small stocks, with associated linear or radial dike swarms, extends along the crest of the Ruby Range and includes the Ruby Peak, Mount Owen, Afley, Augusta, and Paradise Pass stocks. The trend extends northeast into the Elk Mountains as the Schofield stock. These small granodioritic stocks have extensive contact metamorphic aureoles containing important metallic mineral deposits. The deposits consist of disseminated pyrite chalcopyrite-molybdenum, quartz-pyrite-base metal sulfide veins, calcite-pyrite-base metal sulfide veins and replacements, and quartz-ruby silver-arsenopyrite-sulfantimonide vein and replacement deposits (Mutschler and others, 1981).

Many large laccoliths intruded into thick sequences of Mesozoic rocks and are now exposed and make up peaks of the West Elk Mountains: Marcellina Mountain, Mount Gunnison, Mount Axtell, the Anthracite Range, Ohio Peak, Mount Whetstone, Carbon Peak, and others. These laccolithic plutons are composed of granodiorite porphyry and do not have extensive contact metamorphic halos. No known economic mineral deposits are associated with these intrusive bodies.

The voluminous Oligocene intrusive rocks were emplaced during 5 m.y. between 34 and 29 Ma (Mutschler and others, 1981). The Middle Tertiary intrusive rocks of the Elk and West Elk Mountains are temporally and chemically similar to the igneous rocks of the San Juan volcanic field (Lipman and others, 1969). In contrast to the San Juan volcanic field, the West Elk Mountains was not the site of large ash-flow tuff eruptions and caldera development.

Vent Facies, Andesitic Lavas, and Breccias—West Elk Volcanic Field (Tpl)

Sometime shortly after the emplacement of large granodiorite plutons and laccoliths in the Elk and West Elk Mountains, a group of composite andesitic stratovolcanoes developed forming the West Elk volcanic field (Figure 2). These volcanoes were surrounded by coalescing aprons of volcaniclastic debris and interbedded volcanic rocks that are collectively termed the West Elk Breccia (Gaskill and others, 1981). The surviving volcanic

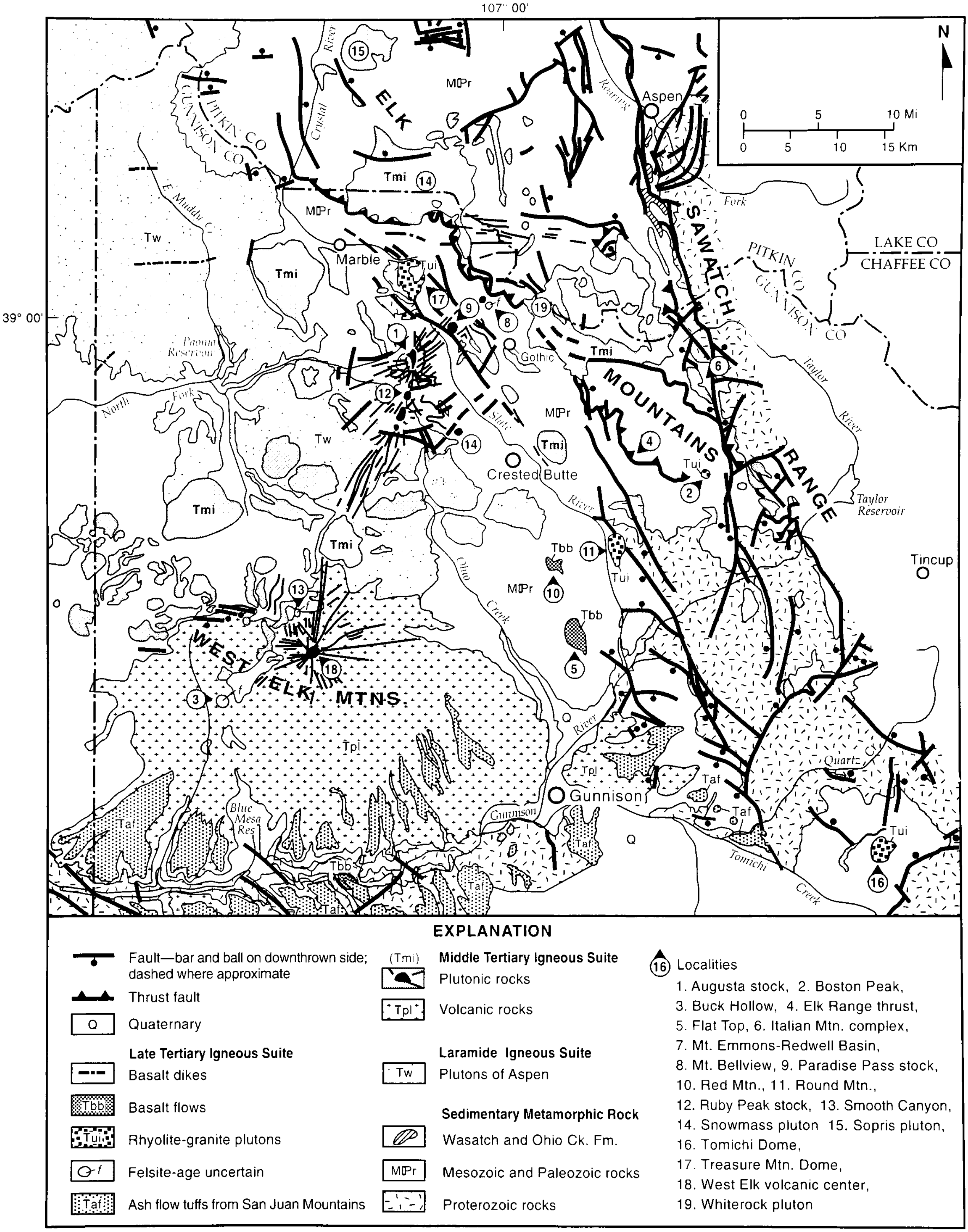


Figure 2. Geologic sketch map, Elk Mountains and vicinity, Colorado. (Modified from Tweto and others, 1976, 1978)

deposits of the West Elk volcanic field form a deeply dissected, south-dipping, volcanic plateau with steep escarpments along its western and northern edges. The volcanic and volcaniclastic rocks of the West Elk Breccia were erupted from numerous fissures and intermediate-composition, composite volcanoes. Volcanic rocks in the northern part of the West Elk volcanic field have been removed by erosion, exposing the large laccolithic intrusive bodies mentioned above and described in the previous section. Many of these laccolithic plutons probably vented and most likely also contributed volcanic ejecta to deposits surviving as the West Elk Breccia (Gaskill and others, 1981). Interbedded tuffs and gravel deposits in the West Elk Breccia indicate the episodic nature of the eruptions.

The West Elk volcanic field is located structurally near the crest of the Paleozoic Uncompahgre highland (Hansen, 1965), and on the north flank of the Laramide Gunnison Uplift (Kelley, 1955). Potassium-argon age dating suggests that the West Elk Breccia and associated granodiorite laccolithic plutons are about 29 to 34 Ma (Lipman and others, 1969; Obradovich and others, 1969). Volcanic deposits in the southern portion of the West Elk volcanic field north of Blue Mesa Reservoir are locally covered by ash-flow tuffs erupted from the San Juan volcanic field. No significant mineral deposit are known to be associated with the volcanic rocks of the West Elk volcanic field.

ASH-FLOW TUFF (Taf)

SAN JUAN VOLCANICS

Ash-flow tuff from volcanic sources in the extensive Oligocene San Juan volcanic field located to the south are present in southern Gunnison County. These deposits, although spotty and discontinuous, extend north of Blue Mesa Reservoir where they cover volcanic deposits of the slightly older West Elk volcanic field. Some isolated remnants of San Juan ash-flow tuff outcrop east of Gunnison near Cabin Creek. The ash-flow tuffs are related to numerous large caldera-type eruptions throughout the San Juan volcanic field (Lipman and others, 1969).

The ash-flow tuffs range from crystal-poor rhyolitic to crystal-rich latitic ignimbrites with a degree of welding that varies widely from unit to unit and with distance from source areas. Although economic mineral deposits are hosted in ash-flow tuffs within and near source calderas in the San Juan volcanic field, no known economic ore deposits have been described in these rocks from Gunnison County.

GRIZZLY PEAK CALDERA

The southern portion of the Oligocene Grizzly Peak caldera extends into the northern part of Gunnison County along the Continental Divide in the vicinity of Independence Pass, at the junction of Gunnison, Pitkin, and Chaffee Counties (Plate 1). The surviving volcanic deposits associated with the Grizzly Peak caldera are exclusively intracaldera ash-flow tuffs. These rocks have been isotopically age dated at 34.8 ± 1.1 Ma (Obradovich and others, 1969; Luedke, 1993). Extensive hydrothermal alteration and minor precious and base metal ores are associated with the central and northern portions of the Grizzly Peak caldera, predominatly in Pitkin, Lake, and Chaffee Counties. Minor economic deposits in these areas do not extend into Gunnison County.

INTER-ASH-FLOW ANDESITIC LAVA AND BRECCIA (Tial)

Fine-grained to porphyritic, intermediate composition lavas and breccias from many small sources occur in the southern portions of Gunnison County. These rocks represent local eruptions, related to the San Juan volcanic field, which occurred after widespread ash-flow tuff eruptions and before major calderas formed. These rocks do not host economic mineral deposits.

LATE TERTIARY INTRUSIVE SUITE (MIOCENE)

During the Miocene a bimodal assemblage of rhyolitic and basaltic magmas reached high crustal levels and locally vented (Mutschler and others, 1981). These bimodal rhyolitic-basaltic suites are believed to be emplaced in extensional tectonic settings (Christiansen and Lipman, 1972; Mutschler and others, 1978). Partial melting of upper lithospheric mantle produced basaltic magmas and partial melting of the lower crust produced rhyolitic magmas (Lipman and others, 1978).

RHYOLITIC ROCKS OF BIMODAL SUITE (Tbr)

Miocene rhyolitic rocks of the bimodal suite in Gunnison County consists of the following: a rhyolite breccia pipe complex in Redwell Basin (Gaskill and others, 1967; Sharp, 1978), a buried rhyolite-granite plug at Mount Emmons and associated molybdenite ores (Dowsett and others, 1981), the Round Mountain rhyolite porphyry stock (the only outcrop of unit Tbr on Plate 1), rhyolite vents and a breccia pipe at Boston Peak (Ernst, 1980), a rhyolite and microgranite pluton at Tomichi Dome (Stark and Behre, 1936; Ernst, 1980), and small dikes and sills in the Elk Mountains and Ruby Range (Mutschler and others, 1981). Rhyolite porphyry at Mount Emmons is isotopically age-dated at 17.7 Ma (Dowsett and others, 1981). Rhyolite porphyry of Round Mountain is isotopically dated at 13.9 ± 0.3 Ma (Cunningham and others, 1977).

Venting occurred at Boston Peak (Ernst, 1980), and may have occurred at Treasure Mountain Dome (Mutschler, 1968), Redwell Basin (Sharp, 1978), and Tomichi Dome (Ernst, 1980). Any one of these sources could have erupted the rhyolite pumice tuff that underlies basalt flows on Red Mountain and Flat Top Mesa (Gaskill and others, 1981). Important stockwork-type molybdenite mineralization at Mount Emmons (Dowsett and others, 1981), and Redwell Basin (Sharp, 1978), and similar but uneconomic molybdenite deposits at Treasure Mountain (Mutschler, 1976), are associated with the rhyolites and granites of this suite (Mutschler and others, 1981).

BASALTIC ROCKS OF BIMODEL SUITE (Tbb)

Basaltic rocks include remnants of lava flows on Red Mountain and Flat Top Mesa between Ohio Creek and the East River (Plate 1). These are dense flows of black basaltic lava with interbedded tuffs, breccias, and volcanic conglomerate. The basalt flows of Red Mountain are isotopically dated at 10.9 Ma. The flows on Flat Top Mesa are dated at 9.7 ± 0.6 Ma. Basaltic-mode rocks also are represented by scattered dikes of gabbro porphyry and lamprophyre in the Elk Mountains and Ruby Range (Mutschler and others, 1981).

GRANITE OF TREASURE MOUNTAIN (Tui)

The granite of Treasure Mountain (Figure 2) forms a dome-shaped intrusive complex isotopically dated at 12.4 ± 0.6 Ma (Obradovich and others, 1969). Treasure Mountain Dome is underlain by rocks from Proterozoic through Createceous ages that have been complexly intruded and contact metamorphosed by the granite of Treasure Mountain.

In the exposed inner portions of the dome along Yule Creek and Crystal River Canyon, contact metamorphosed Paleozoic rocks dip steeply off the uplift in a radial pattern. The section is frequently intruded by sills of Treasure Mountain granite. Trace element enrichment and depletion patterns in the highly differentiated granites of Treasure Mountain, as well as those of the rhyolites of the Elk Range, suggest the possibility of a single silicic batholith at depth (Mutschler and others, 1981).

Miocene base metal ores related to this granite are zoned; skarn replacement and vein deposits of a contact metamorphic origin are concentrated close to the granite contact. These deposits consist of early silicates (hedenbergite, diopside, tremolite, andradite, epidote, scapolite, and quartz), followed by iron oxides (specular hematite and magnetite), followed by pyrite and pyrrhotite, followed by chalcopyrite, bornite, sphalerite, tetrahedrite, galena, and pyrite. Quartz-calcite-base metal sulfide vein and replacement deposits occupy the outer flanks of the dome in metamorphosed Paleozoic and Mesozoic rocks, particularly on the northeast side including Sheep Mountain, Lead King Basin, and Schofield Park. These deposits contain pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, and marcasite in a quartz-calcite gangue. Fluorite is present in all deposits at Treasure Mountain (Mutschler and others, 1981).

5

Surficial Deposits

INTRODUCTION

Large areas in Gunnison County are covered with various Quaternary surficial deposits. The units on the geologic map of Gunnison County (Plate 1) include Holocene age alluvial deposits in modern stream valleys (Qa); numerous landslide deposits (Ql), particularily in the exposed Cretaceous sections in northern Gunnison County; large areas in the Elk Mountains covered by young glacial drift (Qd); and terrace and outwash gravels in the valleys of East and Taylor Rivers (Qg). Outwash gravel (Qg) and modern stream alluvium (Qa) deposits are potentially valuable as sources of sand and gravel.

YOUNG GLACIAL DRIFT (Qd)

Extensive deposits of Bull Lake and younger gravels occur in the valley of East River near Crested Butte and in the West Elk and Elk Mountains, all in northern Gunnison County. Some deposits occur locally in eastern Gunnison County as remnants of glaciation associated with the Sawatch Uplift. The deposits are unsorted, bouldery, glacial till and associated sand and gravel deposits (Tweto and others, 1976). The commercial value of these deposits depends on clast size, lithology, and degree of weathering. Clast lithology varies depending on source area and the depositional history of the deposits. Bull Lake-age gravel deposits may be too weathered to be of commercial value.

YOUNG GRAVELS (Qg)

Bull Lake and younger deposits of stream, terrace, and outwash gravels occur predominantly in the valley of East River south of Crested Butte (Tweto and others, 1976). The deposits are most likely unstratified to very lightly stratified deposits of boulder and pebble gravel with sandy silt matrix. Commercial value of these deposits depends on clast sizes, lithologies, and degree of weathering. Clast lithology varies depending on source areas and depositional history for the deposits. Bull Lake age gravel deposits may be too weathered to be of commercial value.

LANDSLIDES DEPOSITS (Ql)

Landslide deposits are ubiquitous in Gunnison County; they are found almost anywhere steep slopes of bedrock are exposed to weather. Landslides can occur in any rock type but are especially abundant in the exposed shales and softly cemented sandstones of the exposed Cretaceous rocks of northern Gunnison County. These deposits consist of unsorted and unstratified heterogeneous clay, silt, sand, gravel, and rock debris. Texture and clast lithologies depend on source areas and history of deposition. Landslide deposits are variable in nature and are seldom important commercially.

MODERN ALLUVIUM (Qa)

Holocene deposits of gravel, sand, and silt are found in all modern stream valleys in Gunnison County and in alluvial fans (Tweto and others, 1976). These deposits are predominantly clast-supported, silty, sandy, occasionally bouldery, pebble and cobble gravel interbedded with and overlain by sandy silt and silty sand overbank deposits. They may be of commercial use as a source of sand and gravel depending on clast lithologies, degree of weathering, and location.

6

Mineral Resources

PRECIOUS AND BASE METAL DISTRICTS

BOX CANYON DISTRICT

The Box Canyon mining district (Figure 3, Table 1), sometimes also known as the Waunita district, is located generally west of Lincoln Gulch in upper Hot Springs Creek drainage, 2 to 5 mi north of Waunita Hot Springs. The country rocks in this area are predominantly Proterozoic X-age (± 1,700 Ma) granite (Xg) and interlayered felsic and hornblendic gneisses and mica schist (Xfh). In the northern portion of the district near Waunita Pass a small dioritic pluton outcrops (Xm). The southwestern portion of the area contains Upper Jurassic mudstone and sandstone of the Morrison Formation (Jm) and Junction Creek Sandstone (Jmj), which are preserved on the west (downthrown) side of a north-south-trending fault.

Ore deposits in the Box Canyon district are confined to the Proterozoic rocks, particularily at contacts between individual units and in zones where rock types interfinger (Hill, 1909). At the Camp Bird Mine, which was visited during this study, waste rock collected from the main mine dump consisted of relatively fresh, unmineralized, biotite granite and mica schist with quartz blebs showing copper-oxide staining. The Camp Bird Mine produced small amounts of free-milling gold ore hosted in iron-stained and honeycombed quartz located at the contact between lenses of diorite and mica schist (Hill, 1909). Hill also reports that the mine was developed by a two-compartment shaft, which was 100 ft deep. No information concerning the nature of other deposits or production records are available for this mining district.

CEBOLLA DISTRICT

The Cebolla mining district (Figure 3, Table 1) includes some of the most economically valuable precious and base metal deposits and mines in the Gunnison gold belt, an area of exposed Proterozoic-age greenstone (see following chapter: The Gunnison gold belt). The area is located near the old mining towns of Vulcan, Spencer, and Midway, astride State Highway 149 and in the Cebolla and Willow Creek drainages, approximately 15 mi southwest of Gunnison. The area, first described by Lakes (1896), was mapped in detail at a scale of 1:24,000 by Hedlund and Olson (1973) and Olson and Hedlund (1975). It has received further examination as detailed in reports by Drobek (1981), Afifi (1981), Sheridan and others (1981), and Hedlund and Olson (1981). Sheridan and others (1990) summarized the rock types, associated ore deposits, petrogenesis, and references for the area. Numerous other workers have contributed to the general understanding of the Gunnison gold belt and the formation of its massive sulfide deposits.

The Cebolla district is not credited with a large total production, owing in part to a lack of production figures for the districts formative pre-1900 days. Reported production from the years 1931–1941 amounts to 55 oz gold, 208 oz silver, 100 lb copper, and 100 lb lead. Modern re-examination of Proterozoic massive-sulfide deposits, including those of the Gunnison gold belt, is generally attributed to the suggestion of Giles (1974) that southern Colorado may be a "previously unrecognized volcanogenic massive sulfide metallogenic province."

THE GUNNISON GOLD BELT

The Gunnison gold belt is an area of Proterozoic age metavolcanic, the Dubois Greenstone, and subordinate metasedimentary rocks exposed in the Gunnison Uplift. This belt occurs in southern Gunnison and northern Saguache Counties, extending from the Lake Fork of the Gunnison River east and northeast to Cochetopa Creek (Figure 4). The Gunnison gold belt extendes to the northeast into the Cochetopa (Iris) mining district.

The Dubois Greenstone was named for the old mining camp of Dubois by Hunter (1925), the first worker to describe in detail the Proterozoic geology of the area. The Dubois Greenstone was divided into 1) metavolcanic hornblende schist, amphibolite, and chlorite-hornblende schist with intercalated purplish-gray, meta-chert beds; 2) felsic metavolcanic rocks

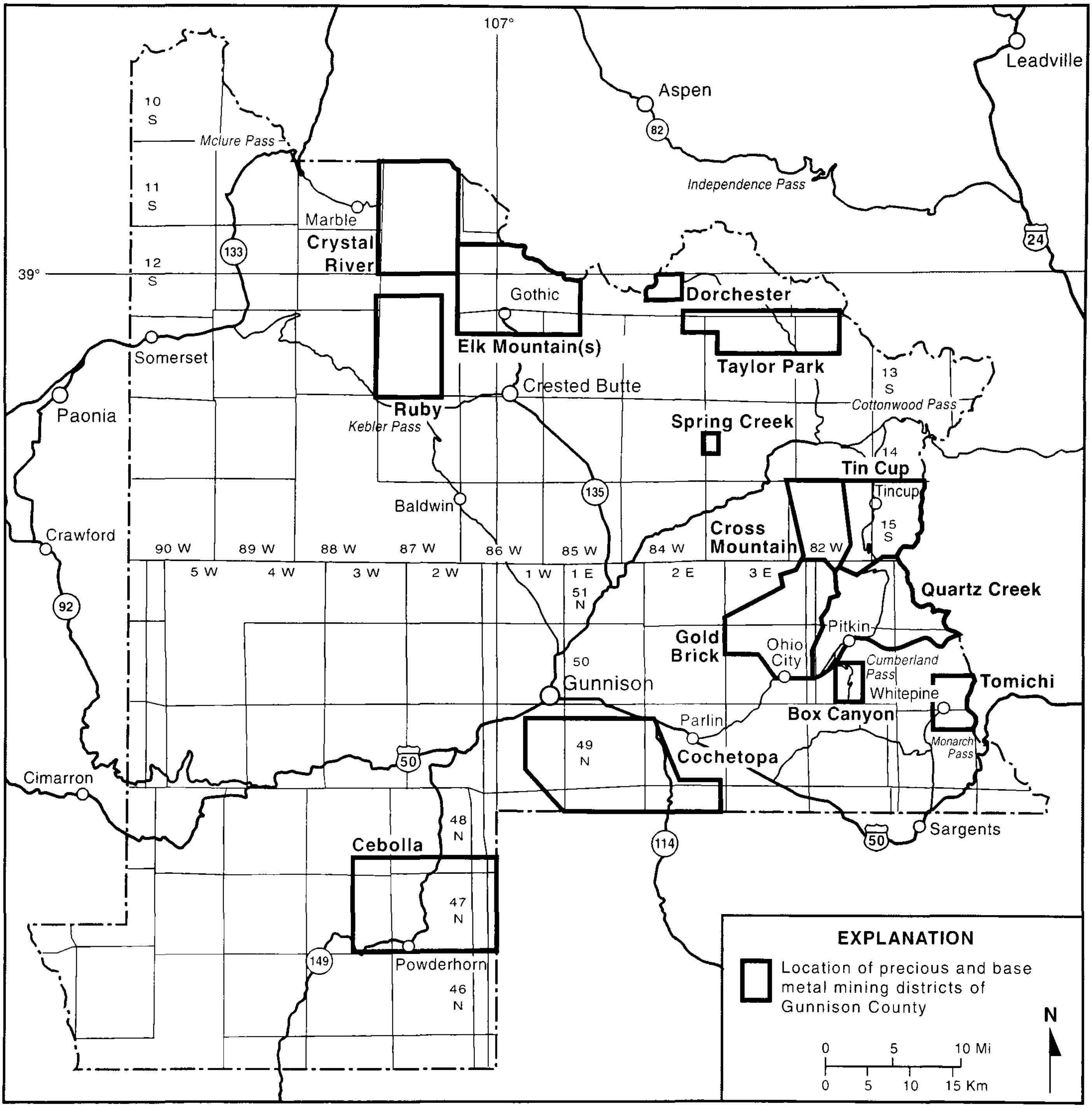


Figure 3. Map showing precious and base metal mining districts in Gunnison County.

including quartz prophyry flows and dikes and thinly interlayered muscovite-chlorite schist locally containing kyanite, staurolite, spinel, garnet, and sericitized andalusite; and 3) diverse metamorphosed epiclastic and pyroclastic rocks (Hedlund and Olson, 1981). Most of the Proterozoic terrane of the Dubois Greenstone has been metamorphosed to lower amphibolite facies, although metamorphic grades are as high as upper amphibolite facies. Upper amphibolite facies rock are associated with staurolite, kyanite, or andalusite and are concentrated in the western end of the belt. Greenschist facies rocks with recognizable pillow-structures in metabasalts and shard and pumice fragments in felsic metavolcanic rocks occur in the easternmost part of the greenstone belt (Sheridan and others, 1990). Also included in the Gunnison gold belt are metasedimentary

Table 1. Table showing precious and base metal mining district data in Gunnison County.

Mining District	Alternative Name	Major Mines	Commodities	Location
Box Canyon	Tomichi, Waunita Hot Springs	Independence,Camp Bird, Roosevelt Tunnel	gold, silver	T50N; R4E; Vicinity of Waunita Pass between Quartz Creek and Hot Springs Creek; 2 to 3 mi south of Pitkin; 3 to 4 mi north of Waunita Hot Springs
Cebolla	Vulcan, Domingo, White Earth, Goose Creek,	Vulcan/Good Hope, Anaconda, Headlight, Iron Cap, White Iron	gold, silver, copper, lead, manganese, zinc, arsenic, iron	T47–48N; R1–3W; Vicinity of old towns of Vulcan, Spencer, and Midway astride Hwy 149 on Cebolla and Willow Creeks
Cochetopa	Green Mountain, Gold Basin	Denver City, Maple Leaf, Graflin	gold, silver, copper, lead, tungsten	T48N; R1–2E, between Cochetopa and Gold Basin Creeks in vicinity of towns of Iris and Chance, SE of Gunnison, SW of Parlin
Cross Mountain	Lottis Creek	Gold Bug, Wahl	silver, lead, gold, copper	T15S; R82W, East side of Cross Mountain and upper Lottis Creek
Crystal River	Rock Creek, Marble, Treasure Mountain Dome	Eureka, North Pole, Black Queen, Lead King	zinc, lead, silver	T11–12S; R87W, Northeast side of Treasure Mountain Dome near town of Crystal, includes Lead King Basin and Mineral Point in Crystal Canyon
Dorchester	Upper Taylor River		silver, lead, zinc	T12S; R84W, Headwaters of Taylor River
Elk Mountain(s)	Gothic, White Rock	Sylvanite, Iron King, Copper Queen	silver, copper, lead, zinc, gold	T12–13S; R85–86W, Vicinity of Gothic, 6–8 mi north of Crested Butte, in and along southern margin of White Rock Pluton

Mining District	Geology	Production	References
Box Canyon	Lenses of mica schist and diorite seamed and veined with quartz containing free gold	Considerable production reported for early years 1932–1939: 69 oz Au, 10 oz Ag	Hill,1909
Cebolla	Dubois Greenstone: Massive to disseminated, auriferous and argentiferous, base metal sulfide deposits hosted in Proterozoic age hornblende schists and amphibolite. Thought to be of exhalative origin	Sporadic production in early days pre-1900s 1931–1941: 55 oz Au, 208 oz Ag, 100 lb. copper, 100 lb Pb	Sheridan and others, 1990; Hedlund and Olson, 1981; Drobek, 1981
Cochetopa	Syngenetic, exhalative, and stratabound massive sulfide deposits, containing silver and gold, hosted in metavolcanics of the Dubois Greenstone. District also contains copper-rich veinlets in pre-metamorphic deposits and epigenetic vein-type deposits	Sporadic production 1900–1941; for years 1932–1941: 265 oz Au, 98 oz Ag, 3,100 lbs Pb	Sheridan and others, 1990, 1981; Drobek, 1981; Afifi, 1981; Hill, 1909
Cross Mountain	Silver-lead replacement mineralization in Paleozoic carbonate beds and quartz veins with gold/copper in granite	Mostly prospect grade occurrences reported	Hill, 1909
Crystal River	Vein and replacement sulfide deposits in Paleozoic and Mesozoic sedimentary rocks on the northeast flank of Treasure Mountain Dome	Minor production in early years; 1933–1945: 8,000 oz Ag, 19,000 lbs Pb, 25,800 lb Zn, 2,200 lb Cu, 19 oz Au	Vanderwilt, 1937; Mutschler and others, 1981
Dorchester	Base metal mineralization in faulted/folded carbonates		Vanderwilt, 1947
Elk Mountain(s)	Steeply-dipping fissure veins in upper Paleozoic and Mesozoic age metasedimentary rocks adjacent to, and in granodiorite of White Rock Pluton; veins contain wire silver, ruby silver, sulfides, and minor gold	Sporadic early production reported; production of district is: over 100,000 oz Ag, 19,060 lb Cu, 36,700 lb Pb, 9,400 lb Zn; and 173 oz Au	Gaskill and others, 1991

Table 1. Table showing precious and base metal mining district data in Gunnison County (Cont).

Mining District	Alternative Name	Major Mines	Commodities	Location
Gold Brick	Ohio City, Fossil Ridge	Raymond, Carter, Gold Links Sandy Hook	gold, silver, lead, copper, iron	T50–51N; R3–4E, Gold Creek drainage and Fossil Ridge north of Ohio City
Quartz Creek	Pitkin	Red Jacket, Fairview, Cleopatra, Swiss Bell, Silent Friend	silver, gold, lead, copper	T50–51N; R4–5E, North of Pitkin in upper Quartz Creek Basin and Halls, Armstrong, and Jackson Gulches
Ruby	Ruby Camp, Irwin	Ruby, Standard, Painter Boy	zinc, lead, silver, copper, molybdenum, gold	T13–14S; R87W, Vicinity of Lake Irwin and along both east and west sides of the Ruby Range
Spring Creek	Spring Gulch	Doctor	zinc, lead, silver	T14S; R83W, East of Spring Creek Canyon between Manganese Peak and South Matchless Mtn.
Taylor Park	Italian Creek/Trail Creek	Forest Hill, Star, Pieplant	gold, silver, lead, zinc	T12–13S; R82–84W, General vicinity of Upper Taylor River including mines on N. Italian Mountain,Pieplant, Italian Creek
Tincup	Jimmy Mack	Gold Cup, Tincup Group, Drew,	silver, lead, gold, tungsten, molybdenum	T15S; R81–82W, and T51N; R4E, Vicinity of town of Tincup at head of Willow Creek, tributary to Taylor River
Tomichi	Whitepine	Morning Star, Victor, Denver City, Erie	silver, lead, zinc, copper, gold, iron	T49–50N; R5E, Vicinity of Whitepine on upper Tomichi Creek

Mining District	Geology	Production	References
Gold Brick	Steeply-dipping fissure veins, and minor replacements in Proterozoic wall rock; ores are gold, silver, and base-metal bearing sulfides in quartz/carbonate gangue; a few iron skarn deposits in district	Sporadic early production; 1932–1942: 16,395 oz Au, 45,650 oz Ag, 219,000 lb Pb, 2,350 lb Cu	Crawford and Worcester, 1916
Quartz Creek	Carbonate-hosted silver-lead replacement deposits in highly faulted Paleozoic sedimentary rocks w/ minor Precambrian hosted vein deposits	Sporadic early production; 1934–1943: 3,780 oz Ag; 186 oz Au; 13,560 lb Pb; 150 lb Cu	Hill, 1909
Ruby	Vein deposits rich in ruby silver minerals associated with north-northeast-trending faults, dikes, and small stocks on east flank of the Ruby Range		Gaskill and others, 1967
Spring Creek	Completely oxidized, narrow replacement deposits of silver-bearing lead and zinc carbonates hosted in the Leadville Limestone	Sporadic early production, only reported production 1937–1938: 203,000 lbs Zn, 25,900 lbs Pb	Vanderwilt, 1947
Taylor Park	Large area of diverse geology; veins and/or replacements occur in Proterozoic granite, Paleozoic sediments, and Tertiary igneous rocks	Reported production 1932–1945: 268 oz Au, 14,950 oz Ag, 2,500 lb Cu, 454,900 lb Pb, 24,400 lb Zn	Vanderwilt, 1947
Tincup	Silver-lead-gold replacement deposits in Paleozoic carbonate rocks and silver-lead-gold veins in Proterozoic rocks	Reported production 1901–1935, 300 oz Au, 26,500 oz Ag, 150,000 lbs Pb, and 177 lbs Cu	Goddard, 1936
Tomichi	Silver-lead replacements in Paleozoic carbonates and quartzites, fissure veins in Proterozoic granite and Tertiary porphyry, sulfide/magnetite skarn deposits	Considerable early production, reported production for years 1933–1945: 75,700 oz Ag, 2,400,000 lb. Pb, 2,640,000 lb Zn, and, 69,500 lb Cu, 180 oz Au	Crawford, 1913; Hill, 1909

rocks including phyllite and schist which were most likely argillites, siltites, and graywackes originally (Sheridan and others, 1990).

PROTEROZOIC STRATABOUND SULFIDE DEPOSITS

Detailed descriptions of Early Proterozoic, syngenetic, massive sulfide deposits hosted in rocks of the Dubois Greenstone are published in Sheridan and others (1990, 1981); most of the following summary is extracted from them. Ore deposits of the Gunnison gold belt are also described by Drobek (1981). Massive sulfide deposits are stratabound and elongate parallel to gradational and interfingering contacts between mafic and felsic metavolcanic rocks. The predominant sulfide minerals in Gunnison County deposits are sphalerite, chalcopyrite, pyrite, arsenopyrite, and galena. Ores are base metal sulfides alone or classic massive sulfide with base metal sulfides in a pyrite or arsenopyrite-rich matrix. Ores are disseminated with concentrations of base metal sulfides in a matrix of silicate minerals. The zinc spinel, gahnite, occurs in ores from districts in higher (upper amphibolite facies and greater) metamorphic grades. At two of the Gunnison County deposits, Vulcan and Good Hope Mines, a younger (probably Tertiary) mineralizing event has overprinted Proterozoic sulfides with telluride ores. Average grades of ores from the five mines in the Powderhorn quadrangle (Headlight, Anaconda, Ironcap, Good Hope, and Vulcan mines) are copper 2.3 percent, zinc >6 percent, lead 0.13 percent, silver 30 grams per metric ton, and gold 0.71 grams per metric ton.

Vulcan–Good Hope Mine

The Vulcan–Good Hope deposits (Figure 4) are hosted in metabasaltic and meta-andesitic rocks that were most likely formed from a protolith of dacitic to rhyolitic flows, water-laid tuffs, and tuffaceous sediments. Metasedimentary rocks at the site are interpreted as having been directly eroded off a volcanic edifice. (Drobek, 1981; Hartley, 1976). A massive sulfide ore body, predominantly pyrite but with some crude banding of pyrite and sphalerite, occurs as a lens in bleached sericite schist host rocks (Drobek, 1981; Sheridan and others, 1981). The deposit is surrounded by an intense quartz-sericite-pyrite alteration halo which in turn is partially surrounded by an outer quartz-chlorite alteration envelope (Drobek, 1981). Near the top of the deposit against the hangingwall is a narrow band of quartz and bleached schist containing opaline chalcedony veinlets which carry silver, gold, and copper tellurides as well as native tellurium. These quartz veinlets crosscut massive sulfide mineralization and are clearly unmetamorphosed, and probably represent a later overprinting event (Hartley, 1976; Drobek, 1981). The Vulcan–Good Hope deposit, the most prolific in the Gunnison gold belt, reportedly produced $500,000 of gold-silver ore (25,000 oz gold equivalents) during its best years from 1898–1902 (Drobek, 1981).

Ironcap Mine

The Ironcap deposit and surrounding area was described by Drobek (1981). Host rocks are metasediments consisting of fine-grained arkoses, graywackes, and siltites. Some sedimentary structures such as ripple-marks and graded bedding have survived metamorphism. Metavolcanic rocks at the mine are mafic to intermediate flows metamorphosed to mafic schist containing actinolite-tremolite, chlorite, talc, and trace pyrite, magnetite, and relict olivine phenocrysts. The site also contains some metamorphosed basaltic lava flows, and chert horizons. Ores occur in an exhalite dome that was built around a fumarole (Drobek, 1981). Lamination, veins, and stockwork-type veinlets contain sphalerite, pyrite, chalcopyrite, galena, in quartz, calcite, epidote, and, occasionally actinolite. A partial extraction chemical analysis from a 1 m channel sample from the Ironcap deposit indicated 2.6 percent copper, 2.0 oz per ton (opt) silver, and 0.15 oz opt (Drobek, 1981).

COCHETOPA (IRIS) DISTRICT

The Cochetopa, or Iris, mining district (Figure 3, Table 1) is located in southeastern Gunnison County; deposits occur in the lower drainage basins of Gold Basin and Cochetopa Creeks near the old mining camps of Chance and Iris. The area discussed herein as the Cochetopa (Iris) district includes the mining areas of Gold Basin, Green Mountain, and Cochetopa, which were discussed as individual mining districts by Hill (1909). The Cochetopa (Iris) mining district in part includes the Gunnison gold belt (see Cebolla Mining District, this report). Hedlund and Olson (1974) and Olson (1974) completed geologic quadrangle mapping at a scale of 1:24,000 in this area. The geology and mineral deposits near Iris are described by Afifi (1981a, 1981b), Drobek (1981), and Sheridan and others (1990, 1981).

The diverse deposits of the Cochetopa (Iris) mining district include Proterozoic syngenetic massive sulfide deposits (Denver City Mine), premetamorphic copper-bearing veins (Graflin Mine), and younger postmetamorphic epigenetic vein deposits (Lucky Strike Mine—not described in this report).

PROTEROZOIC STRATABOUND SULFIDE DEPOSITS

Denver City Mine

The eastern portion of the Gunnison gold belt coincides with an area of Proterozoic rocks exposed in the eastern end of the Gunnison Uplift. Proterozoic rocks in this area are similar to those to the southwest in the

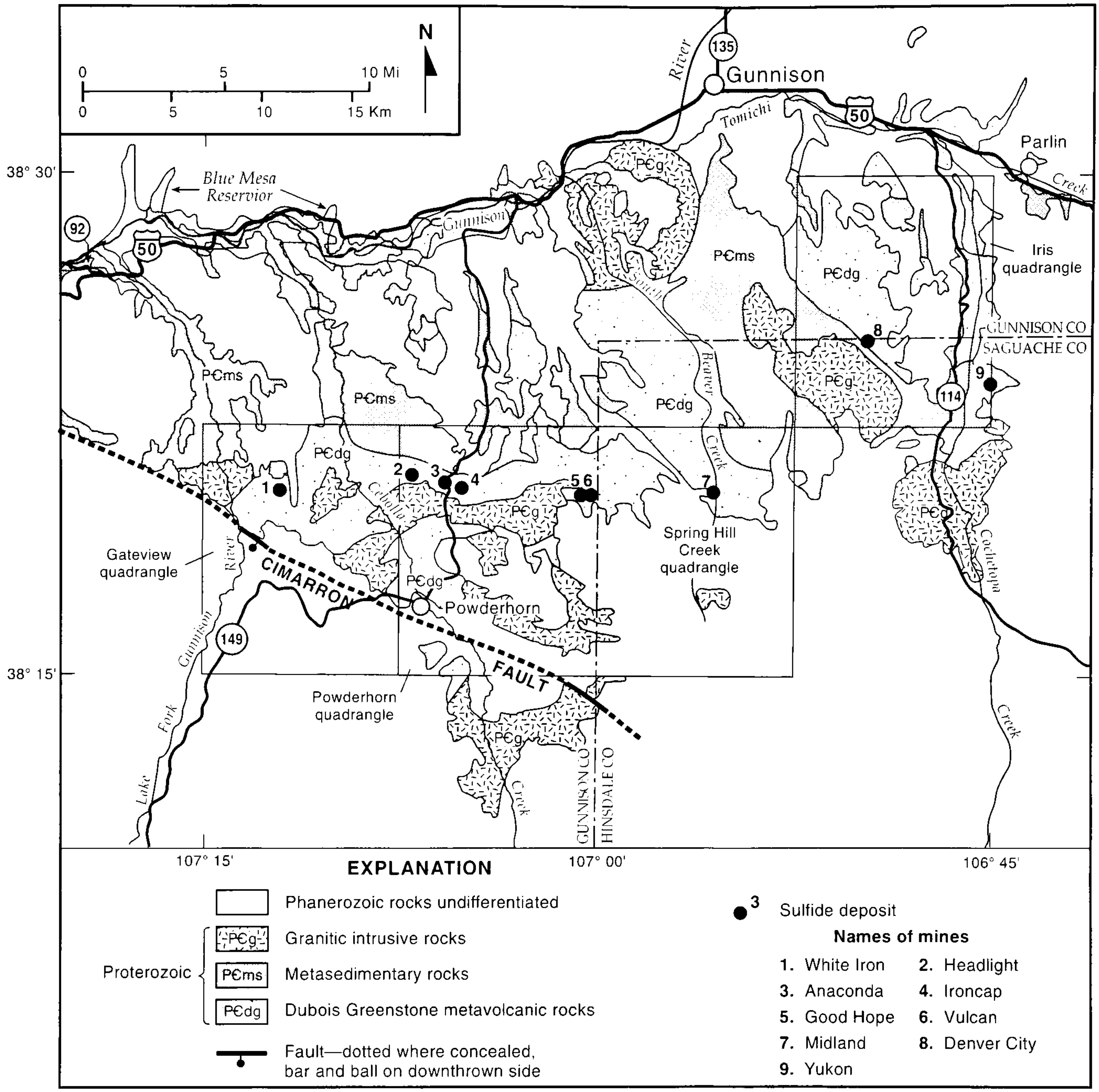


Figure 4. Distribution of Precambrian sulfide deposits in the Gunnison region, southwestern Colorado. (After Tweto and others, 1976, 1978)

main portions of the Gunnison gold belt, but they are generally less metamorphosed. This lesser metamorphism allows a better understanding of original depositional histories of these volcanic and volcaniclastic rocks. Stratabound massive sulfide deposits occur around the town of Iris where Proterozoic metavolcanic rocks of the Dubois Greenstone underlie a large portion of the area. Sequences of metasedimentary rocks, also Proterozoic, lie stratigraphically above and below the Dubois Greenstone, which is exposed in the axis of a large syncline. Metasedimentary rocks also are interbedded with metavolcanic rocks in many places. The stratigraphy in the district records periods of volcanic eruption and intervals of epiclastic sedimentation, including submarine reworking of pyroclastic deposits (Afifi, 1981a,b). The Dubois Greenstone in the district consists of a sequence of metafelsic tuffs, metalapilli tuff, dacitic and rhyolitic flows, and turbidites, all of which can contain recrystallized pumice lapilli (Drobek, 1981).

At the Denver City Mine (Figure 4), a stratiform massive sulfide body dips steeply to the southeast following bedding in a metamorphosed rhyolite of the Dubois Greenstone. Massive sulfides are intercalated with quartz, calcite, and fine-grained tuffaceous material. Sulfide-rich ore at the mine containes 35–45 percent quartz-calcite-muscovite gangue, 30–40 percent black sphalerite, 20–25 percent pyrite, 2–5 percent chalcopyrite, and less than 2 percent pyrrhotite (Drobek, 1981). The Denver City Mine reportedly produced copper, zinc, lead, silver, gold, and arsenic when operated in 1894–1897 and 1901–1902. No production figures are available (Sheridan and others, 1990).

PREMETAMORPHIC COPPER VEINS

Graflin Mine

A system of veinlets containing copper occurs at the Graflin Mine. These foliated veinlets of biotite-pyrite-chalcopyrite were emplaced before metamorphism as fracture fillings (Afifi, 1981a,b). These deposits may be similar to copper-tungsten veins in the Cleora mining district near Salida, which Sheridan and others (1990) described as related to shear-zone feeder systems. These veinlet systems may be the root zones that supplied hydrothermal fluids leading to stratabound copper-tungsten deposits (which have been subsequently removed by erosion or have yet to be discovered). No production records are available for the Graflin Mine although a small amount of copper has reportedly been produced.

CROSS MOUNTAIN DISTRICT

The Cross Mountain mining district is located to the west of the Tincup mining district in northeastern Gunnison County (Figure 3, Table 1). The district includes the area on the east side of the ridge that runs north from Broncho Mountain to Cross Mountain, encompasses the drainage of Lottis Creek, and extendes to the drainage divide between Lottis and Willow Creeks on the east . The Cross Mountain mining area was discussed briefly by Hill (1909) in a report on the eastern Gunnison County gold and silver mining districts. The two principal mines in the district, the Wahl and Gold Bug, were described by Goddard (1936) in a report on the Tincup mining district. More recently, the geology and mineral deposits in the area of Cross Mountain were described by Zech (1988).

The north-south-trending ridge between Broncho Mountain and Cross Mountain is capped by lower Paleozoic rocks, which occur in a number of discontinuous erosional remnants separated by Proterozoic granite. These isolated Paleozoic outcrops, and thin veneer of underlying Proterozoic rocks, are in the upper plate of a low-angle thrust fault (Zech, 1988). Upper thrust plate rocks are highly faulted and folded, truncating in many places against the trace of this west-vergent, north-south-trending, low angle thrust fault. Exposure of the fault near the crest of Cross Mountain shows rocks of the Cambrian Sawatch Quartzite (MЄr) in contact across the fault, indicating that this quartzite was the décollement surface for thrusting in this area. This thrust fault can be traced to the south into a similar structure called the Broncho Mountain Fault. Zech (1988) reports a minimum of one mile of horizontal displacement on the Broncho Mountain thrust fault, indicating that exposed Proterozoic granites across the fault northeast of Broncho Mountain are parts of terranes originally seperated by a mile or more. If similar displacement on the low-angle thrust fault on Cross Mountain is assumed, Paleozoic remnants and faulted Proterozic rocks in the upper thrust plate on Cross Mountain could be parts of a terrane thrust to its present position from the east. The youngest movement on the Sheep Mountain thrust fault to the south in the vicinity of Fossil Mountain post-dates intrusion of 69 Ma andesite porphyry (Zech, 1988), although it is possible from map data that these early Laramide intrusives may have been localized along these thrust faults. It is not clear if vein and replacement ores in the Paleozoic rocks on Cross Mountain were emplaced before or after thrust faulting. These deposits appear to have formed in association with intrusive sills and small stocks of early Laramide (69 Ma) andesite porphyry.

REPLACEMENT DEPOSITS IN PALEOZOIC CARBONATE ROCKS

Wahl Mine

The Wahl Mine is located northeast of the summit of Cross Mountain at approximately 12,000 ft (3,650 m). The Wahl lode is a replacement ore body in the Ordovician Fremont Limestone (MЄr), just below the Devonian Parting Formation (MЄr), known locally as the "Fairview shale" (Goddard, 1936). The deposit consists of a group of small, flat, lenticular zones of iron and copper-iron sulfides in a quartz and calcite gangue. The well-oxidized ore is composed of limonite and malachite containing free gold and copper. Ore zones are 10 to 15 ft (3 to 4.5 m) long and 3 to 6 ft (1 to 2 m) wide. A 10-ft-thick sill of hornblende monzonite porphyry occurs in the Devonian rocks just above the ore zone. The Wahl Mine produced some very high-grade gold ore in the late 1800s (Goddard, 1936).

VEIN DEPOSITS IN PALEOZOIC ROCKS

Gold Bug Mine

The Gold Bug deposit is in a fissure vein cutting the Sawatch Quartzite and Ordovician limestones and quartzites (Manitou, Harding, and Fremont Formations). Irregular masses and veinlets of chalcopyrite occur in a gangue of sugary, medium- to coarse-grained, quartz. Gold-copper ore from the Gold Bug Mine was in oxidized, granular, vuggy quartz with abundant limonite and considerable malachite (Goddard, 1936).

CRYSTAL RIVER DISTRICT

The Crystal River mining district is located in the northern portion of Gunnison County in the vicinity of Treasure Mountain Dome, Lead King Basin, and the town of Crystal. (Figure 3, Table 1). Precious and base metal ores have been mined from these deposits in Upper Paleozoic to Cretaceous rocks exposed in the Treasure Mountain Dome, from vein deposits in Cretaceous quartzites on the flank of Treasure Mountain at Mineral Point, and to the north in metamorphosed Cretaceous rocks in an overturned syncline at the intrusive boundary of a Middle Tertiary (34.1 ± 1.4 Ma) granodioritic stock (Snowmass Pluton). The geology and mineral deposits of this area are described by Vanderwilt (1937). The Treasure Mountain Dome-Marble area is mapped at 1:24,000 scale by Gaskill and Godwin (1966a), and Mutschler (1970), who also mapped the Lead King Basin area. The geology of Treasure Mountain Dome is described by Mutschler (1968). Since these early descriptions, much work has been done in the Treasure Mountain Dome and Elk Mountains areas to further the understanding of this area of diverse and prolific Tertiary magmatism (see Igneous Rocks section, this report). A good summary of the igneous rocks of northern Gunnison County and associated ore deposits is given by Mutschler and others (1981). The geology and mineral deposits of the eastern Elk Mountains are described by Bryant (1971, 1979).

TREASURE MOUNTAIN DOME

Treasure Mountain Dome is located in northernmost Gunnison County, 1 mi (1.6 km) southeast of the town of Marble, in the West Elk Mountains. This dominant geologic feature is an elongate northwest-southeast, Miocene, domal uplift involving rocks from Proterozoic through Upper Cretaceous age. An almost complete Phanerozoic stratigraphic section for this portion of Colorado can be seen on Treasure Mountain Dome. The entire stratigraphic section has been elevated, in places dramatically (see Gaskill and Godwin, 1966a; Mutschler, 1970), by an underlying and interbedded laccolith-shaped pluton of Miocene porphyritic granite. The granite of Treasure Mountain is a pale red-purple to light-gray, equigranular, seriate porphyritic or porphyritic coarse- to very fine grained granite which has been potassium-argon dated at 12.4 ± 0.6 Ma (Mutschler, 1970; Obradovich and others, 1969). The intrusion of large volumes of granitic magma beneath the Paleozoic and Mesozoic rocks now exposed in Treasure Mountain Dome has metamorphosed all sedimentary formations. Petrology and environmental geochemistry of metasedimentary rocks from Treasure Mountian Dome are discussed in the Environmental Geology section of this report.

Base metal ores are related to the emplacement of the granite of Treasure Mountain, and the deposits show distinct zoning (Mutschler and others, 1981). An inner zone of skarn and vein deposits of contact-metamorphic style, close to intrusive contacts, lies on the south and southeast sides of the dome. A surrounding zone of quartz-calcite-base metal sulfide veins and replacement deposits lies on the outer flanks of the dome, particularly on the northeast side in the Sheep Mountain, Lead King Basin, and Schofield Park areas.

Skarn and contact metamorphic ores near intrusive contact are characterized by early silicates (hedenbergite, diopside, tremolite, andradite, epidote, scapolite, and quartz), followed by iron oxides (specular hematite and minor magnetite), followed by base metal-sulfides: pyrite, pyrrhotite, chalcopyrite, bornite, sphalerite, tetrahedrite, and galena. Deposits in the outer zone of quartz-calcite-base metal sulfide vein deposits are characterized by pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, and marcasite in a quartz-calcite gangue. All deposit types contain ubiquitous fluorite (Mutschler and others, 1981).

The productive deposits of either type are hosted in metamorphosed Pennsylvanian, Permian, Jurassic, and Cretaceous rocks exposed on the lower flanks of the dome. Lower Paleozoic carbonate-dominated rocks, which commonly host ore, are only exposed on the upper parts of Treasure Mountain, where they tend to be less mineralized.

DORCHESTER DISTRICT

The Dorchester mining district (Figure 3, Table 1) is located in the northwest corner of Taylor Park near the headwaters of Taylor River. Little information is available but the area is said to have produced some replacement-type silver-lead-zinc ore (Vanderwilt, 1947). The deposits are hosted in Cambrian through Mississippian carbonate and marine clastic rocks that crop out in a north-south-trending band on the eastern margin of the Middle Tertiary White Rock pluton. These rocks are continuous in surface expression with and similar to those in the Paleozoic section at Aspen, 12 mi to the north. The Aspen section hosts abundant silver-base metal ores. Both replacement and disseminated ores have been described in the Aspen/Eastern Elk Mountains area by Bryant (1971, 1979). Lower Paleozoic rocks adjacent to the White Rock pluton are frequently metamorphosed and occasionally host precious and base metal deposits in other areas of the Elk Mountains. Mineral deposits in the Dorchester district are also hosted by Proterozoic granites that occur in the upper Taylor River area.

ELK MOUNTAIN DISTRICT

The Elk Mountain mining district is located in northern Gunnison County, near the town of Gothic, 6 to 8 mi (9.6 to 12.8 km) north of Crested Butte (Figure 3, Table 1). The district encompasses the area in and around the southern margin of the Middle Tertiary White Rock pluton. The geology and mineral resources of the Gothic quadrangle have been recently described by Gaskill and others (1991) who provide extensive mineral deposits information and mine maps. Much of the following synopsis is taken from this comprehensive work.

Mines in the area near Gothic have produced several hundred-thousand ounces of silver, minor gold, and copper, lead, and zinc. The productive mineral deposits are found in a band of steeply dipping, locally overturned Paleozoic and Mesozoic rocks, to the northeast of Gothic, which are folded up onto the southwestern flank of the White Rock pluton. Sedimentary rocks, particularily the Upper Paleozoic rocks nearest the contact with the White Rock pluton, are locally contact-metamorphosed to hornfels, granofels, and quartzite. Although mines and prospects have been opened in the Mesozoic rocks, most productive mines have been hosted by Upper Paleozoic carbonate and clastic rocks, and to a lesser degree in the granodiorite of the White Rock pluton. At the Sylvanite Mine on the north boundary of the Gothic quadrangle, metalliferous veins are more persistent in the granodiorite pluton than in metasedimentary rocks. Ore grades in quartz-barite-pyrite-sulfosalts-native silver veins tend to be higher in the metasedimentary rocks (Zahoney in Gaskill and others, 1991).

The Elk Mountain district contains 1) vein deposits of silver-lead-copper-zinc-gold, hosted in metasedimentary rocks, some which contain skarn-type zones of lime-silicates and hornfels, 2) silver ores in masses of pyritized rock in metasedimentary rocks and dikes of rhyolite porphyry, and 3) contact metamorphic deposits of massive magnetite and iron-sulfide, iron-copper-sulfide, and gold. The Elk Mountain district contains some areas of anomalous molybdenum mineralization, although no molybdenum has been produced. Stockwork deposits of molybdenum in the adjoining Oh-Be-Joyful quadrangle have been described by Gaskill and others (1967). Small amounts of coal (anthracite and semianthracite) have been produced in the area from beds of the Upper Cretaceous Mesaverde Group in the Crested Butte Coal Field (see "Coal Resources" chapter).

VEIN DEPOSITS

The vein deposits are typically steeply dipping fissure fillings along normal faults cutting metasedimentary rocks and underlying granodiorite of the White Rock pluton. The veins contain a diverse assemblage of silver and base metal sulfides, sulfosalts, and minor gold and which frequently contains secondary copper hydroxides. Some of the silver ore from vein deposits was reportedly of bonanza grade (hundreds of ounces per ton). Over 100,000 oz of silver have been produced from vein deposits in the district (Gaskill and others, 1991).

Sylvanite Mine

The Sylvanite Mine is located 3 mi (4.8 km) north northeast of Gothic at the contact of Paleozoic metasedimentary rocks with the White Rock pluton. The area and history of the mine are described by Zahoney on the geologic quadrangle map of the Gothic quadrangle (Gaskill and others, 1991). The mine is developed with more than 2,200 ft (670 m) of tunnels and more than 1,200 ft (365 m) of vertical workings. There has been extensive stoping along two veins of native (wire) silver, ruby silver (prousite and pyrargyrite), argentiferous tetrahedrite, chalcopyrite, arsenopyrite, barite, massive sulfides, minor gold, and galena. The veins are developed both in metasedimentary rocks, and in granodiorite porphyry of the stock. Ore from the mine had grades of 1 to 4 opt silver. Production from the Sylvanite Mine is estimated between 100,000 and 300,000 oz of silver (Zahoney, 1986).

SILVER MINERALIZATION IN PYRITIZED ROCK

Copper Queen Mine

At the Copper Queen Mine located in Queen Basin a mass of pyritized rock hosted by metasedimentary rocks and a rhyolite porphyry dike contains silver, copper, argentiferous tetrahedrite, sphalerite, galena, and calcite along sheared and brecciated zones in metasediments (Gaskill and others, 1991). The silver ore assayed at 350 to 500 opt.

CONTACT METAMORPHIC DEPOSITS OF IRON-OXIDES AND SULFIDES

Iron King Mine

The Iron King Mine, located on the ridge between Copper Creek and Virginia Basin, is developed by 600 ft (183 m) of workings. The mine exploits a magnetite-dominant contact metamorphic deposit containing silver, gold, chalcopyrite, sphalerite, and barite (Gaskill and others, 1991).

GOLD BRICK DISTRICT

The Gold Brick mining district is located in eastern Gunnison County, in the drainage of Gold Creek, several miles north of its confluence with Quartz Creek at Ohio City (Figure 3, Table 1). The productive mineral deposits mostly occur on the east side of Gold Creek, east to the divide between Islet Mountain and Quartz Dome. The Gold Brick district as described in this report refers predominantly to vein deposits that occur in Proterozoic rocks to the east of Gold Creek. The district proper includes some sediment-hosted deposits in Paleozoic rocks which are described in the following section on the Quartz Creek mining district. Full production records do not exist for the Gold Brick district but partial production is reported as 16,395 oz gold, 45,650 oz silver, 219,000 lb lead, and 2,350 lb copper during the years 1932–1942 (Vanderwilt, 1947).

Some sulfide ore, but probably a greater quantity of oxide ore, was produced from steeply dipping fissure veins hosted in Proterozoic metavolcanic (Xfh), and granitic (Xg) rocks. Oxide ore could be very rich in gold in some mines; however, sulfide ore from the very lowest level of the Gold Links Mine assayed 11.76 opt gold, 15.5 opt silver, and 15.3 percent lead (Crawford and Worcester, 1916). The district also contains some contact metamorphic iron and iron sulfide deposits, in addition to the replacement deposits in Paleozoic carbonates described above. Production from these type of deposits has been minimal.

The Proterozoic rocks and thin overlying Paleozoic erosional remnants in and around Gold Creek are most likely part of the upper plate of a west-vergent, low-angle thrust fault with a minimum of 1.0 mi (1.6 km) of displacement. This interpretation is suggested by mapping on Fossil Ridge to the west of the Gold Brick district by Zech (1988). It is possible that ore deposits in the Gold Brick district may have formed in a terrane located to the east, which has subsequently been thrusted into its present position as part of upper thrust plate rocks. This interpretation has implications for future prospecting.

VEIN DEPOSITS IN PROTEROZOIC ROCKS

Raymond Mine

The Raymond Mine is located on the east side of Gold Creek about 1 mi (1.6 km) north of the mouth of Jones Gulch. The Raymond Mine was one of the largest producers in the district and is one of the most widely developed. Specific production records for the mine are lacking but Crawford and Worcester (1916) report that the Raymond Mine was a leading producer in Gunnison County in the early 1900. The mine is developed by a 3,000 ft (915 m) crosscut decline tunnel that intersects nine veins. The veins are from 1 to 6 ft (0.3 to 1.8 m) wide generally and contain gold-bearing galena and pyrite in a gangue of quartz and gouge. The wall rocks are interlayered felsic and hornblendic gneisses (Xfh), and granodioritic and quartz monzonitic granite (Xg) (Tweto and others, 1976). Some veins do not persist into bodies of mica schist wallrock, which are up to 30 ft (9m) in length. Gold is the predominant commodity at the Raymond Mine with high-grade streaks assaying as high as 8 opt gold. Average tenor of the ore is 1.5 to 2 opt (Crawford and Worcester, 1916).

Gold Links Mine

The Gold Links Mine is located on the east side of Gold Creek just south of Hill Gulch. The mine was the largest producer in the district during the years 1908–1912, with values chiefly in gold. The mine is developed by a crosscut tunnel running S. 65° E. for 3,900 ft (1.2 km). It intersected a porphyry dike and six ore-bearing veins. The only vein that has been developed is 2,150 ft (655 m) from the portal. This structure has been drifted upon for 500 ft (152 m) to the south and 1,500 ft (457 m) to the north. The vein is parallel to foliation in a highly kaolinized, quartzose gneiss, or quartz schist, containing small flakes of sericite, talc (?), and small crystals of pyrite. The vein is inconsistent. Sometimes it has well-defined walls and a sharp vein boundary; at others it changes into a zone of mineralized country rock lacking gangue minerals or vein-like characteristics. The vein, where present, ranges in width from a few inches to 8 ft (2.4 m). In places, the vein was faulted off and not recovered (Crawford and Worcester, 1916). Ore in the mine consists of gold-bearing pyrite and galena with sphalerite.

QUARTZ CREEK DISTRICT

The Quartz Creek mining district (Figure 3, Table 1) is a broad area encompassing much of the upper headwater basin of Quartz Creek and part of the Continental Divide. The majority of productive deposits occur on the exposed rim of a large bowl-shaped erosional remnant of Paleozoic carbonate and marine clastic rocks. This remnant outcrops in the area between the town of Pitkin, on Quartz Creek, and Halls Gulch to the north near Fairview Peak. The northern end of the district includes deposits of gold-silver, tungsten, and molybdenum near Cumberland Pass. This area has been described by Rosenlund (1984). To the east the Quartz Creek district includes small precious and base metal deposits in Proterozoic rocks occurring east of Sherrod on the Continental Divide. Most production has come from replacement deposits in dolomitic beds. Production from vein-type deposits is appreciably less. Reported production figures are sparse but the district produced 3,780 oz silver, 186 oz gold, 13,560 lb lead, and 150 lb copper in the years 1934–1943 (Vanderwilt, 1947).

REPLACEMENT DEPOSITS IN PALEOZOIC ROCKS

Replacement deposits of argentiferous galena, gray copper (tetrahedrite-tennantite), and possibly stephanite, have been the most prolific in the district. The deposits occur in a belt of exposed Paleozoic rocks known locally as the Pitkin lime belt. Lower Paleozoic rocks are exposed around the rim of a large erosional remnant which has been folded into a structural bowl, dipping from all directions into the drainage of Armstrong Gulch north of Pitkin. Most ore is in dolomites of the Ordovician Fremont Limestone, just below carbonaceous shales of the Devonian Parting Formation ("Fairview shale" of local usage), although some ore occurs in the Devonian Dyer Dolomite or in the Mississippian Leadville Limestone. The ore bodies, which are generally irregular, contain galena and dark sulfides in an often vuggy gangue of calcite and quartz. Some ore has no gangue other than dolomite. The ore from these deposits contains secondary copper and lead carbonates (Hill, 1909).

FAIRVIEW MINE

The Fairview Mine is located on the divide between Armstrong and Hall Gulches, 7.5 mi (12 km) north of Pitkin. The mine is situated on exposed Paleozoic rocks on the structural edge of the Pitkin lime bowl near the summit of Terrible Mountain. Replacement mineralization occurs in the Ordovician Fremont Limestone (ore zone 1). This ore zone contains the most valuable ore at the Fairview Mine. This frequently mineralized stratigraphic interval is recognized as an important ore horizon elsewhere in eastern Gunnison County in areas of Paleozoic carbonate-hosted replacement deposits. Early workers in Quartz Creek and other mining districts also recognized that the best ore in this zone occurred directly beneath a shale interval (Fairview shale) that seems to have trapped ore-forming solutions. Outcrops of the entire lower Paleozoic stratigraphic sequence are well exposed at the Fairview Mine site.

A visit to the Fairview Mine for this study included a cursory measured section and full-suite sample traverse through known ore zones for acid-base accounting (see Environmental Geology section of this report). This limited inspection indicates that the most productive ore zone (Fairview ore zone) occurs at the top of the Ordovician Fremont Limestone and directly beneath thin-bedded, very fine-grained and micritic dolomitie and shaly dolomite of the Devonian Parting Formation (Fairview shale). Ore has also been produced from dolomitic rocks in the Devonian and Mississippian part of the section (ore zones 2 and 3). Mineralization in the Devonian Dyer Dolomite was caused by the trapping of ore-forming solutions beneath beds of fine-grained, buff-colored, very-smooth-weathering limestone and fine sandy dolomite of the Gilman Sandstone (Buckskin limestone of local usage). Deposits have also been worked in the Mississippian Leadville Limestone.

VEIN DEPOSITS IN PROTEROZOIC ROCKS

In the eastern part of the district in the vicinity of the Continental Divide, vein deposits hosted in Proterozoic gneisses have been worked. The deposits are silver- and gold-bearing lead, zinc and copper sulfides in steeply dipping fissure veins also containing quartz, calcite, and fluorite. Production from this area has been small.

RUBY DISTRICT

The Ruby Mining district (Figure 3, Table 1) encompasses deposits in the Ruby Range in the vicinity of Lake Irwin. Vein deposits rich in ruby silver minerals are associated with north-northeast-trending faults, dikes, and small stocks along the east side of the Ruby Range. The veins contain zinc, lead, silver, copper, molybdenum, and gold, all of which are mostly disseminated. The Ruby Mine reportedly produced rich ruby silver ore from a vein occurring in Cretaceous shale and sandstone of the Mesaverde Formation (Vanderwilt, 1947). The geology of the Ruby Range was described by Gaskill and others (1967, 1966).

In the Ruby Range a thick section of Upper Cretaceous Mesaverde Formation, and Early Tertiary Wasatch Formation, is exposed. These rocks are cut by numerous northeast-trending dikes and small stocks of quartz monzonite, quartz monzonite porphyry, granodiorite porphyry, and biotite granodiorite (Gaskill and others, 1967). Production from the district was minor and most was in the 1880 and 1890. The Standard and Painter Boy Mines were reportedly working in 1964, but no details are known (Gaskill and others, 1967).

SPRING CREEK DISTRICT

The Spring Creek mining district encompasses a small area east of Spring Creek Canyon, between Manganese Peak and South Matchless Mountain (Figure 3, Table 1). The area in question is located 6 mi (9.6 km) west of Taylor Park Reservoir. The geology of the area of Spring Creek Canyon is characterized by Paleozoic carbonate and clastic rocks, and Proterozoic Y-age granites, all of which are highly faulted. Mineralization consists of completely oxidized, narrow, replacement-type deposits of silver-bearing lead and zinc carbonates hosted by the Mississippian Leadville Limestone. The single mine in the district, the Doctor Mine, was one of the biggest producers in Gunnison County. It yielded $1,000,000 in lead, zinc, and silver from sporadic production between the years 1880 to the middle 1920s (Vandenbusche, 1980). The mine reportedly operated again during the years 1937–1938 and produced 203,000 lb zinc and 25,900 lb lead (Vanderwilt, 1947).

TAYLOR PARK DISTRICT

The Taylor Park mining district (Figure 3, Table 1) includes a large area of diverse geology in the general vicinity of Upper Taylor River in T. 12–13 S., R. 82–84 W. The boundaries of the district are not well defined (Figure 3, Table 1). The district includes mines on the northeast slope of North Italian Mountain, the Star Mine in upper Italian Creek, the Forest Hill and Paymaster Mines in the upper drainage of Trail Creek southwest of Taylor Park, and the Pieplant Mine on the southwest slope of Jenkins Mountain, northeast of Taylor Park. Specific information on the mines and deposits for this mining district is lacking. Deposits at the Pieplant Mine to the northeast of Taylor Park are most likely fissure veins in Late Cretaceous-Early Tertiary (Laramide) plutonic rocks that have been worked for gold and silver. Deposits near North Italian Mountain are reportedly of the lead-zinc-silver replacement-type hosted by Paleozoic carbonates that flank the Middle Tertiary intrusive complex of Italian Mountain.

TINCUP DISTRICT

The Tincup Mining district is located in eastern Gunnison County, encompassing the area north of Cumberland Pass and west of the Continental Divide (Figure 3, Table 1). The area is north of, and contiguous with, the Quartz Creek mining district and contains similar deposit types. The district has produced gold, silver, lead, zinc, and minor copper from both replacement- and vein-type deposits. Production records are spotty for the district, especially in the early years. Reported production for the years 1901–1935 is 300 oz gold, 26,500 oz silver, 150,000 lb lead, and 177 lb copper (Goddard, 1936).

Ore has been mined from silver-lead-gold replacement deposits in Paleozoic carbonates, silver-lead-gold vein-type deposits in Paleozoic sedimentary and Proterozoic rocks, and a few iron-bearing skarn-type deposits. Tungsten and molybdenum veins in the southern part of the district on Gold Hill are discussed in the "Energy/Alloy Metals and Industrial Minerals Areas" section on p. 43. The blanket deposits occur in a band of Paleozoic rock that is exposed on the east flank of a broad anticline trending N 25° W. The band of Paleozoic rocks extends N 30° W past Tincup into lower Willow Creek (Figure 5). The Paleozoic section here is the typical carbonate and marine clastic sequence that hosts ores in other eastern Gunnison County metal mining districts. The Paleozoic section was intruded by at least three types of porphyry primarily as large sills and small stocks. Strongly developed faulting influenced vein development and localization of replacement ore bodies. The band of Paleozoic rocks is truncated to the east of Tincup along a thrust fault which brings Proterozoic rocks to the surface where they have been thrust over the Tincup Anticline.

SILVER-LEAD-GOLD REPLACEMENT DEPOSITS IN PALEOZOIC ROCKS

Silver-lead-gold replacement deposits are the most economically important in the Tincup district. The deposits occur as flat-lying replacements in carbonate-rich zones at the intersection with steeply dipping faults or fractures. The deposits are typically 8 to 10 ft (2 to 3 m) thick but can be as much as 59 ft (18 m) thick. The ore bodies are usually from 30 ft (9m)to several hundred feet in length (Goddard, 1936).

The most commonly mineralized horizons at Tincup are similar to those in other areas of Paleozoic mineralization in adjoining mining districts. The Ordovician Fremont Limestone (Fairview ore zone) is commonly the host for this type of blanket deposit, especially beneath a shaly dolomite interval (Devonian Parting Formation) which acted as an aquitard for ore-forming solutions. Carbonate horizons in the Devonian Dyer Dolomite and Mississippian Leadville Limestone also are hosts for silver-lead-gold replacement-type deposits. The deposits contains argentiferous galena and pyrite accompanied by sphalerite and chalcopyrite. Gold is most likely associated with iron and iron-copper sulfides. Some ore contains gray copper (tetrahedrite-tenantite) which frequently contains silver. The gangue is quartz and calcite. A sizeable portion of total production was oxidized ore, which contained lead and silver in oxide minerals such as cerussite, anglesite, cerargyrite, and limonite.

Gold Cup Mine

The Gold Cup Mine is located on the east side of Tincup Gulch, a small tributary stream of the Middle Fork of Willow Creek, about 2.5 mi (4 km) south of the town of Tincup (Figure 5). The Gold Cup was the first lode deposit located and staked in the district and has been one of the leading producers. The deposit is opened by an inclined shaft, extending N. 56° E. for 900 ft (274 m), which was driven directly down-dip following bedding in Paleozoic carbonate and clastic rocks. The most prolific ore bodies were stoped from deposits hosted by the Mississippian Leadville Limestone (Goddard, 1936). The ore shoots in the mine ranged from 30 ft (9 m) to several hundred feet in length, and from 10 ft to 60 ft (3 to 18 m) in width, all with a general pitch to the northeast. Ore in the Gold Cup mine contained 30 to 1,800 opt silver, 0.5 to 4 opt gold, and up to 23 percent lead. The silver-to-gold ratio is 247:1. The mine produced mostly oxidized ore, a sugary or jaspery quartz with abundant limonite and irregular masses and seams of cerussite and anglesite.

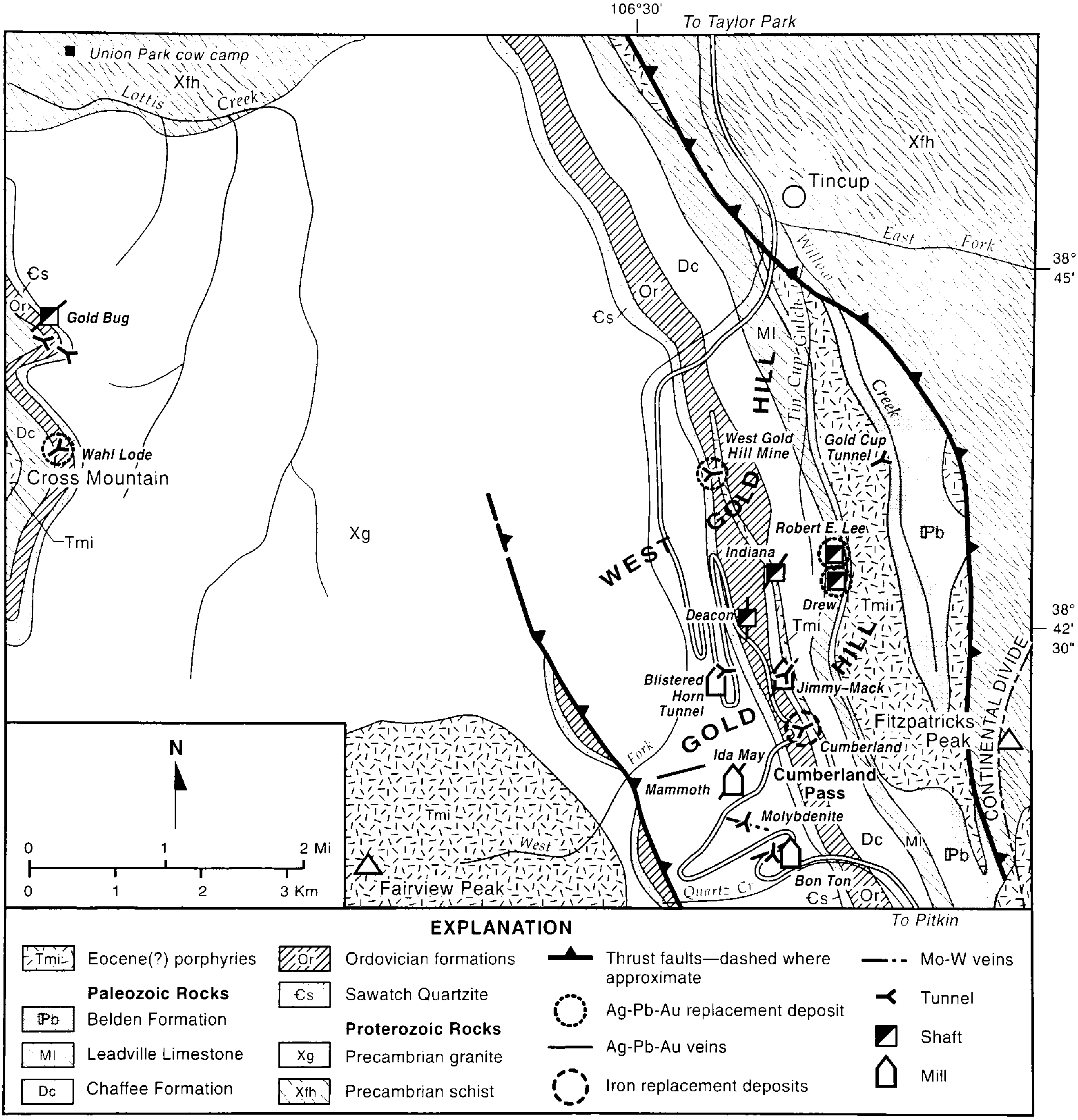


Figure 5. Sketch map of the Tincup mining district, showing the general geology and distribution of the main mines. (Geology after Goddard, 1936)

Pyrite is scarce. The ore also contains malachite, chrysocolla, and calamine in minor amounts. Some quartz gangue with abundant admixed limonite resembles a brown jasperoid (Goddard, 1936).

SILVER-LEAD-GOLD VEIN DEPOSITS

Silver-lead-gold vein deposits in the district are similar mineralogically to the more numerous replacement deposits and are frequently associated with them. Like the blanket deposits, the vein deposits have been oxidized to depths of several hundred feet below the surface and contain abundant secondary lead and copper minerals. If anything distinguishes vein ores from replacement ores, it would be a generally lower gold content of the vein ores. The silver-lead-gold vein deposits are developed in host rocks of the lower Paleozoic section, as well as in Proterozoic crystalline rocks.

Jimmy Mack Mine

The Jimmy Mack Mine is located on the upper west slopes of Gold Hill in the valley of the West Fork about 3.75 mi (6 km) south of Tincup (Figure 5). The Jimmy Mack vein was opened by a 420 ft deep (128 m) inclined shaft (70°) and six levels ranging from 150 ft (45 m) to 350 ft (106 m) long (Goddard, 1936). The vein strikes N. 25°–30° E. and dips 70° E., cutting Proterozoic granite gneiss and lower Paleozoic rocks.

The richest ore occurs where the vein is adjacent to limestones and dolomites of the Manitou, Fremont, and Chaffee formations. The Jimmy Mack vein averages 3.5 to 6 ft (1 to 1.8 m) in width and the ore is oxidized to the level of the base of the shaft at 420 ft (128 m). At the shaft collar a dike of hornblende diorite porphyry lies 5 ft east of the hanging wall of the vein. The dike and vein diverge with depth. The Jimmy Mack vein was intersected at the 750 ft (228 m) level by the Blistered Horn Tunnel driven from the bottom of the West Fork Valley eastward into Gold Hill. A raise connects the tunnel with the lower shaft workings. Ore at the Blistered Horn level from the Jimmy Mack vein, as well from at least two other northeast-trending veins, consisted of both oxidized and sulfide ore. The Jimmy Mack ores contain argentiferous galena and chalcopyrite, minor argentite and possibly native silver, and the secondary minerals limonite, cerussite, anglesite, malachite, chrysocolla, cerargyrite, and calamine (Goddard, 1936).

TOMICHI (WHITEPINE) DISTRICT

The Tomichi (Whitepine) district (Figure 3) is located in southeastern Gunnison County in the area of upper Tomichi Creek and adjacent to the village of Whitepine. The district is contiguous with, and similar geologically to, the Monarch Mining District to the east in Chaffee County. These two mining districts are separated by the Continental Divide. The geology of this area has been discussed by Dings and Robinson (1957), Crawford (1913), and Hill (1909). Near Whitepine, lower Paleozoic sedimentary rocks, including the Pennsylvanian Belden Formation through Cambrian Sawatch Quartzite, are in contact with Proterozoic Y-age granites to the east. The Proterozoic rocks have been faulted against the sedimentary rocks along a number of steeply dipping structures; cumulative vertical displacement is as much as 2,000 ft (609 m). The Paleozoic strata dip 30° to 60° to the east. This faulting is most likely Laramide in age but may be younger. To the west the lower Paleozoic rocks are truncated by a southern portion of the Middle Tertiary Mount Princeton batholith, which in this area is quartz monzonitic in composition. A number of dikes of similar composition cut the sedimentary formations. This intrusive event locally metamorphosed the lower Paleozoic sedimentary rocks creating marbles, hornfels, and quartzites from the original carbonate and clastic rocks. Limestones and dolomites, and their metamorphic equivalents, are the main host for precious and base metal ores in the Tomichi district. The deposits in the district consists of (in desreasing order of importance) replacement deposits in carbonate rocks near faults, fissure veins in Proterozoic granite and Tertiary quartz monzonite, and contact metamorphic deposits of sulfides and magnetite (Crawford, 1913). Ores of the Tomichi district have produced silver, lead, zinc, copper, and gold. Most metals from the district were produced in the late 1800s and early 1900s. Posted production for the years 1933–1945 is 75,700 oz silver, 2,400,000 lb lead, 2,640,000 lb copper, and 180 oz gold (Vanderwilt, 1947).

REPLACEMENT DEPOSITS IN PALEOZOIC ROCKS

Replacement deposits occurring in Paleozoic limestones, dolomites, and quartzites have been the most productive in the district. In a general sense, these deposits are located east and southeast of Whitepine and east of Tomichi Creek. The deposits occur mostly in and near fault zones where rock units that were chemically favorable for replacement were near or in contact with feeder conduits that circulated hydrothermal solutions. These deposits were chiefly valued for their silver and lead content but some contained minor gold. The replacement deposits range from massive sulfide to sulfide-dominant mantos in a mixed gangue of limestone, dolomite, quartz, calcite, and locally barite (Crawford, 1913). Some ore shoots are as long as 200 ft (61 m) but most tend to be less. Thicknesses of the deposits are variable but are seldom greater than 30 to 40 ft (9 to 12 m). Replacement ores consist of chalcopyrite, galena, tennantite-tetrahedrite, and sphalerite in the gangue described above. Silver is predominantly associated with galena and gray copper (tennantite-tetrahedrite). Many of these deposits are oxidized and commonly show higher silver assays associated with the secondary minerals anglesite, cerussite, and malachite. Primary minerals include stephanite, native silver, enargite, and native gold.

Morning Star Mine

The Morning Star Mine is located 1 mi (1.6 km) southeast of Whitepine townsite in Sec. 2, T. 49 N., R. 5 E. The mine was worked through an inclined shaft, 240 ft (73 m) deep, which was driven down-dip to the east (47°) in ore-bearing carbonate beds (Crawford, 1913). Based on site investigations for this study, the producing horizon at this mine was the Devonian Dyer

Dolomite or Mississippian Leadville Limestone, or both. The deposit occurs in the carbonate rocks and also in the Star Fault, which is the bounding fault to the east which brings Proterozoic rock up into contact with Paleozoic rocks. Stoping has occurred both in the main inclined shaft and in a crosscut tunnel of 600 ft (183 m) that intersects the shaft about at mid-depth. Both oxidized and sulfide ores were produced. Sulfide ore consists of galena, sphalerite, and pyrite which reportedly has an average grade of 19 opt silver, 0.14 opt gold, 22.7 percent lead, and 45.0 percent zinc (Crawford, 1913).

VEIN DEPOSITS IN PROTEROZOIC AND MIDDLE TERTIARY ROCKS

Fissure veins containing native gold and silver, tetrahedrite, chalcopyrite, galena, and sphalerite have been mined or sought in the Tomichi district. These deposits occur mostly west of Tomichi Creek in quartz monzonites of the Mount Princeton batholith; however, some veins are hosted in Proterozoic granite. The fact that granite-hosted veins occur exclusively within a few hundred feet of quartz monzonitic plutonic rocks suggests a genetic association of deposits and intrusive rocks of the Mount Princeton batholith. The veins are classic fissure fillings of sulfide minerals within a quartz gangue (Crawford, 1913). The veins vary in width from a few inches to 5 ft (1.5 m), and they strike from due north to N. 65° E. Dips are vertical or very high angle to the northwest.

Spar Copper Mine

The Spar Copper Mine is located east of Whitepine townsite in Sec. 35, T. 50 N., R. 5 E. The mine consists of two tunnels, the Morning Glim and the Parole, both of which were driven along a prominent fissure vein for 1,200 ft (366 m). The Copper Spar vein varies from a few inches to 5 ft (1.5 m) in width, a general average is 3.5 ft (1 m) in width (Crawford, 1913). The pay streak is usually about 1 ft (0.3 m) in width and it may occupy both the hanging wall and foot wall of the vein in places. The ore consists of galena and chalcopyrite, together with tetrahedrite and pyrite, in a gangue of quartz and calcite. The ore is chiefly valued for silver and lead associated with galena and tetrahedrite, but also contains gold in economic quantities. Samples from the vein assayed from 40 to 112 opt silver and reportedly carried appreciable gold (Crawford, 1913).

ENVIRONMENTAL GEOLOGY

For this study, host rocks and some low-grade sulfide ores from a number of Gunnison County metal mining districts were collected and analyzed for their relative acid-generating or acid-neutralizing potential. Acid-Base Accounting (ABA) is a standard mining industry test performed at mine sites to predict the theoretical affects a mining operation is likely to have on stream water quality. In conjunction with an understanding of minesite geology and hydrology, such data can aid greatly in planning mine sites and optimizing environmental costs.

Complete, or nearly complete, sample suites (Table 2) were collected from host rocks in productive ore zones from selected Gunnison County mining districts. Sample numbers, locations, and descriptions are listed below in Table 2. For each sample, data are reported for paste pH, percent sulfur, acid-neutralization potential (ANP), acid-generation potential (AGP), net neutralization potential (NNP), ratio, and fizz test (Table 3). Paste pH, percent sulfur, and the fizz test are direct measurements taken from initial sample pulps and can determine general acidity or lack thereof of the sample. The more important determinations of ANP and AGP are determined by titration and reflect the environmental risk of an ore type and/or the ability of a host rock sample to neutralize generated acidity. The final determination of NNP and the ratio of ANP/AGP reflect the direct environmental risk factor of a sample. Host rocks with an ANP/AGP ratio of 3:1 or greater reflect an ability to buffer acidity and are considered optimum rocks in which to develop a metal sulfide deposit. In the table of ABA data (Table 3), a reported ratio greater than 3 would generally meet this criterion, although much larger ratios are more desirable. This study presents preliminary ABA data for the selected mining districts; it does not pertain to particular mines. Greatly increased sample densities and sampling details are required to gain sufficient site-specific data; however, the collection of such data at a given mine at the beginning of a mining operation can direct the design of mining method, stope backfilling, pit closure, or waste-storage.

Samples were collected from Paleozoic sections in the Tomichi (Whitepine) and Quartz Creek mining districts, both of which have produced from precious and base metal sulfide deposits formed predominantly in carbonate host rocks. An abundance of carbonate host rocks in the vicinity of a sulfide deposit can naturally mitigate acid runoff from a minesite. This is indicated in the high ANP/AGP ratio numbers for carbonate host rocks from these districts (Table 3). In contrast, samples collected from the Proterozoic host rocks in the Gold Brick and Box Canyon mining districts are a good example of sulfides hosted in carbonate-poor, crystalline silicate rocks. These host rocks are much less able to absorb the acid generated by weathering of sulfides and generally cannot absorb the effects of mining. Thus, clean-up operations must be pursued at project inception or after mine closure.

Table 2. ABA Samples—Gunnison County

WHITEPINE DISTRICT

Sample No.	Formation	Description
WP-1	Sawatch Quartzite (MЄr)	white, vitreous quartzite, unmineralized
WP-2	Manitou Formation (MOr)	micritic limestone/dolomite, unmineralized
WP-3	Fremont Limestone (MOr)	white limestone, coarse grained, minor sulfides
WP-4	Leadville Limestone (MOr)	gray to blue-black limestone, unmineralized
WP-5	Belden Formation (ℙmb)	hornfels, minor sulfide mineralization
WP-6	Proterozoic granite (Xg)	partially weathered granite, unmineralized
WP-7	Tertiary intrusive (Tmi)	quartz monzonite, slightly altered, minor sulfides
GOLD BRICK DISTRICT		
GB-1	Proterozoic metavolcanics(Xfh)	felsic gneiss, minor sulfides
GB-2	Proterozoic metavolcanics (Xfh)	amphibolite, no mineralization
GB-3	Proterozoic metavolcanics (Xfh)	muscovite schist, no mineralization
GB-4	Proterozoic granite (Xg)	foliated biotite granite, no mineralization
BOX CANYON DISTRICT		
BC-1	Sulfide ore (Xb)	quartz/schist with low grade sulfide, secondary Cu
BC-2	Proterozoic granite (Xg)	biotite granite, no mineralization
BC-3	Proterozoic migmatite (Xm)	diorite, unmineralized
BC-4	Proterozoic metavolcanics (Xfh)	mica schist, unmineralized
QUARTZ CREEK DISTRICT		
QC-4	Manitou Dolomite (MOr)	gray, crystalline dolomite
QC-5	Harding Sandstone (MOr)	white quartzite with minor Cu oxides, pit grab
QC-6	Fremont Dolomite (MOr)	gray, fine-grained, crystalline dolomite
QC-7	Parting Formation (MOr)	low-grade sulfide ore, with Cu oxides, dump rock
QC-8	"Fairview shale" (MOr)	gray to buff, micritic sandy dolomite
QC-9	Dyer Dolomite (MOr)	gray micritic dolomite/limestone
QC-10	"Buckskin limestone" (MOr)	buff, very fine–grained, micritic sandy dolomite
QC-11	Harding Sandstone (MOr)	quartzite, with Cu oxides and galena — sort pile grab
Ore Samples		
QC-1	Ore Zone 2	sulfides in gouge grab across 1 ft vein in pit
QC-2	Ore Zone 2	sulfides in gouge-channel across 1 ft vein in pit
QC-3	Ore Zone 2	select grab from 1 in. qtz zone against hanging wall
Bon Ton Mine		
QC-12	Proterozoic granite and Paleozoic rocks	select grab, dump/massive sulfides with qtz and calcite
QC-13	Proterozoic granite (Xg)	country rock adjacent to portal, unmineralized
TREASURE MOUNTAIN DOME (TMD)		
TM-1	Mancos Shale (Km)	gray limestone, unmetamorphosed
TM-2	Mancos Shale-Lower (Km)	metamorphosed shale with Fe staining
TM-3	Dakota Sandstone (Kd)	orthoquartzite, white to tan
TM-4	Morrison Formation (Jm and Jme)	hornfels
TM-5	Entrada Sandstone (KJde)	white quartzite
TM-6	Gothic Formation (ℙm and ℙmb)	metaquartzite
TM-7	Belden Formation (ℙb and ℙmb)	hornfels
TM-8	Porphyry of TMD (Tui)	granite porphyry
TM-9	"Yule marble" (Mor)	white marble
TM-10	Mancos Shale-Upper (Km)	unmetamorphosed black and gray shale

Acid Neutralization Potential (ANCP), Acid generation Potential (AGP), and Net Neutralization Potential (NNP) data are given in tons $CaCO_3$/kilo-tons of sample.

Table 3. ABA Data.

Acid Sample Number	Acid Paste pH	Net Percent Sulpher	Neutralization Potential	Generation Potential	Neutralization Potential	Ratio	Fizz Test
WP-1	9.3	0.01	1018	1	1017	1018	4
WP-2	9.7	0.16	752	5	747	150.4	4
WP-3	9.4	0.09	961	3	958	320.3	4
WP-4	8.9	0.04	984	1	983	984	4
WP-5	8.4	4.94	250	154	96	1.62	4
WP-6	8.6	0.01	6	1	5	6	1
WP-7	7.7	0.1	1	3	-2	0.33	1
BC-1	8.3	0.03	7	1	6	7	1
BC-2	9.5	0.04	7	1	6	7	2
BC-3	8.6	0.01	5	1	4	5	1
BC-4	9	0.01	3	1	2	3	1
GB-1	9.1	0.1	8	3	5	2.67	2
GB-2	9.6	0.01	13	1	12	13	2
GB-3	9.3	0.01	4	1	3	4	1
GB-4	8.8	0.01	3	1	2	3	1
QC-01	7.9	0.07	7	2	5	3.5	1
QC-02	7.9	0.13	9	4	5	2.25	2
QC-03	7.7	0.13	4	4	0	1	2
QC-04	9.1	0.01	1048	1	1047	1048	3
QC-05	8.3	0.03	4	1	3	4	1
QC-06	9.1	0.01	1052	1	1051	1052	3
QC-07	9.2	0.01	1052	1	1051	1052	4
QC-08	9.3	0.01	857	1	856	857	4
QC-09	8.6	0.03	959	1	958	959	4
QC-10	8.8	0.01	913	1	912	913	4
QC-11	8.2	0.15	49	5	44	9.8	2
QC-12	8.1	0.01	4	1	3	4	1
QC-13	7.7	5.68	33	178	-145	0.19	3
TM-01	8.7	0.02	762	1	761	762	4
TM-02	7.8	0.01	11	1	10	11	1
TM-03	8.1	0.01	0	1	-1	0	1
TM-04	8.6	0.01	6	1	5	6	1
TM-05	8.3	0.03	77	1	76	77	3
TM-06	9	0.01	15	1	14	15	2
TM-07	10.3	0.01	94	1	93	94	2
TM-08	8.7	0.01	2	1	1	2	1
TM-09	9.3	0.01	943	1	942	943	4
TM-10	8.2	0.06	57	2	55	28.5	3

Acid Neutralization Potential (ANP), Acid Generation Potential (AGP), and Net Neutralization Potential (NNP) data are given in tons $CaCO_3$/kilotons of sample.

ENERGY/ALLOY METAL AND INDUSTRIAL MINERAL AREAS

POWDERHORN DISTRICT

The Powderhorn district encompasses a large area in the southern portion of Gunnison County in T. 45–47 N, and R 1–3 W. (Figure 6, Table 4). The area includes the upper basin of Cebolla Creek, and its tributaries, in the vicinity of Huntsman Mesa and Tolvar Peak. Although the district extends northwest to Sapinero Mesa, most of the mineral resources in the district are found near the town of Powderhorn. The Powderhorn district has been prospected for thorium, niobium, rare-earth elements, titanium, iron, uranium, vanadium, and vermiculite. The district contains measured resources of titanium, iron, niobium, thorium, uranium, and rare-earth oxides; however, as of 1998 none have been produced. Many of the mineral resources in the Powderhorn district are associated with alkalic rocks at Iron Hill, an early Cambrian intrusive complex containing pyroxenite, uncompahgrite, ijolite, nepheline syenite,

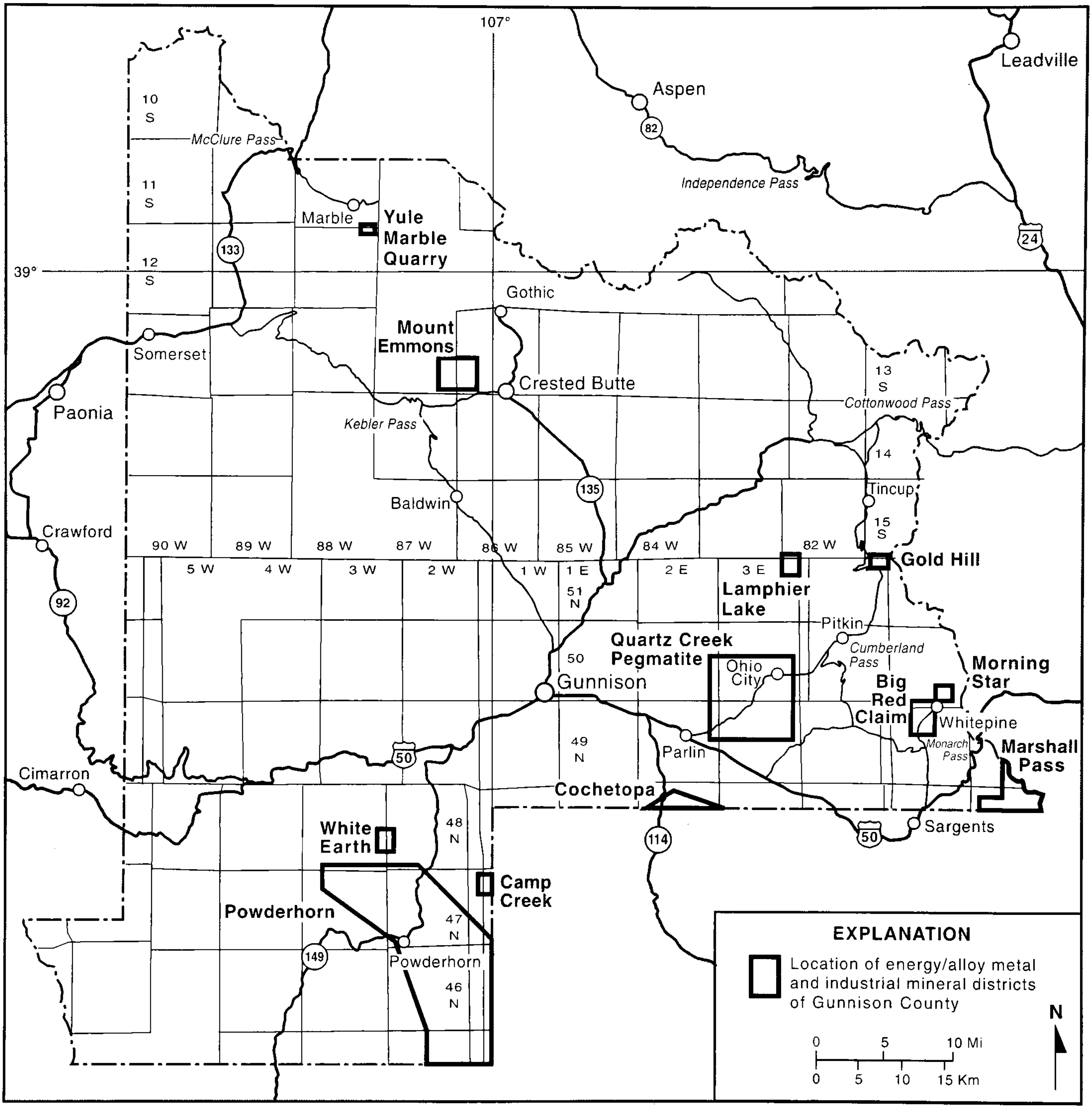


Figure 6. Map showing energy/alloy metal and industrial minerals areas in Gunnison County.

and carbonatite (Olson and Hedlund, 1981). The Powderhorn district is included in the following 1:24,000 scale geologic maps: Powderhorn (Hedlund and Olson, 1975), Rudolph Hill (Olson, 1974), Gateview (Olson and Hedlund, 1973), and Carpenter Ridge (Hedlund and Olson, 1973). The mineral resources of the area have been described by many workers including: Singewald (1912), Wallace and Olson (1956), Rose and Shannon (1960), Hedlund and Olson (1961), and Armbrustmacher (1981, 1980).

ALKALIC ROCKS AT IRON HILL–POWDERHORN CARBONATITE COMPLEX

The complex of alkalic rocks at Iron Hill consists of intrusive bodies of pyroxenite with abundant magnetite-ilmenite-perovskite segregations, uncompahgrite, ijolite,

Table 4. Table showing energy/alloy metal and industrial minerals locations data in Gunnison County.

Mining District	Alternative Name	Major Mines	Commodities	Location
Big Red Claims		Big Red 22, Big Red 39	uranium, thorium	T49N; R5E, Vicinity of No Name Creek and upper Tomichi Creek, 2.5 mi south of Whitepine
Camp Creek	Vulcan/Good Hope	Vulcan, Good Hope, Mammoth, Chimney	sulfur	T47N; R1W, Area is located on Camp Creek 12 mi southeast of Iola
Cochetopa	Los Ochos	Los Ocho (Saguache County)	uranium, thorium, mercury	T48–49N; R2E, Majority of district in Saguache County. Prospects/occurrences only in Gunnison County, located east of Cochetopa Creek and south of Hwy. 50
Gold Hill	Cumberland Pass	Ida May, Bon Ton, Molybdenite	tungsten, molybdenum, gold, silver	T51N; R4E, Sec. 11–14, Deposits are located near crest of Gold Hill, 1 mi southwest of Napoleon Pass and in upper headwater basin of Quartz Creek south and southeastof Cumberland Pass
Lamphier Lake		prospects only	molybdenum	T51N, R3E, Sec. 13; In vicinity of Lamphier Lake, south of Gunsight Pass and northeast of Fossil Mtn.
Marshall Pass		Little Indian No. 36, Pitch (Saguache Co.)	uranium, iron, feldspar	T48N; R6E, Headwaters of Agate, Marshall, and Indian Creeks, 6.5 mi east-southeast of Sargents
Morning Star	Whitepine	Morning Star	perlite	T50N; R5E, Sec. 35, Located in or just east of Whitepine/Tomichi precious/base metal mining district in upper reaches of Tomichi Creek
Mount Emmons	Redwell Basin, Red Lady Basin	Mt. Emmons Project (undeveloped), Standard, Daisy	molybdenum, lead, zinc, silver, copper, gold	T13S, R86W, Sec. 30–31 and T13S, R87W, Sec. 25, 36; Molybdenum deposit is approx. 4 mi northwest of Crested Butte beneath upper south slope of Mt. Emmons; Standard Mine is located in upper Elk Creek, Daisy Mine located on north side of Mt. Emmons
Powderhorn	Iron Hill, Rudolph Hill		thorium, niobium, rare-earth elements, titanium, iron, vanadium, uranium, vermiculite	T45–47N; R1–3W, Area includes upper headwater basin of Cebolla Creek and tributaries in vicinity of Huntsman Mesa, Tolvar Peak, and northwest to Sapinero Mesa. Majority of resource occurs at Iron Hill complex in northeast portion of T46N, R2W
Quartz Creek Pegmatite		Brown Derby, Black Wonder, Bucky, Opportunity No. 1	feldspar, beryllium, lithium, columbium-tantalum, rare-earth elements, mica, uranium, thorium	T49–50N; R3E, Vicinity of Ohio City on either side of Quartz Creek and west to Alder Creek
White Earth		Kezer No. 2, Lilly Belle	tungsten	T48N; R2W, Sec. 19 and 30, Located on divide between Wolf Creek and Wildcat Gulch, both tributaries of Cebolla Creek
Yule Marble Deposit		Yule Marble Quarry	dimension stone-marble	T12S, R88W, Sec. 1, Quarry is located in Yule Creek drainage on west side of Treasure Mountain Dome, 3 mi southeast of the town of Marble

Table 4. Table showing energy/alloy metal and industrial minerals locations data in Gunnison County. (Cont)

Mining District	Geology	Production	References
Big Red Claims	Autunite and thorite hosted in a remnant of Paleozoic quartzite caught in the footwall of a steeply-dipping reverse fault in Proterozoic granite	Big Red 22 Claim produced 127 tons of autunite ore yielding 557 lbs. U_3O_8	Nelson-Moore and others, 1978; Goodknight, 1981
Camp Creek	A 15 to 20 ft thick bed of native, granulated, sulfur occurring in the near-surface portion of a Proterozoic age massive sulfide deposit. Deposit grades at depth into a body of massive pyrite from which the sulfur was undoubtedly formed due to oxidation. Host rocks are Proterozoic schists and gneiss.	Several carloads of sulfur ore were reportedly shipped, yielding 80 percent native sulfur, around 1900. District was again mined for sulfur in 1907. All sulfur ore reportedly assayed high in gold.	Sharps, 1965b
Cochetopa	Vein-hosted uranium minerals Fractures with autunite and pitchblende hosted in Morrison Formation sandstone in Gunnison County	Minor to none — all production in district from Saguache County	Olson, 1988; Nelson-Moore and others, 1978; Goodknight, 1981
Gold Hill	Huebnerite-bearing veins hosted in Proterozoic granite and granitic gneiss and in Tertiary quartz monzonite porphyry. Veins also contain minor amounts of scheelite and powellite with molybdenite, chalcopyrite, and pyrite.	Ida May and Bon Ton mines worked for tungsten during World Wars I and II, no exact production figures available	Rosenlund, 1984; Sharps, 1965a; Belser, 1956, Worcester, 1919
Lamphier Lake	Iron-stained muscovite, molybdenite and molybdite, associated with malachite in quartz veins emplaced along contact of Proterozoic Y muscovite granite and Proterozoic X metasediments and metavolcanic rocks	No production — prospect area only	Zech, 1988; Worcester, 1919
Marshall Pass	Mineralized breccia and shear zones in Proterozoic granites and in replacements in carbonaceous Paleozoic sediments along the footwall of the Chester reverse fault	Little Indian No. 36 Mine produced 8,152 tons of oxidized ore yielding 71,762 lb Of U_3O_8	Olson, 1988, 1983; Goodknight, 1981
Morning Star	Perlite reportedly associated with two intrusive dikes, one 5 ft thick and the other 50 ft thick, at an elevation of 9,800 ft	No production reported.	Sharps, 1961; Bush, 1951
Mount Emmons	Mt. Emmons molybdenite deposit is a concentrically draped zone stockwork and vein type mineralization and multi-stage alteration over a Late Tertiary porphyry stock. Host rocks are Late Tertiary rhyolite-granite porphyry and contact metamorphic rocks in the Cretaceous Mancos and Mesaverde Formations. Deposit is undeveloped. Other mines in area have produced lead-zinc-silver.	No molybdenum production; Geologic reserves are 155 million tons at an average grade of 0.44 percent molybdenite with 0.2 percent ore-grade cutoff	Dowsett, and others, 1981; Gaskill and others, 1967
Powderhorn	Iron Hill carbonatite complex is a late Precambrian/early Cambrian, zoned, alkalic intrusive composed of pyroxenite, uncompahgrite, ijolite, nepheline syenite, and dolomitic carbonatite, in order of generally decreasing age. Thorite occurs in veins, carbonatite bodies, carbonatite dikes, trachyte dikes, magnetite-ilmenite-perovskite dikes or segregations, and as disseminations in small plutons of granite or quartz syenite. Magnetite-ilmenite-perovskite rocks constitute a sizable titanium resource occurring in the following minerals in decreasing order of concentration: perovskite, ilmenite, leucoxene, sphene, melanite, garnet, diopside, and biotite.	Numerous resource studies have been conducted in the district but actual production to date has been minor.	Armbrustmacher, 1980; Olson and Hedlund, 1981; Goodknight, 1981

Table 4. Table showing energy/alloy metal and industrial minerals locations data in Gunnison County. (Cont)

Mining District	Geology	Production	References
Quartz Creek Pegmatite	District includes 1,803 pegmatite bodies hosted in Proterozoic hornblende gneiss, granite, and quartz monzonite. Pegmatites are mostly homogeneous but some are zoned with discontinuous cores. District resources include beryl, scrap mica, feldspar, lepidolite, columbite-tantalite, topaz, monazite, and microlite.	51 tons beryl, 283 tons lepidolite, 140 tons scrap mica, 5,000 lbs tantalum/columbium minerals, and 15 lb monazite reported.	Staatz and Trites, 1955; Goodknight, 1981
White Earth	Scheelite, associated with quartz, talc, and epidote occurs in an altered Proterozoic hornblende gneiss, schist, and granite cut by Tertiary rhyolite and quartz-latite intrusives.	Small production reported from Lilly Belle Mine. Large scheelite crystals up to 4.5 lb in weight have reportedly been found at the Lilly Belle site.	Sharps, 1965a; Belser, 1956
Yule Marble Deposit	Beds of pure white marble, and veined white marble are quarried on the west side of Treasure Mountain Dome at Yule Creek from an outcrop of metamorphosed Mississippian Leadville Limestone. The mine was worked historically and blocks of white marble from the quarry are now in such monuments as the Tomb of the Unknown Soldier, and the Lincoln Memorial.	The Yule Marble Quarry has operated on a limited basis in recent years under the leadership of Colorado Yule Marble Company.	

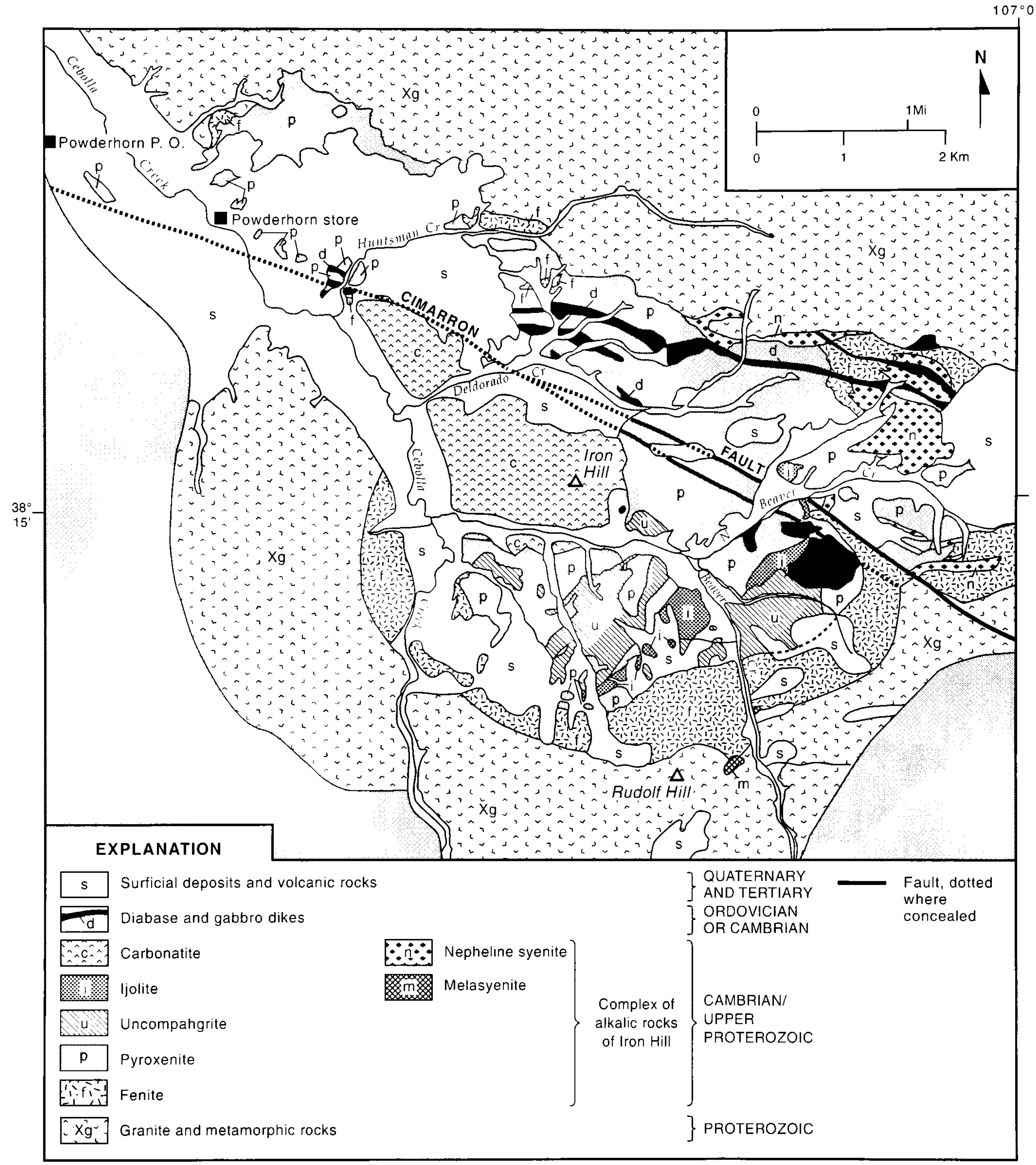


Figure 7. Generalized geologic map of the alkalic rock complex at Iron Hill, Powderhorn district. (After Olson and Hedlund, 1981)

nepheline syenite, and a late carbonatite stock, in general order of decreasing age (Olson and Hedlund, 1981). The alkalic rocks at Iron Hill were emplaced about 570 Ma into Proterozoic X-age granite (Powderhorn Granite) and metamorphic rocks. A fenite alteration halo encircles the margin of the complex in the Proterozoic wall rock and adjacent to alkalic dikes. These rocks crop out across an area of approximately

31 sq km immediately southeast of the town of Powderhorn (Figure 7). Parts of the intrusive complex are covered by ash-flow tuffs, welded tuffs, and colluvium, mostly of Oligocene age, and by alluvium and colluvium of Quaternary age.

The complex is bisected by the Cimarron fault, a large northwest-trending, dip-slip fault which most likely is Laramide in age. The Cimarron fault is downthrown to the southwest such that intrusive rocks of the alkalic complex exposed on the upthrown, or northeast, side of the fault represent a deeper structural level of the complex. Erosion since faulting has placed rocks from different levels of the intrusive complex in contact across the fault at the present ground surface (Hedlund and Olson, 1975). In the present outcrop pattern of the intrusive complex, nearly all of the uncompahgrite, most of the ijolite, and the carbonatite stock are found southwest of the fault, while the pyroxenite with magnetite-ilmenite-perovskite segregations and the nepheline syenites are found northeast of the fault.

Carbonatite dikes, similar in composition to the carbonatite stock, cut both the older rock types of the intrusive complex and the Proterozoic granite (Powderhorn Granite) that host the complex, especially in the fenitized aureole. The intrusive complex at Iron Hill is a classic example of a carbonatite-nephelinite magmatic igneous association. Erosion may have removed nephelinitic extrusive volcanic rocks usually associated with similar complexes (Armbrustmacher, 1981).

Pyroxenite, the oldest intrusive rock type in the Powderhorn alkalic complex, is highly variable in mineralogic and chemical composition. It is predominantly medium to coarse grained and locally pegmatitic. Its mineralogy is 50 to 70 percent clinopyroxene, 10–15 percent magnetite and ilmenite, 5 to 25 percent melanite garnet, 5 percent fluorapatite, and 10 percent biotite and phlogophite, with accessory sphene, calcite, perovskite, leucoxene, sericite, pyrite, chalcopyrite, and pyrrhotite (Hedlund and Olson, 1975; Olson, 1974). Vermiculite and magnetite-ilmenite-perovskite segregations and dikes are common, especially to the northeast of the Cimmaron fault (Armbrustmacher, 1981).

Uncompahgrite in the Powderhorn alkalic complex is light-gray, medium to coarse grained, and contains melilite, varying amounts of clinopyroxene, and minor magnetite, apatite, phlogopite, melanite garnet, and perovskite (Olson, 1974).

Ijolite is coarse to fine grained, has a hypidiomorphic-granular texture, and typically contains 30–50 percent nepheline, 30 to 40 percent sodic clinopyroxene, 10–30 percent melanite garnet, and accessory orthoclase, magnetite, apatite, biotite, sphene, and alteration products of nepheline (Hedlund and Olson, 1975).

Nepheline syenite at Iron Hill is light gray to pinkish gray, medium to coarse grained, has a trachytic texture, and contains orthoclase, microperthite, and albite, with interstitial sodic clinopyroxene and nepheline. Accessories include melanite garnet, magnetite, sphene, biotite, apatite, calcite, sericite, and zircon (Armbrustmacher, 1981).

Carbonatite is the youngest intrusive rock at Iron Hill. The carbonatite stock is a light-brown to light-gray, foliated to massive carbonatite body containing dolomite, barite, goethite, hematite, calcite, quartz, fluorapatite, pyrochlore, pyrite, magnetite, biotite, rutile, fluorite, bastnaesite, aegirine, anatase, sphalerite, synchisite, zircon, magnesite, and manganese oxide minerals (Armbrustmacher, 1981). The carbonatite stock contains greater than 20 times as much barium, cerium, and neodymium, and greater than 15 to 20 times as much lanthanum, niobium, phosphorus, and total rare-earth elements as do average igneous rocks (Armbrustmacher, 1980).

THORIUM

Thorium is found in six types of deposits in the Powderhorn district. In decreasing order of importance these deposits are thorite veins, a massive carbonatite stock (Iron Hill carbonatite stock), carbonatite dikes, trachyte dikes, magnetite-ilmenite-perovskite dikes or segregations, and disseminations in small plutons of granite or quartz syenite that predate the Iron Hill intrusive body (Olson and Hedlund, 1981). Thorite veins occur in steeply dipping, crosscutting shear or breccia zones in Proterozoic igneous and metamorphic rocks. The thorite veins, the most widespread type of deposit in the Powderhorn mining district (Figure 8) are not confined to the area near the Iron Hill intrusive complex as are other deposit types. The thorite veins contain potassic feldspar, white to smoky quartz, calcite, barite, and goethite and hematite, with thorite, jasper, magnetite, pyrite, galena, chalcopyrite, sphalerite, synchisite, apatite, fluorite, biotite, sodic amphibole, rutile, monazite, bastnaesite, and vanadinite. The ThO_2 content of the veins ranges from 0.01 percent to as high as 4.9 percent (Olson and Hedlund, 1981). The carbonatite stock at Iron Hill contains thorium but is very inhomogeneous (Figure 9); concentrations range from 0.0007 to 0.017 percent ThO_2 (Armbrustmacher, 1980). The remaining deposit types generally contain lesser concentrations of thorium: carbonatite dikes - 30 to 3,200 ppm thorium, trachyte dikes and associated rocks — 32 to 281 ppm thorium, and magnetite-ilmenite-perovskite segregations — 0.12 to 0.15 percent thorium (Olson and Hedlund, 1981). Thorium in all of these types of deposits is commonly accompanied by niobium and rare-earth elements, although the thorium-to-niobium and rare-earth element ratios vary greatly

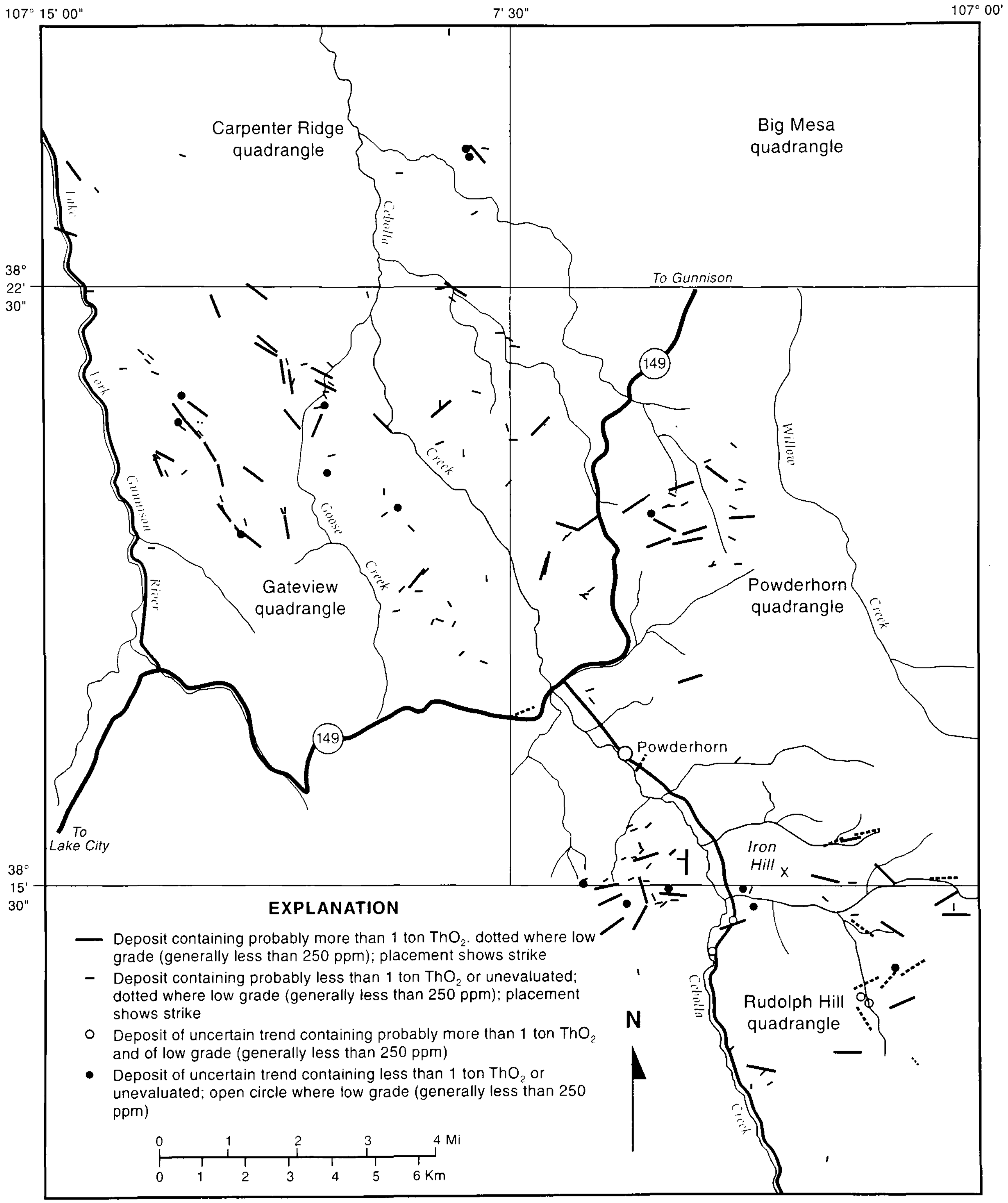
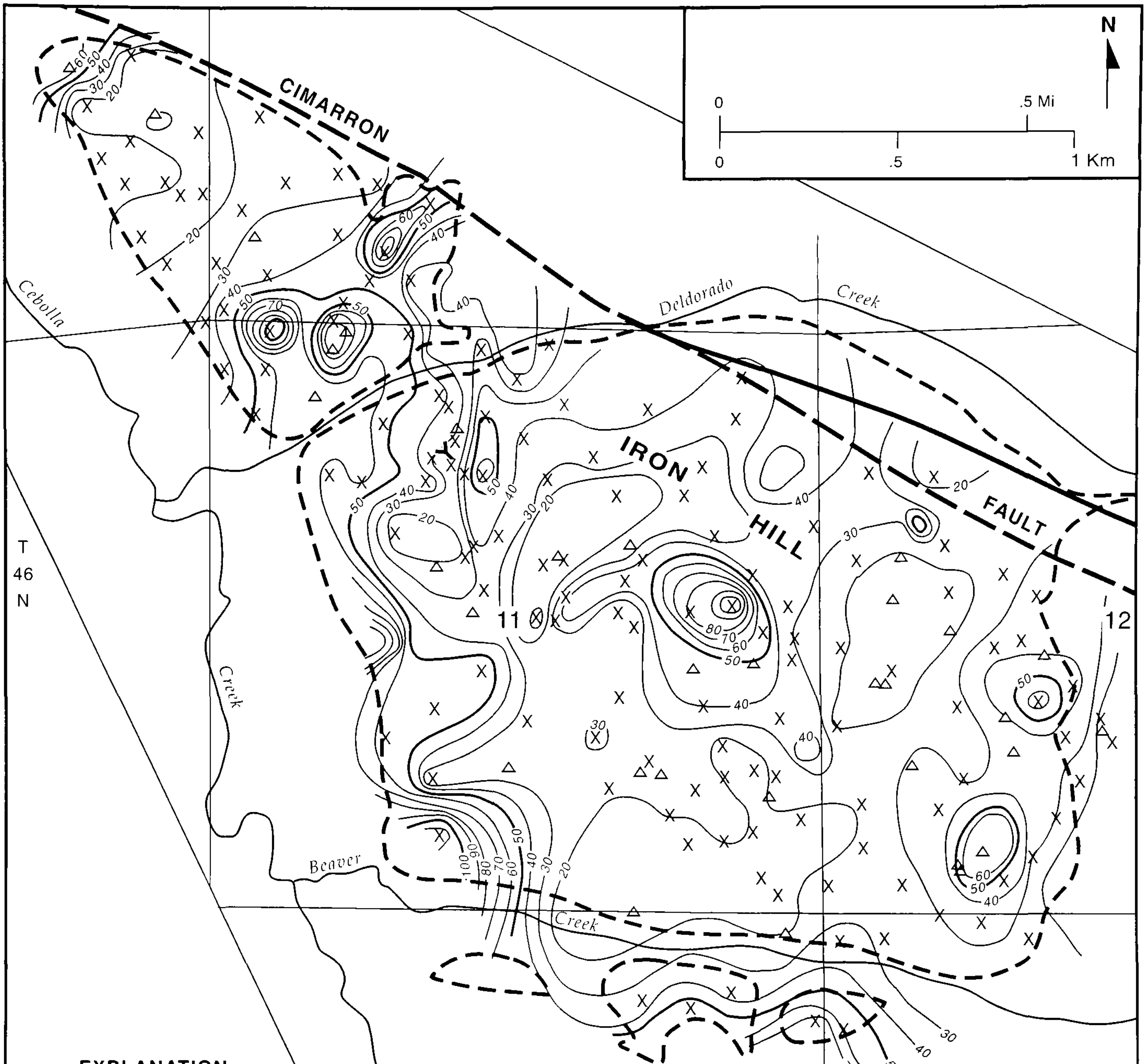


Figure 8. Map showing distribution and trend of thorium deposits. (After Olson and Hedlund, 1981)

throughout the district. In the carbonatite body at Iron Hill the Nb_2O_5 content is much greater than that of ThO_2, while in thorite veins in the northwest end of the district the ThO_2/Nb_2O_5 ratio can be as much as 10.7 (Olson and Hedlund, 1981). Olson and Wallace (1956) showed that thorium is mostly concentrated in



EXPLANATION

X	Locality of field gamma-ray spectrometer measurements
△	Geochemical and mineralogical sample locality and field gamma-ray spectrometer measurements
— — —	Contact between carbonatite (including carbonatite-rich talus) and alkalic rocks (including alluvium)
—40— —50—	Contours of equal thorium content; contour interval 10 ppm Th
⅄	Dupont adit

Figure 9. Contour map of thorium distribution in the carbonatite at Iron Hill. (After Olson and Hedlund, 1981)

veins and shear zones beyond the Iron Hill intrusive complex, and that rare-earth elements mainly are concentrated within the carbonatite stock and associated dikes.

TITANIUM

A large resource of titanium occurs in the Powderhorn district predominantly in the mineral perovskite ($CaTiO_3$). The titanium resource at Powderhorn is believed to be the largest in the United States, accounting for over half of the known domestic supply of useable titaniferous raw material (Thompson, 1987). The titanium reserve has been estimated at 390 million tons of ore averaging 11.5 percent TiO_2. Perovskite is a constituent in both pyroxenite and uncompahgrite intrusive rocks, but it is particularly concentrated in magnetite-ilmenite-perovskite segregations and dikes, most of which occur in the pyroxenite intrusive body northeast of the Cimarron fault (Armbrustmacher, 1981). Some of these magmatic segregations are as much as 50 percent perovskite. Perovskite may also contain minor amounts of niobium, rare-earth elements, and iron. Titanium is also present in the minerals ilmenite, leucoxene, sphene, melanite garnet, and titaniferous magnetite, although in far lesser concentrations than in the mineral perovskite. Production of titanium from the Powderhorn district has been delayed because of processing difficulties. Economics and beneficiation of titanium-bearing ores from the Powderhorn district are discussed by Thompson (1987).

NIOBIUM

Niobium concentrations are highest in the carbonatite stock of Iron Hill, which contains disseminations of the mineral pyrochlore. Temple and Grogan (1965) reported a niobium resource of 100,000 tons Nb_2O_5 in ore averaging at least 0.25 percent Nb_2O_5. Staatz and others (1979) estimate a reserve of 412,000 tons Nb_2O_5 in just the portion of the carbonatite stock that is above ground level. Concentrations of niobium in thorite veins outside the intrusive complex decrease away from the carbonatite stock. Niobium concentrations reported from the mineral perovskite are 0.17, 0.2, and 0.7 percent. Niobium occurs as a trace element in other minerals in the Powderhorn district such as ilmenite, magnetite, sphene, and melanite (Olson and Hedlund, 1981).

RARE-EARTH ELEMENTS

In the Iron Hill intrusive complex the rare-earth elements are mostly concentrated in the carbonatite stock and associated dikes. Staatz and others (1980) report reserves of 21,000 tons total rare-earth oxide in a study of 13 carbonatite dikes. The carbonatite stock contains reserves totaling 2,865,500 tons rare-earth oxides (Staatz and others, 1979). Rare-earth elements are also found in the thorite veins throughout the district. Within the thorite veins, ratios of light (cerium-group) rare-earth elements to heavy (yttrium-group) rare-earth elements are inversely proportional to the distance from the carbonatite stock. Cerium-group elements are most concentrated in and near the complex (Olson and Hedlund, 1981). Rare-earth element minerals in the district include monazite, bastnaesite, thorite, rhabdophane, synchisite, and thorite.

URANIUM/VANADIUM

Uranium and vanadium occur in the Powderhorn district but are less important than other commodities. The carbonatite stock at Iron Hill contains a reserve of 9,180 tons U_3O_8, and an additional 57 tons of U_3O_8 is contained in associated carbonatite dikes (Staatz and others, 1979, 1980). Vanadium occurs in the uncompahgrite rocks of the Iron Hill intrusive complex in concentrations up to 0.21 percent V_2O_5; concentrations in magnetite-ilmenite-perovskite segregations range up to 0.14 percent V_2O_5. Fisher (1975) estimates a resource of 50,000 tons of vanadium in magnetite-ilmenite-perovskite rock.

VERMICULITE

Vermiculite in altered pyroxenites of the Iron Hill intrusive complex is a possible resource. Vermiculite, a hydrated and expanded mica-group mineral, is used in lightweight concrete aggregate, refractories, oil well drilling mud, insulation, and fireproofing. No data are available on reserves or quality (Armbrustmacher, 1981).

QUARTZ CREEK PEGMATITE DISTRICT

The Quartz Creek pegmatite area is located on both the east and west sides of lower Quartz Creek, in T. 49–50 N., R. 3 E., in the vicinity of Ohio City (Figure 3). The district covers an area of roughly 29 sq mi. The area contains 1,803 known pegmatite bodies occurring in Proterozoic hornblende gneiss, granite, and quartz monzonite. The shapes of pegmatite bodies in the district include lenticular, lenticular-branching, oval, and irregular. The size of pegmatite bodies ranges from 2–3 in. (5–7 mm) wide and 2–3 ft (0.6–0.9 m) long to very large pegmatite bodies such as the Black Wonder, which is 12,600 ft (3, 800 m) long and up to 6,700 ft (2,000 m) wide. Most pegmatites are from 100 to 400 ft (30 to 122 m) in length. A lack of correlation between host rock foliation and pegmatite body shape, random orientations of pegmatites, and the existence of many pegmatite bodies occurring along structures (line-rock pegmatites), all suggest that pegmatites were emplaced along irregular fractures and joints (Staatz and Trites, 1955).

The majority of the pegmatites are homogeneous, but a few show crude zoning: a narrow border zone, a large wall zone, and a small discontinuous core. The district contains few well-zoned pegmatites. Some of the pegmatites are layered both in texture and mineralogy. Homogeneous or unzoned pegmatites are by far the most common; they typically contain plagioclase, quartz, and perthite, and subordinate muscovite, garnet, biotite, and magnetite. The unzoned pegmatites may also contain small amounts (less than 1 percent) of beryl and tourmaline. The zoned pegmatites, which make up roughly 14 percent of the total population in the district, commonly have cores of massive quartz, perthite-quartz, cleavelandite-quartz, or cleavelandite-lepidolite-quartz.

The wall zones in the heterogeneous pegmatites usually are identical in composition to unzoned pegmatites in part of the district. Lepidolite and cleavelandite are found in both zoned and unzoned pegmatites. A few pegmatites contain attributes of all types in the district and may have resulted from multiple overprinting intrusive events (Staatz and Trites, 1955).

About 30 mineral species have been recognized from pegmatites of the Quartz Creek district including plagioclase, perthite, quartz, muscovite, garnet, magnetite-martite, biotite, beryl, tourmaline, columbite-tantalite, monazite, lepidolite, pyrochlore-microlite, topaz, gahnite, and allanite (Staatz and Trites, 1955). Other less abundant mineral species include chlorite, samarskite, euxenite, epidote, apatite, fluorite, spodumene, amblygonite, and betafite. Reported production from the Quartz Creek pegmatite district is 51 tons beryl, 238 tons lepidolite, 140 tons scrap mica, 5,000 lb columbite-tantalite, and 15 lb monazite (Goodknight, 1981). The district contains resources of feldspar, beryllium, lithium, columbium-tantalum, rare-earth elements, mica, uranium, and thorium. Calculated reserves are as follows: 251,300,000 tons of milling-grade feldspar, 13,500 tons scrap mica, 350 tons beryl, 3,560 tons lepidolite, 900 tons topaz, 4,000 lb columbite-tantalite, and 400 lb monazite (Staatz and Trites, 1955).

Brown Derby Mine

The Brown Derby Mine, one of the most developed of the pegmatite deposits in the district (Staatz and Trites, 1955), is located about 1 mi (1.6 km) southeast of Quartz Creek in the NE¼, Sec. 3, T. 49 N., R. 3 E. The mine consists of three tunnels and numerous open cuts that have been developed on a series of three dike shaped pegmatites. The easternmost pegmatite body, the Brown Derby No. 1 is the most developed. The Brown Derby No. 1 pegmatite is lenticular and has two large branching zones at its southern end. The pegmatite, which is exposed for a total length of 913 ft (278 m) (Staatz and Trites, 1955), is both zoned and partially layered. The main body of the pegmatite contained a high-grade, pod-shaped concentration of lepidolite in a lepidolite-quartz-cleavelandite core, which has been completely mined out. The main body of the dike is layered from hangingwall to footwall as follows: perthite-albite-quartz (hangingwall zone), quartz-lepidolite, lepidolite-microlite, quartz-cleavelandite-lepidolite-topaz, and albite pegmatite (footwall zone). The lepidolite-microlite zones occur in discontinuous pods, some of which have been mined out. Beryl crystals up to 4 in. (10 mm) in length occur in the quartz-cleavelandite-lepidolite-topaz layer.

URANIUM IN GUNNISON COUNTY

Uranium prospecting in Gunnison County has met with moderate success and has led to the discovery of two mineable ore bodies. Although a modest number of uranium prospects are reported from the county, virtually all of the uranium production has come from one mine in the Marshall Pass district. The Cochetopa district which extends in Gunnison County (Figure 10) does not contribute any production as all of the producing mines were located to the south in Saguache County. Minor production of uranium and thorium from a vein on the Big Red Claims near Whitepine completes the production rank of Gunnison County. The combined production from these areas to date has been 2.64 M lb of U_3O_8 (Goodknight, 1981). Uranium is most often closely associated with fault and shear zones in brittle host formations of Paleozoic and Mesozoic age. Some uranium is associated with alkalic rocks of the Cambrian Powderhorn carbonatite complex, and with rare-earth-bearing pegmatites of the Quartz Creek pegmatite district, but these deposits have not been mined for uranium.

MARSHALL PASS URANIUM DISTRICT

The Marshall Pass district is located in the southeastern corner of Gunnison County and includes the area between Marshall Pass (Saguache County) on the south and Monarch Pass on the north (Figure 10). The Gunnison County portion of the mining district (Figure 10) is almost entirely underlain by Proterozoic igneous and metamorphic rocks, with a portion of a remnant of Paleozoic rocks. The Marshall Pass district as a whole is underlain by rocks ranging from Proteozoic to Tertiary. Proterozoic rocks include mica gneiss and schist, hornblende gneiss and schist, gneissic hornblende diorite, and gneissic quartz monzonite, and also six mappable units of intrusive rocks (Olson, 1988). Paleozoic formations, which unconformably overlie the Proterozoic rocks, include Sawatch Quartzite through Belden Formations. Mesozoic rocks are absent from the Marshall Pass district. To the south in Saguache County the district includes Tertiary volcanic and sedimentary rocks that are not present in the district in Gunnison County. The mining district and uranium deposits are affected by two large faults, both

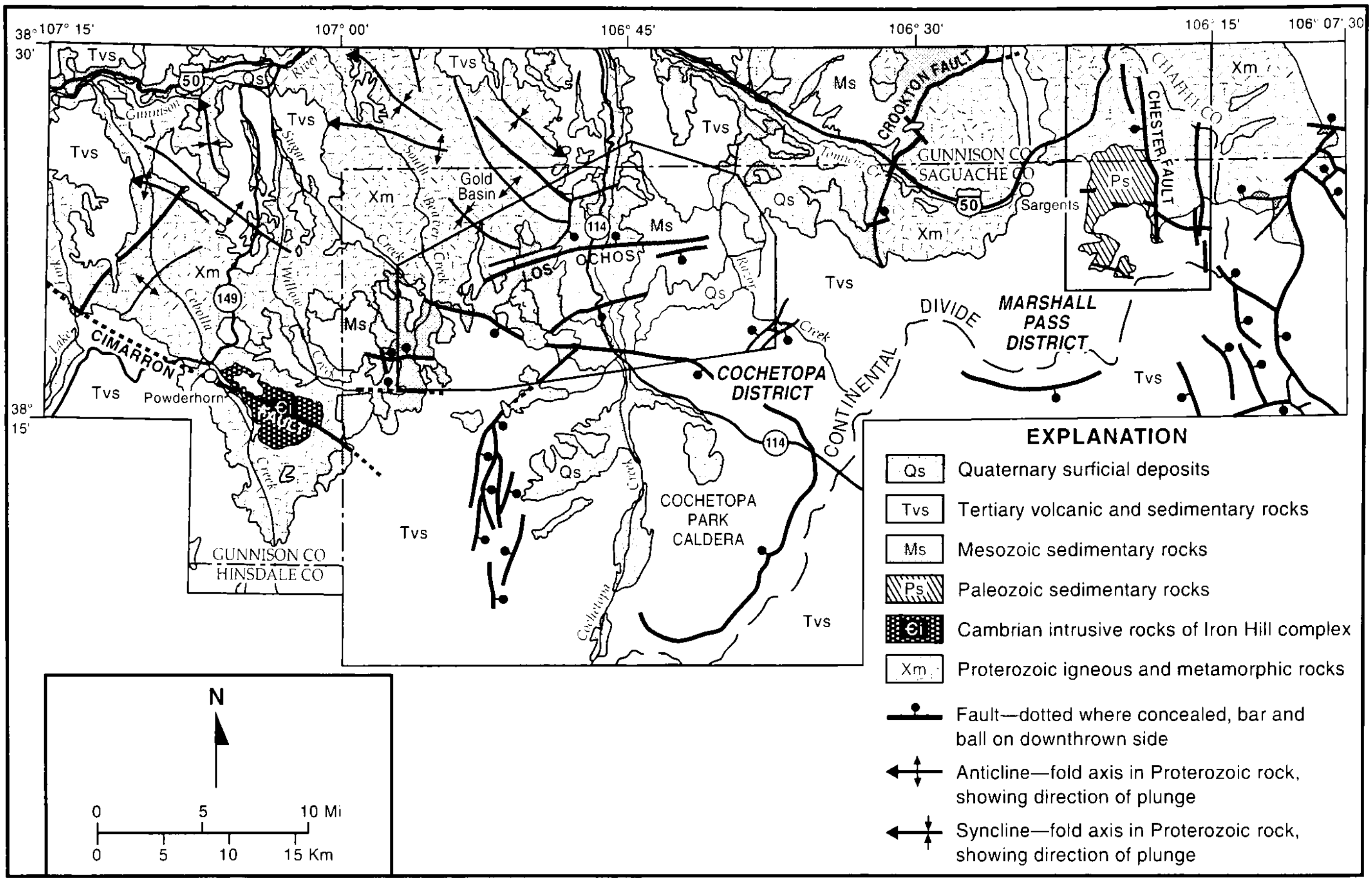


Figure 10. Generalized geology of region including the Cochetopa and Marshall Pass uranium districts.

of which are probably Laramide age. Uranium deposits in the Gunnison County portion of the district are localized near the Chester fault. This large north-south -trending reverse fault thrust Proterozoic igneous and metamorphic rocks westward over Paleozoic and Proterozoic rocks, folding footwall rocks into a large syncline (Olson, 1988). The Gunnison County uranium production is attributable to the Little Indian No. 36 Mine, although the largest producer in the district was the Pitch Mine in Saguache County (Figure 11a).

Little Indian No. 36 Mine

The Little Indian No. 36 Mine is located just inside Gunnison County in the headwaters of Agate Creek. It produced 8,152 tons of oxidized ore, yielding 71,762 lb of U_3O_8, from mineralized breccia and shear zones in Proterozoic granites, and from replacements in carbonaceous Paleozoic sediments, along the footwall of the Chester fault (Olson, 1988). Ore in a limonitic zone near the top of the Ordovician Harding Sandstone is characterized by carbonaceous material, fish scales, and other fossil remains. At this mine ore with an average uranium oxide content of 0.44 percent was mined from steeply dipping to overturned beds of Harding Quartzite adjacent to the Chester fault (Olson, 1988). Uranium minerals reported from the mine include uranophane, uraninite, autunite, and boltwoodite (Olson, 1988).

Big Red Uranium Claims

The Big Red 22 and Big Red 39 claims are located near No Name Creek and upper Tomichi Creek 2.5 mi south of Whitepine (not on map). The prospects are about 3,200 ft (1 km) apart in separate small remnants of Cambrian Sawatch Quartzite along the footwall of a northwest-trending reverse fault (Goodknight, 1981). Uranium oxide with an average grade of 0.22 percent was mined from the Big Red 22 claim in the 1950s and 1960s. Quadrangle investigation in the area by Nelson-Moore and others (1978) reported 0.064 percent U_3O_8 and 10 percent iron in a sample of fault gouge. The main uranium mineral in the area is autunite, but torbernite and parsonite occur at the Big Red No. 22 Mine. Thorium is fairly abundant at the Big Red 39 claim but completely absent at the Big Red 22 claims (Goodknight, 1981). The area has reportedly produced 127 tons of ore yielding 557 lb U_3O_8 from remnants of Sawatch Quartzite caught in the footwall of a steeply dipping reverse fault in Proterozoic granite.

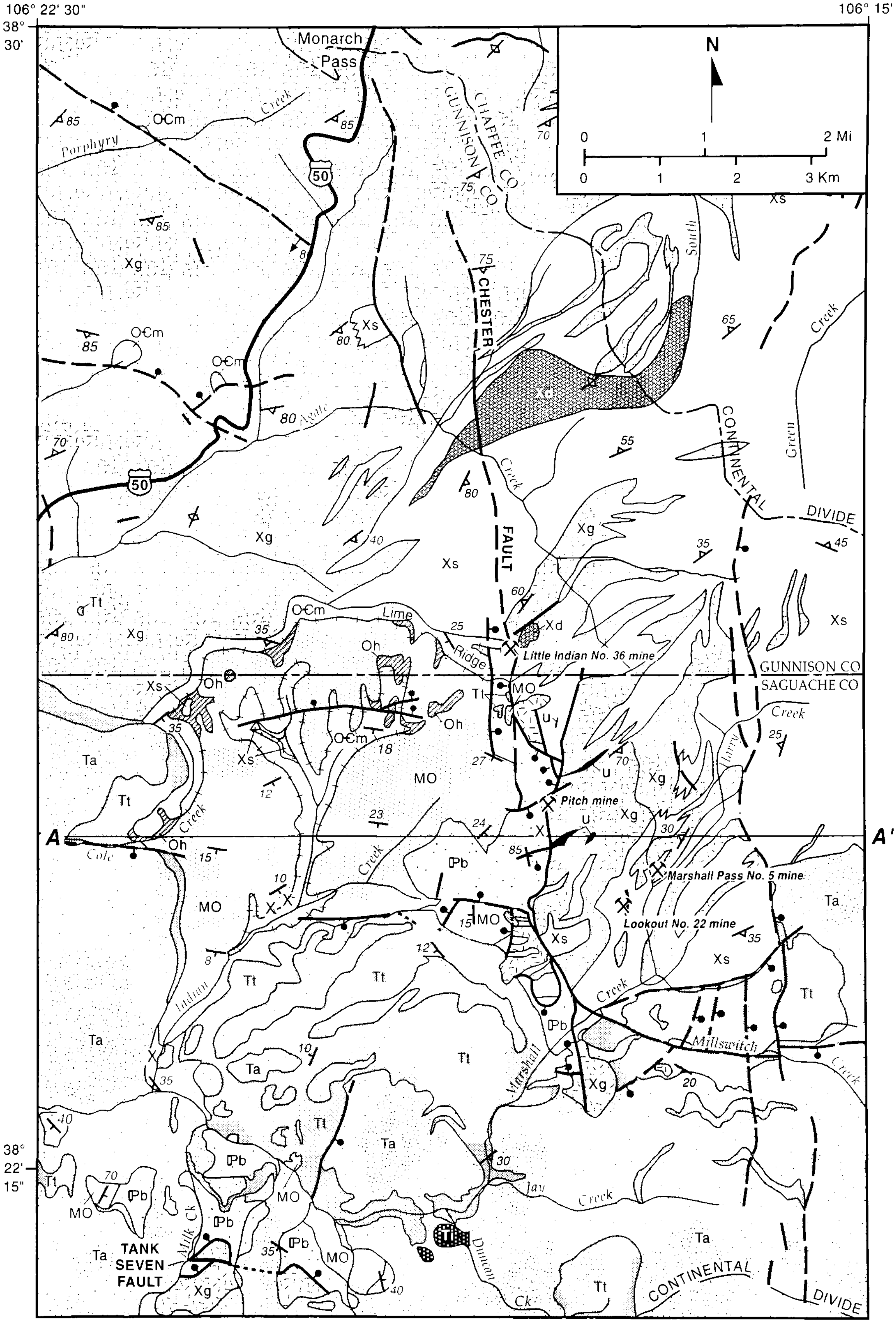


Figure 11a. Generalized geology and cross section of the Marshall Pass district.

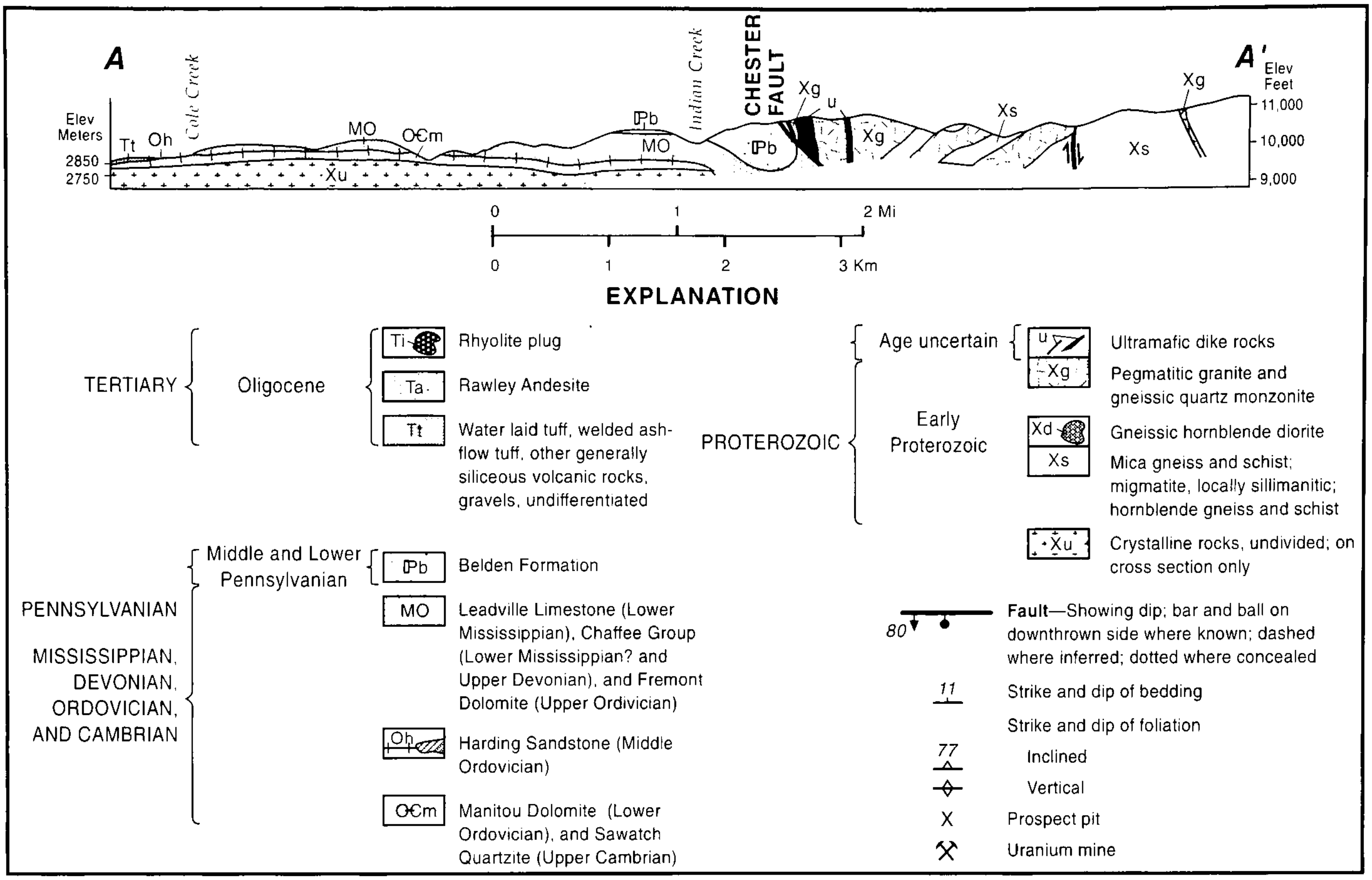


Figure 11b. Explanation and cross-section A – A' for Figure 11.

MOUNT EMMONS MOLYBDENUM DEPOSIT

The Mount Emmons molybdenum deposit (Figure 12) is described by Dowsett and others (1981). The following summary is taken from that work. The deposit is located in the Ruby Range on Mt. Emmons about 3.75 mi (6 km) northwest of the town of Crested Butte. Molybdenite discovered in Redwell Basin in 1970 was described by Sharp (1978). The property was optioned by AMAX Exploration in 1974 and the Mount Emmons molybdenite deposit was discovered soon there after. A drilling program begun in 1977 delineated the ore body; reserves are estimated at 155 million tons at a grade of 0.44 percent MoS_2, with 0.2 percent as a lower limit to ore grade (Ganster and others, 1981). The discovery of the deposit is credited to Thomas and Galey (1978) of AMAX Exploration. The deposit is undeveloped at this time. (1999)

At Mount Emmons an inverted-cup-shaped zone of molybdenite ore is draped over the top of a multi-phase intrusive plug emanating from a stock of rhyolite-granite porphyry beneath Mount Emmons (Figure 12). The molybdenite ore extends well out into altered and metamorphosed Cretaceous clastic wall rocks. The molybdenite zone is the only known economic resource in the deposit. At its shallowest point the top of the molybdenite zone is 885 ft (270 m) below the surface of Red Lady Basin. The ore zone is between 245 ft (75 m) and 395 ft (120 m) thick with a cross-sectional dimension averaging 2,100 ft (650 m). Ore consists of stockwork veinlets of molybdenite; fine-grained quartz and fluorite are developed in both the Mount Emmons intrusive plug and metamorphosed sedimentary rocks adjacent to the intrusive.

Hydrothermal alteration in and adjacent to the Mount Emmons stock overlaps in several distinct zones (Figure 12). Altered Cretaceous and Tertiary sedimentary rocks include the Mancos Shale and the Mesaverde and Ohio Creek Formations (Cretaceous), and the Wasatch Formation (Tertiary). Alteration zoning in sedimentary rocks inward to the stock itself includes: 1) disseminated pyrrhotite peripheral to pyrite, 2) a propylitic zone with chlorite, epidote, and calcite, 3) a phyllic assemblage with quartz, sericite, and pyrite, 4) potassic alteration with secondary potassium feldspar and biotite, and 5) a zone of pervasive quartz-magnetite and local biotite and potassium

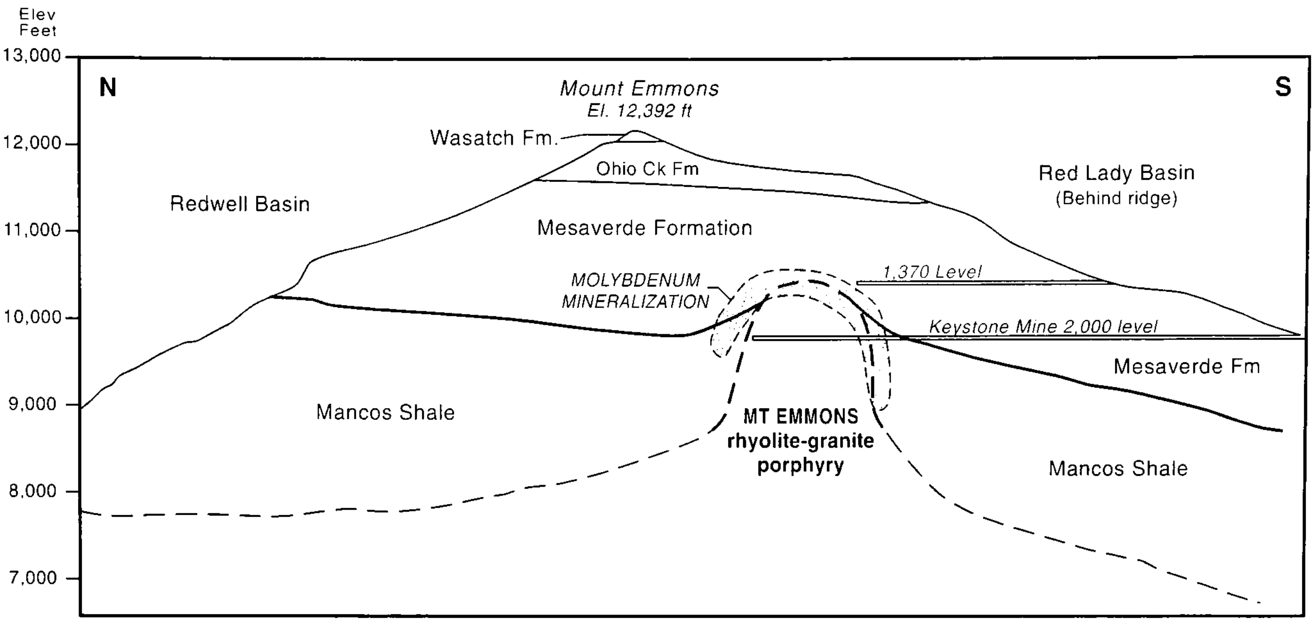


Figure 12. Generalized cross section of Mount Emmons. (after Dowsett and others, 1981)

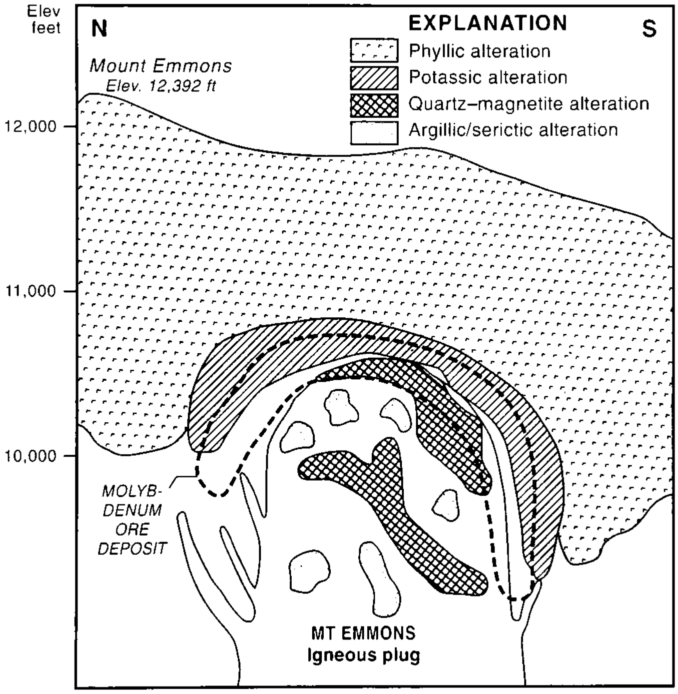


Figure 13. Hydrothermal alteration of Mount Emmons deposit.

feldspar. Molybdenum ore in the metamorphosed sediments (hornfels) lies within potassically altered rock and ocassionally in the transition zone with phyllically altered rock. The outer margins of the ore zone grades into stockwork pyrite or pyrite-quartz-sericite veins at the transition from potassic to phyllic alteration. The Mount Emmons stock is less mineralized in the outer part of a zone of quartz-magnetite altered rocks.

GOLD HILL TUNGSTEN/ MOLYBDENUM AREA

Gold Hill and the area around Cumberland Pass are part of the Tincup and Quartz Creek precious and base metal mining districts located in eastern Gunnison County (Figure 6, Table 4). Huebnerite-bearing veins, hosted by Proterozoic granite and granitic gneiss and by Tertiary quartz monzonite, have been worked for tungsten and molybdenum. At the Ida May and Molybdenite Mines on the crest of Gold Hill, huebnerite veins containing molybdenite and minor amounts of scheelite and powellite were mined during World War II. At the Bon Ton Mine on the south side of Cumberland Pass in upper Quartz Creek, tungsten-molybdenum veins were also worked during World War II. No exact production figures are available (Rosenlund, 1984; Sharps,1965a)

WHITE EARTH TUNGSTEN AREA

The White Earth tungsten area (Figure 6, Table 4) is located in Sec. 19 and 30, T. 48 N., R. 2 W., on the divide between Wolf Creek and Wildcat Gulch, both tributaries of Cebolla Creek. Scheelite is associated with quartz, talc, and epidote in a deposit occurring in altered Proterozoic hornblende gneiss, schist and granite cut by Tertiary rhyolite and quartz-latite intrusives. Small production of tungsten was reported from the Lilly Belle Mine, including scheelite crystals up to 4.5 lb (Sharps, 1965a).

MORNING STAR PERLITE DEPOSIT

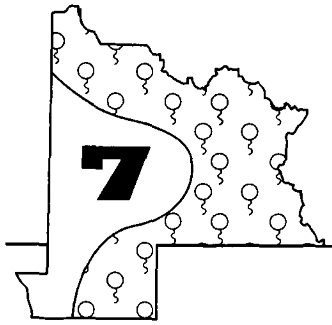
The Morning Star perlite area is located in Sec. 35, T. 50 N., R. 5 E. The area is east of the Tomichi (Whitepine) mining district in the upper reaches of Tomichi Creek (Figure 6). Perlite is associated with two intrusive dikes.

YULE MARBLE DEPOSIT

The Yule Marble quarry is located on the west side of Yule Creek, 3 mi (4.8 km) south of the town of Marble (Figure 6, Table 4). The deposit consists of calcic marble that is pure white and white with yellow veining. Chert bands and lenses of dolomite make quarrying difficult in places. The marble was formed in the Mississippian Leadville Limestone, which was contact metamorphosed by intrusion of the granite of Treasure Mountain (see Igneous Rocks section, this report). Intrusion and metamorphism of the Paleozoic and Mesozoic section in this area was accompanied by doming in the formation of Treasure Mountain Dome. The marble beds were subsequently exposed by downcutting by Yule Creek.

The marble in the area was recognized as early as 1880, owing to the development of silver-lead-zinc veins deposits in the Crystal River mining district. Production of the marble however, did not occur until 1908-1909 (Vanderwilt, 1947). Marble from the Yule quarry was used to build the Lincoln Memorial building and the Tomb of the Unknown Soldier, as well as in numerous other buildings throughout the United States. Production and shipping from the site has always been hampered by its remote location and high elevation, and hence the mine has experienced many idle periods. The quarry was most active in the first part of the 1900s and was operated ocassionally thereafter. In 1988, the quarry reopened and has remained active since.

The present operator, Colorado Yule Marble Company uses underground column and diamond-wire saw techniques to remove blocks. Sized blocks are shipped by truck to Glenwood Springs where they are loaded onto rail cars for delivery to markets worldwide. The quarry is operated on mining claims that cover 44 acres near the head of Yule Creek. Reserves are uncalculated at this time but are substantial. The property was in the process of being transferred to a new owner at the time of the site visit for this report (1998). Marble from the Yule quarry is among the best in the world and is highly prized by architects and sculptors.



7 Geothermal Resources

Pearl (1981) reports there are 30 thermal areas containing approximately 103 thermal springs and wells west of the Continental Divide in Colorado (Figure 14). Four of these are in Gunnison County: Cebolla Hot Springs, Cement Creek Warm Springs, Ranger Hot Springs, and Waunita Hot Springs. Discharge, water temperature, and Total Dissolved Solids data for these four sites are given in Table 5. Discharge rates for the Gunnison County springs range from a low maximum discharge rate of 3 gallons per minute (gpm) at Cebolla Hot Springs, to a high maximum discharge rate of 132 gpm at Ranger Hot Springs. The hottest maximum temperature, 80° C, occurs at Waunita Hot Springs Resort, which has a maximum discharge rate of 50 gpm. The Cement Creek Warm Springs has a maximum temperature of 25° C at a discharge rate of 80 gpm (Pearl, 1981). Geothermal resources in Colorado are mostly used for recreational purposes. Energy uses are local and limited. Geothermal resources are most likely under-utilized, both in Gunnison County, and statewide in Colorado.

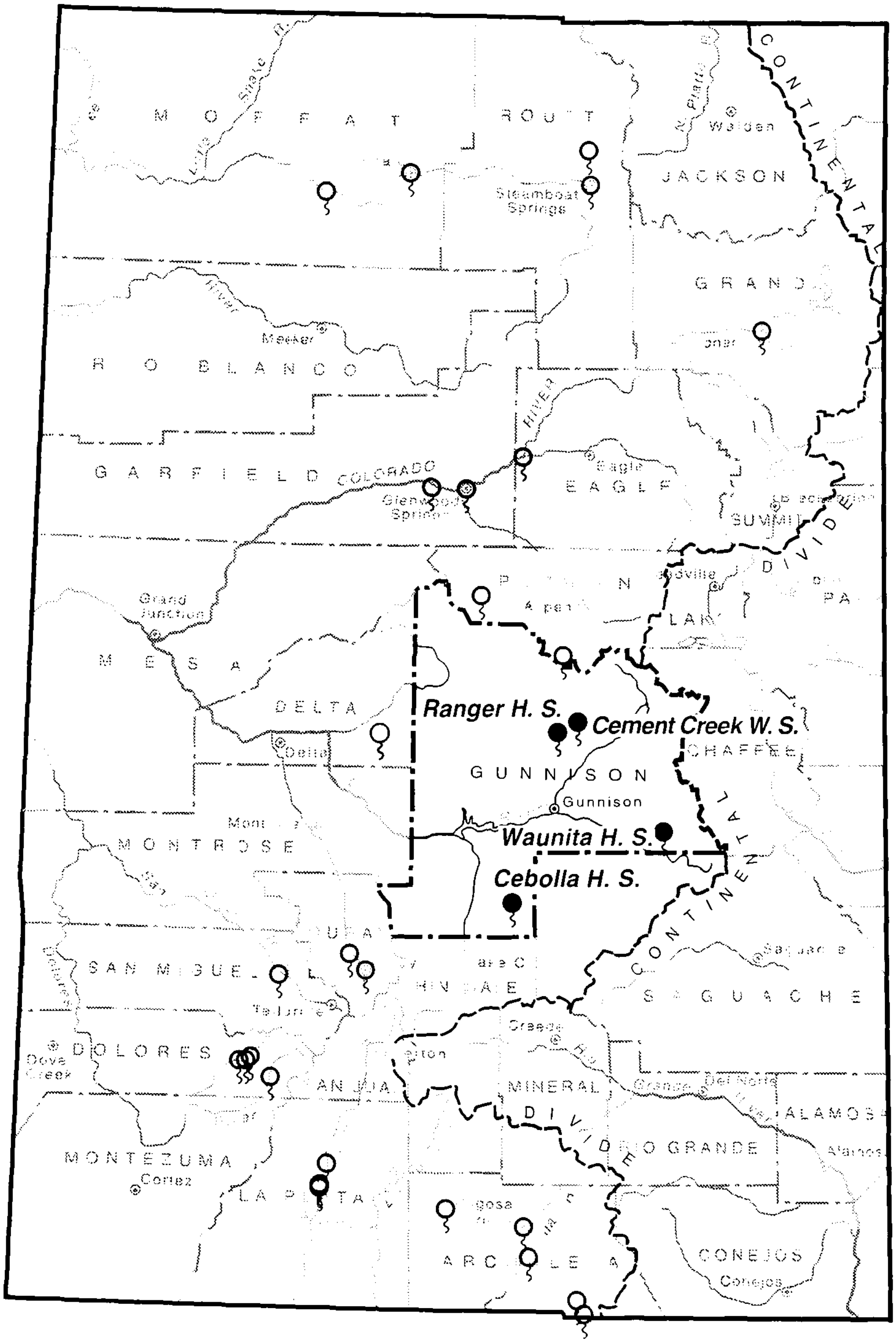


Figure 14. Map showing location of hot springs in Gunnison County and western slope.

Table 5. Characteristics of thermal springs in Gunnison County (From Pearl, 1981).

Thermal Spring	Maximum Discharge (gpm)	Maximum Total Dissolved Solids (mg/l)	Maximum Temperature (°C)	Estimated Reservior Temperature (°C)
Cebolla Hot Spring	3	1,450	40	200?
Cement Creek Warm Spring	80	390	25	60
Ranger Hot Spring	132	465	27	60
Waunita Hot Spring	50	575	80	225

8 Coal Resources

Parts of two coal regions, the Uinta Coal Region and the San Juan River Coal Region, are within Gunnison County (Figures 15 and 16). The southeastern Uinta Region extends into the northwestern part of the county and contains the entire Crested Butte Coal Field, a majority of the Somerset Coal Field, and a small part of the Carbondale Coal Field. The Gunnison County portion of these three coal fields occupies about 500 sq mi. The northeastern part of the San Juan River Region extends into southwestern Gunnison County; there the Tongue Mesa coal field occupies less than 100 sq mi.

Approximately 10 percent of Colorado's cumulative production through 1997 came from Gunnison County. The two mines operating in the county produced almost 27 percent of the state's coal in 1997.

UINTA COAL REGION

Approximately one-half of the Uinta Coal Region lies in west-central Colorado; the remainder is the main coal-bearing region of eastern Utah. Most of the Colorado portion of the Uinta Region coincides with the Piceance Creek structural basin of Laramide age and is located in the eastern part of the Colorado Plateau physiographic province. The Uinta Region in Colorado is bounded by the Grand Hogback Monocline to the east, the Axial Basin Uplift to the north, the Utah state line to the west, Grand Valley and the Colorado River to the southwest and the North Fork Valley and Gunnison Uplifts to the south and southeast (Figure 15) (Tremain and others, 1996).

Figure 15. Map showing location of major coal regions on western slope.

The Piceance Creek Basin (Figure 1) is the largest structural basin in western Colorado, covering an area exceeding 7,200 sq mi as defined by the base of the Upper Cretaceous Mesaverde Group. The basin is asymmetric; its steep flank is on the east and its long axis trends northwest. This basin, one of the deepest in the Rocky Mountain region, contains at least 25,000 ft (8,000 m) of sediments at the north end of the basin in Rio Blanco County.

The southeastern part of the region, in Gunnison County, contains coal-bearing strata of the Mesaverde Formation and numerous Tertiary intrusive complexes, including the Elk and West Elk Mountains (Figure 1), sills, laccoliths, and dikes. The high geothermal heat flow characteristic of this part of the region has increased the rank of much of the coal, producing large resources of coking coal.

The Colorado Geological Survey evaluated coking coals in Colorado and showed that original in-place identified coking coal resources total more than 4.2 billion tons (Goolsby and others, 1979). The Uinta Region contains an estimated 0.5 billion tons of coking-coal resources, ranging from premium grade medium-volatile bituminous to marginal grade medium-volatile bituminous. Much of this coking coal is of premium grade but high in methane and commonly under more than 1,000 ft of overburden. The southeastern third of the Uinta Region has produced the most desirable coke-oven feedstock in Colorado. Depth of overburden and the abnormally gassy nature of the coals have tended to retard development of the resource in this area.

More than 15 million tons of coal were produced in the Uinta Region in 1997, or more than 55 percent of the state's total output. Since the late 1880s, this important region has produced nearly 230 million tons of coal from 300 mines. This production constitutes more than 26 percent of the total for all of Colorado. Resource estimates indicate the Piceance Basin portion of the region may contain 289 billion tons of coal, or 113 billion tons at less than 6,000 ft of overburden (Tyler and others, 1996).

The three Uinta Region coal fields that are within Gunnison County are briefly discussed below. In all of these fields coal is or has been produced from the Mesaverde Formation. The ranges of analyses for each field are given in Table 6.

CARBONDALE COAL FIELD

Located at the eastern edge of the Uinta Region, primarily in Garfield and Pitkin Counties, the Carbondale field also extends slightly into Gunnison County (Figure 16). The field has been a source of high-quality coking coal from the Mesaverde Formation. In the Coal Basin area, the southern part of the field, some of the coals have been metamorphosed to high-volatile A and medium-volatile bituminous and, locally, to semi-anthracite and anthracite.

Original in-place coal resources, to a depth of 6,000 ft in the 165 sq mi area of the coal field, have been estimated at more than 5.2 billion tons (Landis, 1959).

No mines operated in the Carbondale coal field during 1997. A single mine, the Genter Mine, produced less than 7,000 tons of anthracite from the Gunnison County portion of the Carbondale coal field during an unknown period of operation.

CRESTED BUTTE COAL FIELD

This field forms the southeastern tip of the Uinta Region, near the town of Crested Butte. Much of the field lies at elevations above 10,000 ft. Coal-bearing Mesaverde strata in this area have been folded, faulted and intruded by igneous rocks. The coals range from high-volatile C bituminous to anthracite. South of the town of Crested Butte, the coals are increased in rank through metamorphism to high-volatile C and B bituminous and are of good coking quality. North and west of town, in areas of igneous activity, the coals were metamorphosed to semi-anthracite and anthracite. Coal beds vary from 2 to 14 ft (0.6 to 4.5 m) in thickness.

Original in-place coal resources to a depth of 6,000 ft in the 240 sq mi area surveyed are estimated at 1.56 billion tons (Landis, 1959). In a 35 sq mi area near the town of Crested Butte, resources are estimated at 240 million tons, of which about 15 percent are semi-anthracite or anthracite. In the remaining 155 square mi of the field to a depth of 3,000 ft, resources are estimated at 1 billion tons. About 50 additional sq mi of the field contain resources of an estimated 320 million tons at depths to 6,000 ft.

No coal was produced in the Crested Butte coal field during 1997. Thirty-three producing mines operated during the period from 1884 to 1992. Fourteen of these mines each produced more than 100,000 tons (Table 7). Total production for the field exceeds 19 million tons, primarily from the No. 1 and No. 2 seams. More than 3 million tons of anthracite were produced from the Crested Butte coal field.

SOMERSET COAL FIELD

The Somerset coal field, in Delta and Gunnison Counties, lies in a valley cut by the North Fork of the Gunnison River and its tributaries (Figure 16). The coals in this area occur in the lower Williams Fork Formation, are high-volatile B and C bituminous, and reach up to 25 ft (8 m) or more in thickness. The eastern part of the field, near the town of Somerset, contains relatively good quality coking coal. This coal, however, typically has fairly high levels of methane.

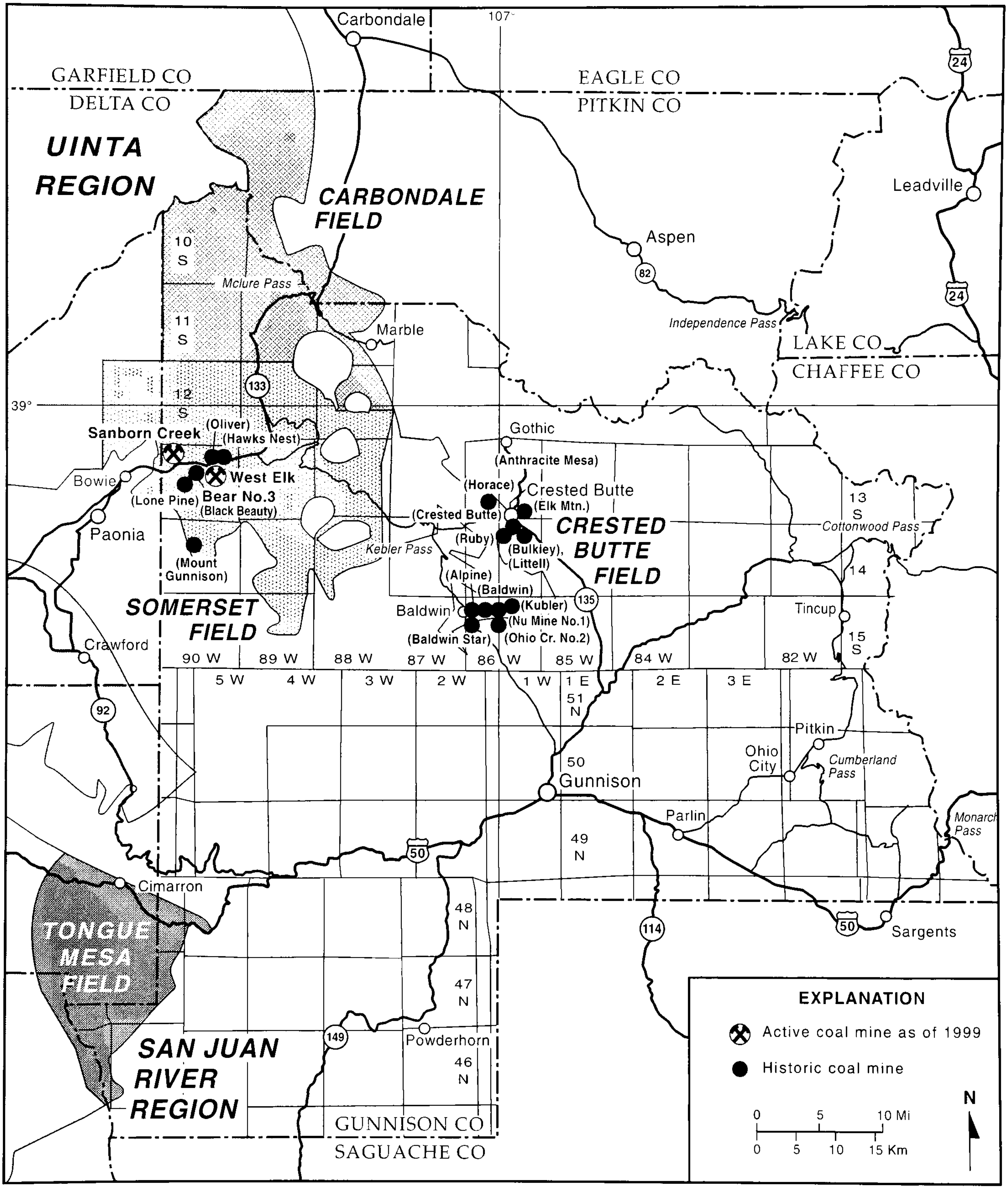


Figure 16. Map showing location of Somerset, Carbondale, Crested Butte, and Tongue Mesa coal fields, and the individual mines within Gunnison County and those fields.

In-place coal resources to a depth of 6,000 ft in a 320 sq mi area of the Somerset coal field (in both Delta and Gunnison counties) are estimated at more than 8 billion tons (Landis, 1959). A 210 sq mi area of coal up to 3,000 ft deep is estimated to be 5.5 billion tons. A 130 sq mi area is estimated to contain over 3.3 billion tons of bituminous coal, about one-half of which is high-volatile B bituminous and of good coking quality.

The Colorado Geological Survey studied two coal resources in the Somerset coal field during 1997 and 1998. The Demonstrated Reserve Base for Gunnison County, which represents coal within 0.75 mi of a data point and less than 2,000 ft in depth, was updated to an estimated 1.85 billion tons (Eakins and others, 1998a). An estimated 1.32 billion tons is considered accessible and about 55 percent, or 720 million tons, is estimated to be recoverable. The coal availability of the Somerset quadrangle, which is entirely within Gunnison County, was also studied (Eakins and others, 1998b). An estimated 2.8 billion tons of coal was originally in place, of which about 75 percent, or 2.1 billion tons, is available for development after land-use and technological restrictions are considered.

The two active Gunnison County underground mines in this field, the West Elk and Sanborn Creek Mines, produced a combined 7,322,766 tons of coal during 1997, all from the B seam. The Gunnison County production represents over 26 percent of the state's overall 1997 production. Total production for the Gunnison County portion of the coal field is approximately 75 million tons. About half of the Somerset Mine, which produced more that 31 million tons of coal, is in Delta County. (Historic production records were not segregated by county, and the entire production was attributed to Gunnison County because the mine portal is in that county). About 80 percent of the coal mined from Gunnison County was produced from the B or C seam, although the D, E and F seams have also been mined.

SAN JUAN RIVER COAL REGION

TONGUE MESA COAL FIELD

The Tongue Mesa Coal Field is an isolated erosional remnant of Upper Cretaceous sedimentary rock (equivalent to at least part of the Mesaverde Formation) capped by volcanic rocks of Late Cretaceous and early Tertiary ages. The field is located on Cimarron Ridge, about 20 mi southeast of Montrose and 8 mi east of U.S. Highway 550, straddling the Montrose County-Ouray County line (Figure 16). The coal field extends slightly into the southwestern part of Gunnison County; less than 100 sq mi area within the county.

The coals occur within a 900-ft-thick (290 m) sequence that correlates with the Kirtland-Fruitland-Pictured Cliffs formations in the San Juan Basin to the south. At least four coal beds, ranging from 2 to more than 40 ft (0.6 to 13 m) in thickness, occur on Tongue Mesa in the lower 200 ft (65 m) of the Fruitland Formation (Tremain and others, 1996). Tongue Mesa coals generally are subbituminous B in rank and often are considerably oxidized and bony. General information on Tongue Mesa coal quality is provided in Table 6.

The most persistent and the thickest coal bed, the Cimarron, and several thinner coal beds were mined underground intermittently from the 1890s until 1950. A single mine, the Cimarron Mine, operated in Gunnison County. This mine produced only about 2,500 tons of coal from 1938 to 1950.

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Table 6. Analyses of Gunnison County coals. Source: Tremain and others, 1999 (in press). For additional analytical data, see references.

Coal Field	Moisture (%)	Volatile Matter (%)	Ash (%)	Sulfur (%)	Heating Value (Btu/lb)	Ash Fusion Temperature (F)	FSI*
Carbondale (4 beds)	2.0–5.2	21.8–39.3	4.3–9.9	0.4–1.5	12,609–15,088	2,180–2,455	1–9
Crested Butte (6 beds)	2.5–13.3	33.6–41.9	3.2–9.1	0.4–1.9	11,400–14,170	2,130–2,480	0
Somerset (6 beds)	3.9–16.3	30.9–40.0	3.2–15.0	0.2–2.3	10,040–13,900	2,120–2,910+	0–4.5
Tongue Mesa (Cimarron bed)	14.2–16.0	36.0–47.3	6.7–8.4	0.5–0.9	9,350–10,200	2,450–2,480	0

*FSI– Free Swelling Index

Table 7. Coal mines producing 100,000 tons or more in the Crested Butte and Somerset Coal Fields.

Mine Name (Alternate Name)	Dates of Operation	Production (Thousand tons)	Reference/Comments
		Crested Butte Coal Field	
Alpine (Alpine Nos. 1 & 2)	1897–1946	2,200	
Anthracite Mesa (Smith)	1884–1929	1,300	Anthracite mined
Baldwin (Old) (Sunbeam)	1884–1897	297	
Baldwin Star	1896–1951	126	
Bulkley	1907–1919	580	
Bulkley No. 2	1920–1924	788	
Crested Butte Nos. 1 & 2	1884–1952	10,000	Coking coal (Jones and Murray, 1976)
Elk Mountain (New Ruby)	1919–1927	262	Anthracite mined
Horace	1909–1953	715	Anthracite mined
Kubler (New Baldwin Nu Mine No. 2)	1885–1969	506	
Littell (Porter)	1905–1918	461	Coking coal
Nu Mine No. 1	1939–1955	222	
Ohio Creek No. 2	1968–1992	119	Primarily domestic market
Ruby (Floresta No. 1)	1893–1919	825	Anthracite mined
		Somerset Coal Field	
Bear	1932–1982		Production combined with Bear No. 3 Mine
Bear No. 21	1934–1982		Production combined with Bear No. 3 Mine
Bear No. 31	1934–1996	9,107	
Black Beauty (Hawks Nest No. 3)	1951–1976	1,400	Metallurgical coal (Jones and Murray, 1976)
Hawks Nest East	1975–1982	1,992	Kelso and others, 1981 and Rushworth and others,
1984			
Hawks Nest No. 1	1931–1970	946	
Hawks Nest West	1970–1982	1,940	Kelso and others, 1981 and Rushworth and others,
1984Lone Pine (Edwards)	1934–1965	505	
Mt. Gunnison No. 1	1982–1991	4,872	Rushworth and others, 1984
Oliver No. 1 (North Fork, Oliver No. 3)	1923–1960	1,300	
Oliver No. 2	1945–1954	760	
Sanborn Creek	1992–	7,729	Zook and Tremain, 1998. Mine is operating as of 1998 Production is through 1998
Somerset	1903–1985	31,170	Mine operated in Delta and Gunnison counties Half of production from each
West Elk	1992–	36,519	Zook and Tremain, 1998. Mine is operating as of 1998 Production is through 1998

Source: Boreck and Murray, 1979, unless otherwise noted. Post-1989 production from Colorado Division of Minerals and Geology files.

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9

Petroleum Resources

GEOLOGICAL SETTING

The Piceance Basin of northwest Colorado is kidney-shaped and oriented northwest-southeast. It is about 100 mi long and 40–50 mi wide and lies within portions of seven counties; Moffat, Rio Blanco, Garfield, Mesa, Delta, Pitkin, and Gunnison. The basin is asymmetrical and deepest along its east side near the White River Uplift in central Rio Blanco County, where more than 20,000 ft of Phanerozoic sedimentary rocks are present. The southeastern margin of the basin, which lies in the northwest portion of Gunnison County, includes a maximum thickness of approximately 11,000 ft of Phanerozoic sedimentary rock.

Numerous gas fields, but only a few oil fields, have been discovered in the Piceance Basin. Exploration in the province began in the late 1880s. The first field in the basin, now called White River (T. 2 N., R. 97 W., Rio Blanco County), was discovered in 1890 and produces from sandstone in the Tertiary Wasatch Formation and Upper Cretaceous Mesaverde Formation. The oldest producing reservoir in the basin is the Permo-Pennsylvanian Weber Formation; the youngest is the Douglas Creek Member of the Green River Formation. The dominant productive interval is the Mesaverde Formation. Sandstone is the primary gas reservoir, but Mesaverde Formation coal seams also contribute a small amount of gas. Hydrocarbon entrapment within the Piceance Basin province is either entirely stratigraphic or combination of structural stratigraphic.

The largest field in the basin is Piceance Creek (T. 2 S., R. 96 W., Rio Blanco County), which has a cumulative production of 238,253,352 thousand cubic ft (Mcf) of natural gas and 143,596 barrels of oil (BO) through 1996. This field, operated by Mobil Oil Company, was discovered in 1930. Producing reservoirs in the Piceance Creek Field include the Green River Formation, Wasatch Formation, and Mesaverde Formation.

GUNNISON COUNTY EXPLORATION AND DEVELOPMENT

Oil and gas companies drilled 37 wells in Gunnison County between 1954 and 1994. All were located in the Piceance Basin structural province, which occupies about 600 sq mi of the northwestern portion of the county. The first well in the county was a 1,008 ft Cretaceous Mancos Shale test drilled by KD Drilling and Mile High Exploration in the SW¼ of the NE¼ of Sec. 8, T. 13 S., R. 89 W. This well was completed as a dry hole in July 1954. The most recent well, the 21-7 Federal, was a horizontal test into Cretaceous Mesaverde Cozzette Sandstone. The well, operated by A A Production Company, was located in the SW¼ of the NE¼ of Sec. 21, T. 10 S., R. 90 W. Its measured depth was 8,038 ft and true vertical depth was 6,022 ft. The well was completed in January 1994 as a natural gas producer, open hole from 6,136 ft to 8,038 ft. The well's initial potential was reported as 490 Mcf of gas per day with a flow tubing pressure of 1,950 lb. Historic oil and gas production for Gunnison County is shown in Table 8.

The average depth of the oil and gas well tests drilled in Gunnison County is about 4,670 ft. The deepest was a 8,450 ft Jurassic Morrison Formation test drilled in the NE¼ of the SE¼ of Sec. 11, T. 12 S., R. 90 W. This Petro-Lewis Corporation test was completed as a dry hole in January of 1972. The shallowest was the KD Drilling and Mile High Exploration 1,008 ft Cretaceous Mancos Shale test cited above as the first oil and gas test drilled in the county. Twenty-seven Gunnison County oil and gas company wells were suspended in the Cretaceous Mesaverde Formation and the associated Mancos Shale. Six wells were suspended in the either the Cretaceous Dakota or the underlying Jurassic Morrison Formation. One well was reported to be in the Jurassic Entrada at total depth and four were taken to Precambrian basement.

Three oil and gas fields have been discovered in Gunnison County. The first discovery (1964) was the three well Coal Basin field located in Sec. 7, 8. and 9, T. 11 S., R. 90 W. The Coal Basin field discovery well in Sec. 9 tested at a rate of 1,200 Mcf of gas per day from Mesaverde Formation Williams Fork Sandstone perforations (3,982–86 ft, 4,134–38 ft, 4,150–54 ft, and 4,190–94 ft). However, it was never placed in production by the operator. The second discovery (1981) was the 8 well Ragged Mountain field located in Secs. 16, 21, 30, 31, 32, 33, and 34, T. 10 S., R. 90 W. The last discovery (1991) was the two well Oil Mountain field. Oil Mountain field includes one well in Delta County and one well in Gunnison County. The Gunnison County well is located in Sec. 25, T. 10 S., R. 91 W.

Table 8. Oil and gas cumulative production in Gunnison County through 1996.

Oil	Gas	
Field Name	**Barrels**	**Thousand cu ft**
Coal Basin	1,438	456,082
Ragged Mountain	3,536	1,797,193
Oil Mountain	471	75,765
Total	5,445	2,339,040

All Gunnison County hydrocarbon production is obtained from the Cretaceous Mesaverde Cozzette and Corcoran Sandstones. Reservoir depth in the three fields averages about 6,000 ft. Gross reservoir thickness in individual wells varies from 10 to 15 ft. Porosity ranges from 10 to 14 percent and permeability of the reservoir sands is low, less than 5 millidarcies. To improve recovery of gas from these low permeability sandstones, producing wells require hydraulic fracturing. Traps in all three fields are stratigraphically controlled.

In Gunnison County through December 31, 1996 cumulative oil production was 5,445 BO and cumulative natural gas production was 2,339,040 Mcf. Thirty six of Colorado's 63 counties have produced oil and 39 have produced natural gas. At the end of 1996 Gunnison County ranked 33rd of all the counties in cumulative oil production and 31st of all the counties in natural gas production. For comparison, at the end of 1996 Rio Blanco County ranked first in cumulative oil production with 913,150,462 BO; La Plata County ranked first in cumulative natural gas production with 2,257,528,333 Mcf. Cumulative Colorado oil production thru December 31, 1996 was 1,786,893,268 BO; cumulative Colorado natural gas production totaled 8,781,037,173 Mcf. Clearly, Gunnison County up to the present time has not contributed substantially to the state's oil and gas industry.

None of the three Gunnison County fields have been fully developed because of the marginal economics of these projects. Significantly higher wellhead gas prices would be required to spur much additional development of the tight Cozzette and Corcoran reservoirs in this portion of the Piceance Basin.

Other possible plays that could prove productive in Gunnison County's portion of the Piceance Basin are stratigraphic traps in the Dakota and Morrison Formations and basin margin subthrust targets along the shared Gunnison County–Pitkin County line. These targets are in T. 9 S., R. 90 W.; T. 10 S., R. 89 W.; T. 11 S., R. 89 W.; and T. 11 S., R. 88 W.

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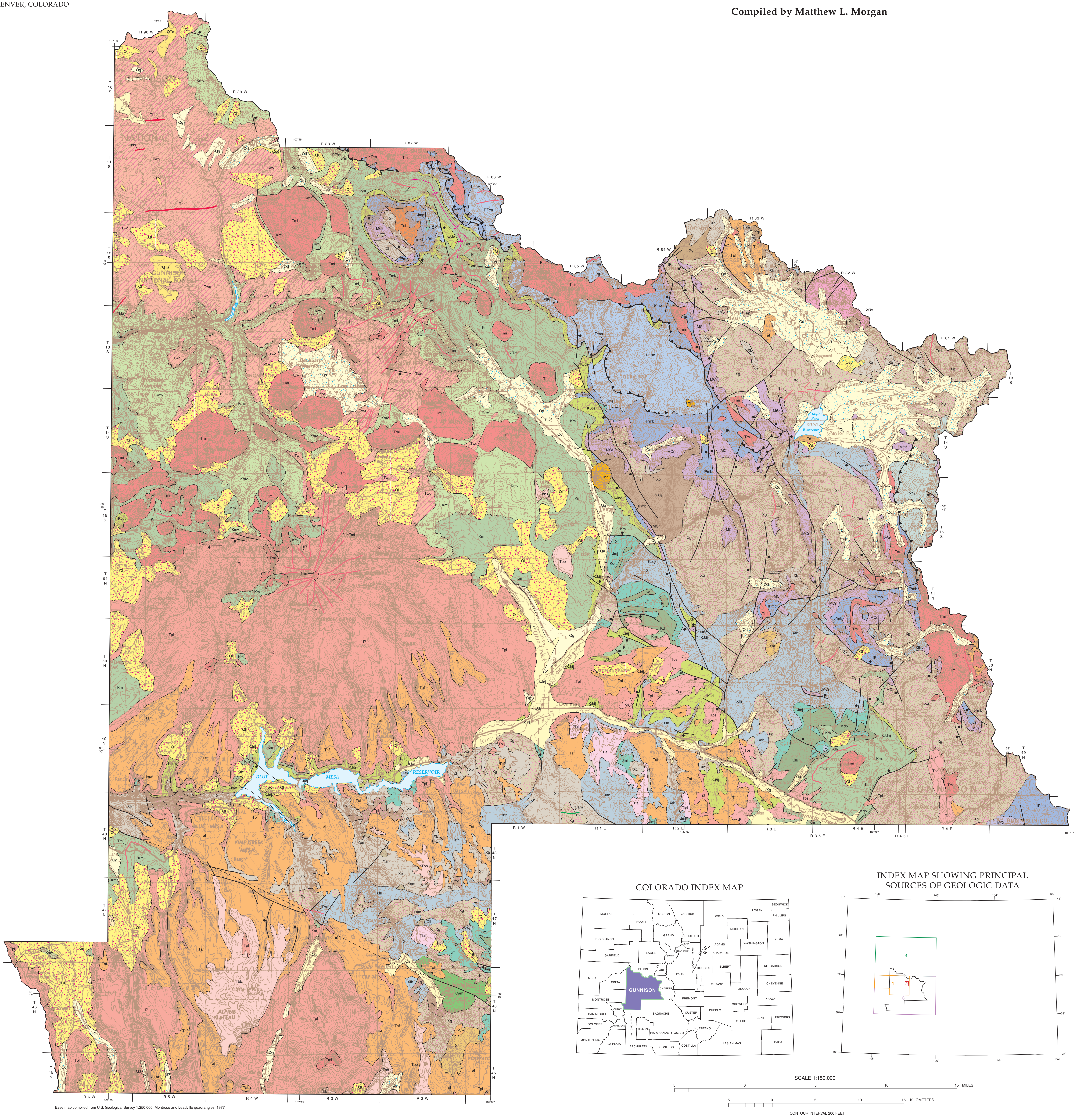
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

GEOLOGIC MAP OF GUNNISON COUNTY, COLORADO

Compiled by Matthew L. Morgan

RESOURCE SERIES 37
PLATE 1
1999



Base map compiled from U.S. Geological Survey 1:250,000, Montrose and Leadville quadrangles, 1977

COLORADO INDEX MAP

INDEX MAP SHOWING PRINCIPAL SOURCES OF GEOLOGIC DATA

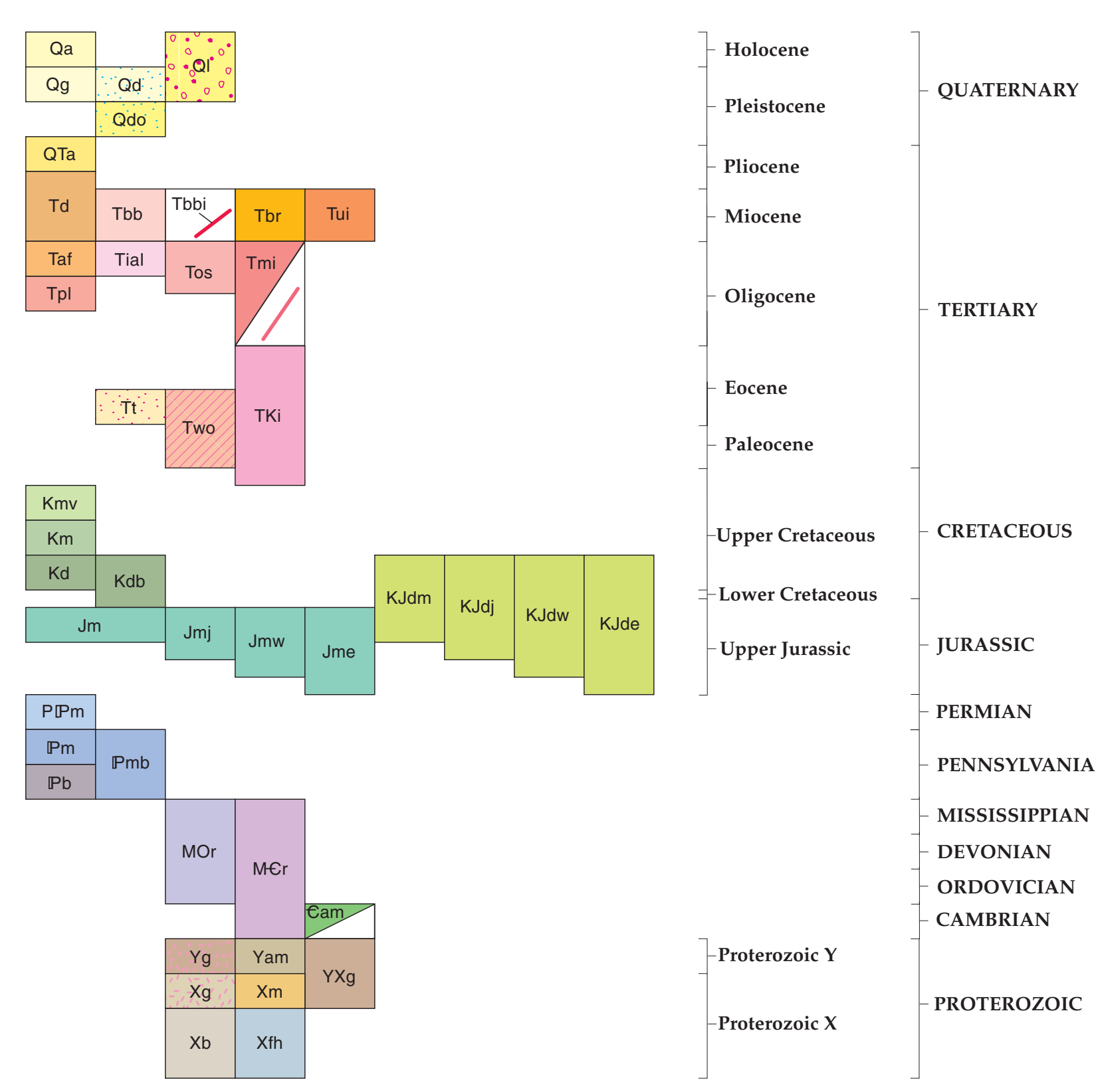
SCALE 1:150,000

5 0 5 10 15 MILES

5 0 5 10 15 KILOMETERS

CONTOUR INTERVAL 200 FEET

CORRELATION OF MAP UNITS



CONDENSED DESCRIPTION OF MAP UNITS

Refer to the text for more complete descriptions of the units.

ALLUVIAL AND COLLUVIAL DEPOSITS—Mixtures of silt, sand, gravel, and clay on debris fans, hillslopes, valley floors, and ridge lines deposited by debris flows, hyperconcentrated flows, colluvial activity, and sheetwash

Qa	**Alluvium (Holocene)**—Gravel, sand, and silt in stream valleys and alluvial fans
Qg	**Young gravels (Bull Lake and younger)**—Stream, terrace, and outwash gravels
Qd	**Young glacial drift (Bull Lake and younger)**—Unsorted, bouldery glacial deposits (till) and associated sand and gravel deposits
Qdo	**Old glacial drift (pre-Bull Lake)**—Unsorted, bouldery glacial deposits (till) and associated gravels; morainal morphology subdued or lacking
QTa	**High-level alluvium (Pleistocene and/or Pliocene)**—Bouldery alluvial deposits high above modern streams

COLLUVIAL DEPOSITS

Ql	**Landslide deposits (Holocene and Pleistocene)**—Includes some rock glaciers and talus

BEDROCK

Td	**Dry Union Formation (Pliocene and Miocene)**—Light-brown sandy siltstone and interbedded friable sandstone, conglomerate, and volcanic ash
Tbb	**Basalt of bimodal suite (Miocene)**—Dense, black, resistant, basalt lava flows 5 to 200 ft (2 to 61 m) thick, and interbedded tuffs, breccias, and volcanic conglomerates; occurs as flow remnants on Red Mountain and Flat Top Mesa, north of Gunnison and in southern Gunnison County associated with the San Juan volcanic field
Tbbi	**Basaltic intrusive dike or sill (Miocene)**—Dikes, sills, and plugs of basalt
Tbr	**Rhyolitic rocks of bimodal suite (Miocene)**—Rhyolite plugs, dikes, sills, laccoliths, and small stocks; occurs on Round Mountain in north-central Gunnison County
Tui	**Granite of Treasure Mountain (Miocene)**—Granite stock on Treasure Mountain Dome south of Marble and satellite dikes and plugs; occurs as sills and irregular bodies, age-dated at 12.5 Ma (Obradovich and others, 1969)
Taf	**Ash-flow tuff (Oligocene)**—Ash-flow tuffs from caldera sources in the San Juan Mountains and Sawatch Range; range from crystal-poor rhyolitic to crystal-rich quartz latitic rocks; degree of welding varies widely from unit to unit and with distance from source; occurs in southern Gunnison County, south of Tomichi Creek and generally south of Gunnison River except for remnants just north of Blue Mesa Reservoir area which overlie volcanic breccias of the West Elk Mountains
Tial	**Inter-ash-flow andesitic lavas and breccia (Oligocene)**—Fine-grained to porphyritic, intermediate, lavas and breccias from many local sources; occurs in southern portion of Gunnison County associated with the San Juan volcanic field
Tos	**Sedimentary deposits (Oligocene)**—Coarse gravel, boulders mantling pediment surfaces, water-laid tuffs, sands, and silts in various stratigraphic positions within the volcanic sequence of the West Elk volcanic field, constitute the Oligocene sedimentary deposits of Gunnison County. Thicknesses are variable. Unit is equivalent to Tog of Ellis and others (1987). Occurs mostly in northern Gunnison County but also includes Precambrian clast-rich sediments northwest of Parlin
Tmi	**Middle Tertiary intrusive rocks (Miocene and Oligocene)**—Granodiorite, quartz monzonite, and granite stocks, laccoliths, dikes, sills, and irregular bodies; occurs in numerous exposed laccoliths flanked by Cretaceous rocks in the West Elk Mountains, and as large plutons in the Elk Mountains
Tpl	**Pre-ash-flow andesitic lavas and breccia (Oligocene)**—Vent-facies andesite lavas and breccias from numerous volcanoes which were surrounded by coalescing aprons of volcaniclastic debris; includes extensive bodies of the West Elk Breccia, and some local units; occurs extensively in West Elk volcanic field in west-central Gunnison County and blankets ridgetops in southern Gunnison County in deposits associated with the San Juan volcanic field
TKi	**Laramide intrusive rocks (Eocene, Paleocene, and Upper Cretaceous)**—Dacitic to rhyolitic stocks, sills, and dikes associated with the Laramide orogeny; occurs exclusively in eastern Gunnison County on the west flank of the Sawatch Uplift
Tt	**Telluride Conglomerate (Eocene)**—Light-gray to red conglomerate, grit, and sandstone with lesser quantities of mudstone and shale. Maximum thickness 500 ft (150 m). Occurs in isolated outcrops in southern Gunnison County in upper drainages of Cimarron and Little Cimarron Creeks
Two	**Wasatch Formation and Ohio Creek Member (Eocene and Paleocene)**—Variegated claystone and shale with local lenses of sandstone, volcanic sandstone, and basal conglomerate. Large mudflows and landslides are common in claystone on over steepened slopes. Maximum thickness in Gunnison County is 2,000 ft (610 m) (Ellis and others, 1987)
Kmv	**Mesaverde Formation (Group), undivided (Upper Cretaceous)**—Gray to brown sandstone, siltstone, shale, and coal. Commercially important coal beds in the lower part. Maximum thickness about 2,500 ft (762 m) in northern Gunnison County (Ellis and others, 1987)
Km	**Mancos Shale (Upper Cretaceous)**—Mostly gray shale, minor sandstone, and siltstone, all of marine origin. In-cludes thin beds of sandy limestone near transition zone at the top. Lower portion time equivalent to Benton Shale of Crested Butte area (Gaskill and others, 1986). Maximum thickness 5,000 ft (1,524 m) in northern Gunnison County (Ellis and others, 1987)
Kd	**Dakota Sandstone (Upper Cretaceous)**—Light gray to brown, resistant sandstone or quartzite, minor shale, a few thin coal beds, and minor chert-pebble conglomeratic sandstone lenses near top. Thickness about 40 to 200 ft (12 to 61 m) in northern Gunnison County (Ellis and others, 1987)
Kdb	**Dakota Sandstone and Burro Canyon Formations (Cretaceous)**—Undivided; Burro Canyon is not mapped separately on Plate 1. Unit mapped predominantly east of East River by Ellis and others, (1987). Burro Canyon Formation is a light-gray sandstone; conglomeratic, chert-pebble sandstone; and light-bluish-gray to light-green claystone, shale, and siltstone. Thickness about 100 ft (30 m) in northern Gunnison County (Ellis and others, 1987). Combined unit is used here
KJdm	**Dakota Sandstone, Burro Canyon Formation, and Morrison Formation (Cretaceous and Upper Jurassic)**—Combined unit is Dakota and Morrison Formations only on Plate 1. Unit is mapped just west of East Maroon Pass in Leadville quadrangle (Tweto and others, 1978), and 2 to 4 mi east of Gunnison on the 1:100,000 scale map of Ellis and others (1987). Occurs on east flank of Tomichi Dome. Morrison Formation consists of variegated claystone, mudstone, sandstone, and siltstone with local thin limestone beds and lenses of pebble conglomerate. May include Brushy Basin Member
KJdj	**Dakota Sandstone, Burro Canyon and Morrison Formations, and Junction Creek Sandstone Member (Cretaceous to Middle Jurassic)**—Combined unit mapped in one queried outcrop just west of Gunnison on 1:100,000 scale geologic map of northern and central Gunnison County (Ellis and others, 1987). Unit is Dakota, Burro Canyon, Morrison, and Junction Creek here. These rocks occur north of Blue Mesa Reservoir, east of the mouth of the Lake Fork of the Gunnison River, the point at which all Wanakah Formation units truncate except for the Junction Creek Sandstone which persists northeast as far as Alkali Creek between Round Mountain and Flattop. Also occurs in Tomichi Creek Valley as far east as Tomichi Dome. To the west of the mouth of Lake Fork, these rocks are mapped as the combined unit (KJdw) as the entire Wanakah Formation is present
KJdw	**Dakota Sandstone, Burro Canyon, Morrison, and Wanakah Formations, undivided**—Wanakah Formation consists of interbedded gray mudstone and cherty algal limestone; Junction Creek Sandstone Member, gypsiferous mudstone and sandstone; and the Pony Express Limestone Member. Maximum thickness is less than 300 ft (90 m)
KJde	**Dakota Sandstone, Morrison Formation, and Entrada Sandstone (Upper Cretaceous and Upper to Middle Jurassic)**—Combined unit mapped on the flanks of Treasure Mountain Dome and along east side of East River as far south as the Taylor River where the Entrada Sandstone wedges out (Ellis and others, 1987). Entrada Sandstone is light gray-white, pale orange and pink cross-bedded sandstone. Unit is a maximum 100 ft (30 m) thick
Jm	**Morrison Formation (Upper Jurassic)**—Variegated claystone, mudstone, sandstone, and siltstone with local thin limestone beds and lenses of pebble conglomerate. May include Brushy Basin Member. Thickness in northern Gunnison County is 400 ft (122 m). Unit mapped separately only at 1:100,000 scale (Ellis and others, 1987). Typically part of a combined unit
Jmj	**Morrison Formation and Junction Creek Sandstone Member (Upper Jurassic)**—Combined unit occurring in abundant outcrops southeast of the Taylor River to the east of Almont and in vicinity of Tomichi Dome
Jmw	**Morrison and Wanakah Formations (Upper Jurassic)**—Combined unit occurring in Myers Gulch, tributary of the Gunnison River in the Black Canyon near west boundary of county. Wanakah Formation proper does not persist east of the mouth of Lake Fork
Jme	**Morrison Formation and Entrada Sandstone (Upper Jurassic)**—Combined unit occurring at Treasure Mountain and as far south as Taylor River. Abundant outcrops in northern Gunnison County (Ellis and others, 1987) in section upturned against White Rock pluton on south flank of White Rock Mountain. Entrada Sandstone is light gray-white, pale orange and pink cross-bedded sandstone. Unit is a maximum 100 ft (30 m) thick
PIPm	**Maroon Formation (Permian and Pennsylvanian)**—Maroon and grayish-red sandstone, conglomerate, and mudstone. Thickness greater than 9,500 ft (2,900 m) in northern map area; wedges out southward between Cement Creek and Taylor River by depositional thinning and truncation beneath pre-Entrada unconformity. Occurs in southern Elk Mountains in north-central part of county
IPm	**Minturn Formation (Middle Pennsylvanian)**—Gray, pale-yellow, and red sandstone, grit, conglomerate, and shale with rare limestone beds. Maximum preserved thickness about 4,000 ft (1,200 m) at eastern edge of county. Unit thins southward and generally pinches out at Taylor River beneath pre-Entrada unconformity; however, unit is preserved in downdropped blocks of Paleozoic rocks in eastern portion of county in Fossil Ridge area and in Tincup, Whitepine, and Quartz Creek mining districts
IPmb	**Minturn and Belden Formations (Pennsylvanian)**—Combined unit is most common. Units are broken out on flanks of Treasure Mountain Dome
IPb	**Belden Formation (Lower Pennsylvanian)**—Dark gray to black shale, carbonate rocks, and minor sandstone. Unit may include thin lenses of locally occurring reddish-purple claystone regolith of the Molas Formation. Maximum thickness in the Elk Mountains 900 ft (275 m). Occurs in southern Elk Mountains, Fossil Ridge area, and in downdropped blocks of Paleozoic rocks in the Tincup, Whitepine, and Quartz Creek mining districts. Wedges out southwestward from southern Elk Mountains due to depositional thinning and truncation beneath the pre-Entrada unconformity
MOr	**Mississippian, Devonian, and Ordovician rocks**—Consists of Leadville Limestone (Mississippian), Chaffee Group (Mississippian? and Devonian), Fremont Limestone (Ordovician), Harding Sandstone (Ordovician), and Manitou Dolomite (Ordovician) in eastern part of Gunnison County. Leadville Limestone (Mississippian) consists of gray to bluish gray lime-stone and dolomite. The Chaffee Group (Mississip-pian? and Devonian) consists of the Parting Formation—sandstone and dolomite; the Dyer Dolomite—grayish red limestone and dolomitic limestone, and the Gilman Sandstone—light gray sandstone and sandy dolomite. The Fremont Limestone (Ordovician) consists of brownish-gray limestone and dolomitic limestone. The Harding Sandstone consists of gray to white, fine-grained sandstone. The Manitou Dolomite consists of gray dolomite. Combined maximum thick-ness of formations 860 ft (280 m)
M€r	**Mississippian, Devonian, Ordovician, and Cambrian rocks**—Occurs in many areas in eastern Gunnison County, combined unit includes entire lower Paleozoic sequence. Cambrian rocks include the Sawatch Quartzite—a white medium-grained orthoquartzite and conglomerate
€am	**Cambrian alkalic and mafic intrusive rocks (Cambrian)**—Includes alkalic complex at Iron Hill near Powderhorn and diabase dikes along trend of Cimmarron and Red Rocks faults. Powderhorn alkalic complex includes nepheline syenite, uncompahgrite, ijolite, and carbonatite
€am	Dike
Yg	**Granitic rocks (Proterozoic Y, ± 1,400 Ma)**—Includes Vernal Mesa and Curecanti Quartz Monzonite and equivalent rocks
Yam	**Alkalic and mafic rocks (Proterozic Y)**—In northwest-trending line of small plutons near Cebolla Creek
YXg	**Proterozoic Y and Proterozoic X, Undivided**—Includes granite of problematic age along Spring Creek north of Taylor River, and areas of mixed 1,400 and 1,700 Ma granites
Xg	**Granitic rocks (Proterozoic X, ± 1,700 Ma)**—Includes Den-ney Creek Granodiorite Gneiss, Kroenke Granodiorite, Pitts Meadow Granodiorite, Browns Pass Quartz Mon-zonite, and rocks previously mapped as Pikes Peak and Silver Plume Granites in Garfield quadrangle, and related rocks
Xm	**Mafic intrusive rocks (Proterozoic X)**—Gabbro and mafic diorites and monzonites in small plutons
Xb	**Biotite gneiss and migmatite (Proterozoic X)**—Dominantly biotite gneiss with minor interlayered hornblende gneiss and calc-silicate rocks and, in places, much pegmatite
Xfh	**Interlayered felsic and horhblende gneiss (Proterozoic X)**—Includes metarhyolites, metabasalts, and interbedded metagraywackes as well as more highly metamorphosed gneisses

MAP SYMBOLS

—	**Contact**
┴	**Fault**—Dashed where approximately located; dotted where concealed; ball and bar on downthrown side
▲▲	**Thrust fault**—Dotted where concealed; sawteeth on upper plate
┼	**Syncline** —Showing axial trace

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(See Data Sources Index Map)

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