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Geology and Ore Deposits of the Uncompahgre (Ouray) Mining District, Southwestern Colorado

Professional Paper 1753

U.S. Department of the Interior
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On the cover: View looking south along the Uncompahgre River valley, one of the few passageways into and through the mountainous terrain of the western San Juan Mountains region of southwestern Colorado. In the foreground is a broad, gently south-sloping bench along this part of the river valley; the bench surface is about 200 to 300 feet above the ranch lands beyond and to the right in the flat-bottomed, glacier-carved valley. The town of Ouray (about 7,800 feet altitude), just visible through the narrow, cliff-edged, V-shaped gap in the valley, is situated in a picturesque mountain park at the confluence of the Uncompahgre River and Canyon Creek valleys and is almost surrounded by mountains towering to as much as 13,500 feet. Because of its setting and scenic splendor, the town and environs are aptly referred to as the "Switzerland of America." The Uncompahgre River can be traced southward through the narrow, deep gorge and continues to the left of Abrams Mountain (12,801 feet) in the distant center. U.S. Highway 550, known locally as the "Million Dollar Highway" south of Ouray, parallels the Uncompahgre River valley to connect Ouray with Montrose to the north and extends through the gorge and other canyons and mountain passes to connect Ouray with Silverton and Durango to the south. The many mines and prospects that constitute the Uncompahgre mining district are located mostly within the cliffy slopes surrounding the town of Ouray. From Atwood, W.W., and Mather, K.F., 1932, U.S. Geological Survey Professional Paper 166, plate 34B; photograph attributed to Whitman Cross, August 1904.

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Preface

Field studies in the Uncompahgre mining district were started by Wilbur S. Burbank in 1928 and a preliminary, incomplete manuscript prepared by the mid-1930s. Because the mining district was part of a larger regional study of the western San Juan Mountains in southwestern Colorado, field studies progressed without hesitation into the adjacent areas. This manuscript was postponed by commitments to studies on the adjacent areas, strategic mineral studies during and after World War II, and various administrative duties. Consequently, only a few short reports pertinent to the district were released during this time. I joined Wilbur in 1956, and we continued the studies of the adjacent areas, although we did publish the geologic map of the Ouray 7.5-min quadrangle. Shortly before his death in 1975, Wilbur asked me to help him complete the mining district report. Unfortunately, I had other commitments in addition to completing studies of the adjacent areas for the next few years. But finally, I added a few chapters and edited the entire manuscript, which necessitated some modification and (or) elimination of material as being incomplete or out-of-date. However, Wilbur's observations and interpretations have been retained as much as possible and are presented here to show the breadth of his understanding of the problems at the time of his study and the first, original writing. The basis of this report, dominantly Wilbur's work, essentially now represents our joint efforts.

Robert G. Luedke
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Reston, VA 20192
January 2008

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Plates

[in pocket]

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Geology and Ore Deposits of the Uncompahgre (Ouray) Mining District, Southwestern Colorado

By Wilbur S. Burbank[1] and Robert G. Luedke

Abstract

The Uncompahgre mining district, part of the Ouray mining district, includes an area of about 15 square miles (mi^2) on the northwestern flank of the San Juan Mountains in southwestern Colorado from which ores of gold, silver, copper, lead, and zinc have had a gross value of $14 to 15 million.

Bedrock within the district ranges in age from Proterozoic to Cenozoic. The oldest or basement rocks, the Uncompahgre Formation of Proterozoic age, consist of metamorphic quartzite and slate and are exposed in a small erosional window in the southern part of the district. Overlying those rocks with a profound angular unconformity are Paleozoic marine sedimentary rocks consisting mostly of limestones and dolomites and some shale and sandstone that are assigned to the Elbert Formation and Ouray Limestone, both of Devonian age, and the Leadville Limestone of Mississippian age. These units are, in turn, overlain by rocks of marine transitional to continental origin that are assigned to the Molas and Hermosa Formations of Pennsylvanian age and the Cutler Formation of Permian age; these three formations are composed predominantly of conglomerates, sandstones, and shales that contain interbedded fossiliferous limestones within the lower two-thirds of the sequence.

The overlying Mesozoic strata rest also on a pronounced angular unconformity upon the Paleozoic section. This thick Mesozoic section, of which much of the upper part was eroded before the region was covered by rocks of Tertiary age, consists of the Dolores Formation of Triassic age, the Entrada Sandstone, Wanakah Formation, and Morrison Formation all of Jurassic age, and the Dakota Sandstone and Mancos Shale of Cretaceous age. These strata dominantly consist of shales, mudstones, and sandstones and minor limestones, breccias, and conglomerates.

In early Tertiary time the region was beveled by erosion and then covered by a thick deposit of volcanic rocks of mid-Tertiary age. These volcanic rocks, assigned to the San Juan Formation, are chiefly tuff breccias of intermediate composition, which were deposited as extensive volcaniclastic aprons around volcanic centers to the east and south of the area.

The Ouray area, in general, exhibits the typical effects of a minimum of three major uplifts of the ancestral San Juan Mountains. The earliest of these uplifts, with accompanying deformation and erosion, occurred within the Proterozoic, and the other two occurred at the close, respectively, of the Paleozoic and Mesozoic. The last event, known as the Laramide orogeny, locally was accompanied by extensive intrusion of igneous rocks of dominantly intermediate composition. Domal uplifts of the ancestral mountains resulted in peripheral monoclinal folds, plunging anticlines radial to the central core of the mountain mass, faults, and minor folds.

The principal ore deposits of the Uncompahgre district were associated with crosscutting and laccolithic intrusions of porphyritic granodiorite formed during the Laramide (Late Cretaceous to early Tertiary) orogeny. The ores were deposited chiefly in the Paleozoic and Mesozoic sedimentary strata having an aggregate thickness of about 4,500 feet (ft) and occur beneath the early Tertiary unconformity, which in places truncated some of the uppermost deposits. A few ore deposits of late Tertiary age occur also in the sedimentary rocks near the southern margin of the district, but are restricted mostly to the overlying volcanic rocks. Ore deposits in the Uncompahgre district range from low-grade, contact-metamorphic through pyritic base-metal bodies containing silver and gold tellurides and native gold to silver-bearing lead-zinc deposits, and are zoned about the center of intrusive activity, a stock in an area referred to as The Blowout.

Ore deposition within the Uncompahgre district was largely controlled by structural trends and axes of uplift established mainly in the late Paleozoic phase of deformation, but also in part by structural lines established in Proterozoic time. Movement on these older structural lineaments was renewed and accentuated by deformation during the Laramide orogeny at the time of the igneous intrusions. There are two main structural axes in the district: (1) a north-northwest-trending axis of uplift, called the Uncompahgre axis, which extends outward from the margin of the mountains, and (2) an intrusive axis of northeastward trend which roughly parallels that of the Paleozoic and Mesozoic mountain-front monoclinal uplifts, respectively, within and north of the district. The two axes intersect near the center of eruptive activity and divide the district into four structural sectors, north, west, south, and east, within which conditions of mineralization varied in

[1]Deceased.

accordance to their relation to the structural axes and to the intrusive center.

Sources of the ore-forming fluids lie along the northeast-trending intrusive zone and appear to be related genetically to the igneous rocks. The fluids evidently rose from depth along the line of the intrusive zone toward the Uncompahgre axis of uplift, and then moved laterally outward into the sedimentary formations in paths that generally conformed to the dip of the strata. Along the Uncompahgre axis the fluids gained access to shallow tensional breaks that permitted their escape more directly upward toward the surface. Most of the channels of mineralization along bedding in the sedimentary rocks and in fractures trend eastward or somewhat diagonal to the strike and appear to have been controlled, in general, by the predominant directions of fracturing or flexing of the rocks.

Contact-metamorphic deposits and most of the pyritic gold-bearing deposits lie in the central parts of the district, within a mile or less of the crossing of the axes and of the main crosscutting eruptive vent. The silver-lead-zinc deposits, which are from 1 to 4 mi from the crossing of the axes, were found chiefly in the northern and southern sectors of the district, inasmuch as the bulk of the fluids that formed this type of ore followed the most direct east-west paths from the high-pressure zones along the intrusive axis to the low-pressure zones along the Uncompahgre axis of uplift. The eastern and western sectors of the district do not contain appreciably large deposits of silver-lead-zinc ore. In addition to the above, the ore deposits also include both tabular bodies and shoots of less regular shape that lie more or less conformably within the bedding and fractures. Different forms of deposits are closely associated in many places.

Ore deposition was controlled by nearness to the intrusive contacts, nearness to zones of shallow tensional fractures, prevailing directions of faults, folds, and fractures in the sedimentary rocks, and the permeability and other physical or chemical properties of the rocks.

The largest and highest grade deposits, most of which are in the northern sector of the district, were either mostly developed or nearly exhausted at the time of our studies; these higher grade deposits occurred in a zone near the Uncompahgre axis of uplift. The Uncompahgre River valley, which follows this axial line, also exposed the mineralized rocks to the best advantage for mining operations. The northern and southern sectors of the district are the most likely to be the sites of any discoveries of new ore channels and to disclose any longer extensions of known ore channels. Future exploration consequently should be directed toward the probable sources of the mineralizing fluids and away from the Uncompahgre axis into zones in which higher temperature mineralization would have prevailed and lower grade deposits were formed.

The ore deposits of late Tertiary age are chiefly silver-lead-zinc veins, principally in the volcanic rocks. Their related centers of mineralization are to the south of the Uncompahgre district. Sedimentary rocks along the south margin of the district, however, do contain a few ore deposits of late Tertiary age, but in general, the younger veins are absent in the northern parts of the district.

Introduction

The Uncompahgre district is a part of the more extensive Ouray mining district and is located at the northwestern edge of the rugged San Juan Mountains, a dominantly volcanic mountain mass occupying much of southwestern Colorado. The district covers an area of about 15 mi^2 in the south-central part of Ouray County (fig. 1) that includes the valley of the Uncompahgre River at and north of the town of Ouray, located in the southern part of the district. The region enclosing the district, near the northwest escarpment of the mountains bordering the adjacent Colorado Plateau country to the north and west, is characterized by high peaks, precipitous slopes, and narrow, deeply incised valleys.

Ouray, the county seat and commercial center for the Uncompahgre and nearby mining districts to the south, is nestled in a mountain park at the junction of the Uncompahgre River and Canyon Creek at an altitude of 7,800 ft (fig. 2). At the southwest edge of town, both streams above their confluence are entrenched in deep, vertical-walled canyons; that in Canyon Creek is a local scenic attraction called Box Canyon. Cliffs tower above the town but recede to the east into The Amphitheater, a large cirque-like or steeply backed bowl-shaped basin. Because of its picturesque mountain setting, the town and environs have appropriately been referred to as the “Switzerland of America.” U.S. Highway 550, which south of town in the Uncompahgre River gorge is known as the Million Dollar Highway, is the principal access route into and out of the area; this highway connects Ouray with Montrose to the north and, across the San Juan Mountains via Silverton, with Durango to the south. A few secondary roads and trails provide access to the remainder of the district. Now serviced by motor freight, Ouray was formerly the southern terminus of a narrow-gauge branch line of the Denver and Rio Grande Western Railroad that extended southward from Montrose.

Commercial development of the mining district was controlled to a very large extent by the physical features of the valley of the Uncompahgre River, one of the major drainage systems in the western San Juan region, which traverses northwestward through the heart of this mineralized area. The river valley to the north is large and broadly U-shaped in profile, characteristic of many valleys in the glaciated western San Juan Mountains region. However, approaching Ouray from the north, the valley narrows and the precipitous canyon walls carved into sedimentary rocks rise about 1,400 ft above the gravelly river bottom as cliffy, step-like slopes to an altitude of about 9,000 ft; the valley sides above that altitude consist generally of somewhat more gentle slopes that are surmounted by still higher pinnacled and jagged cliffs. Ranging from an altitude of about 7,260 ft in the river bottom at the north edge to 12,275 ft on the eastern edge, total relief within the district

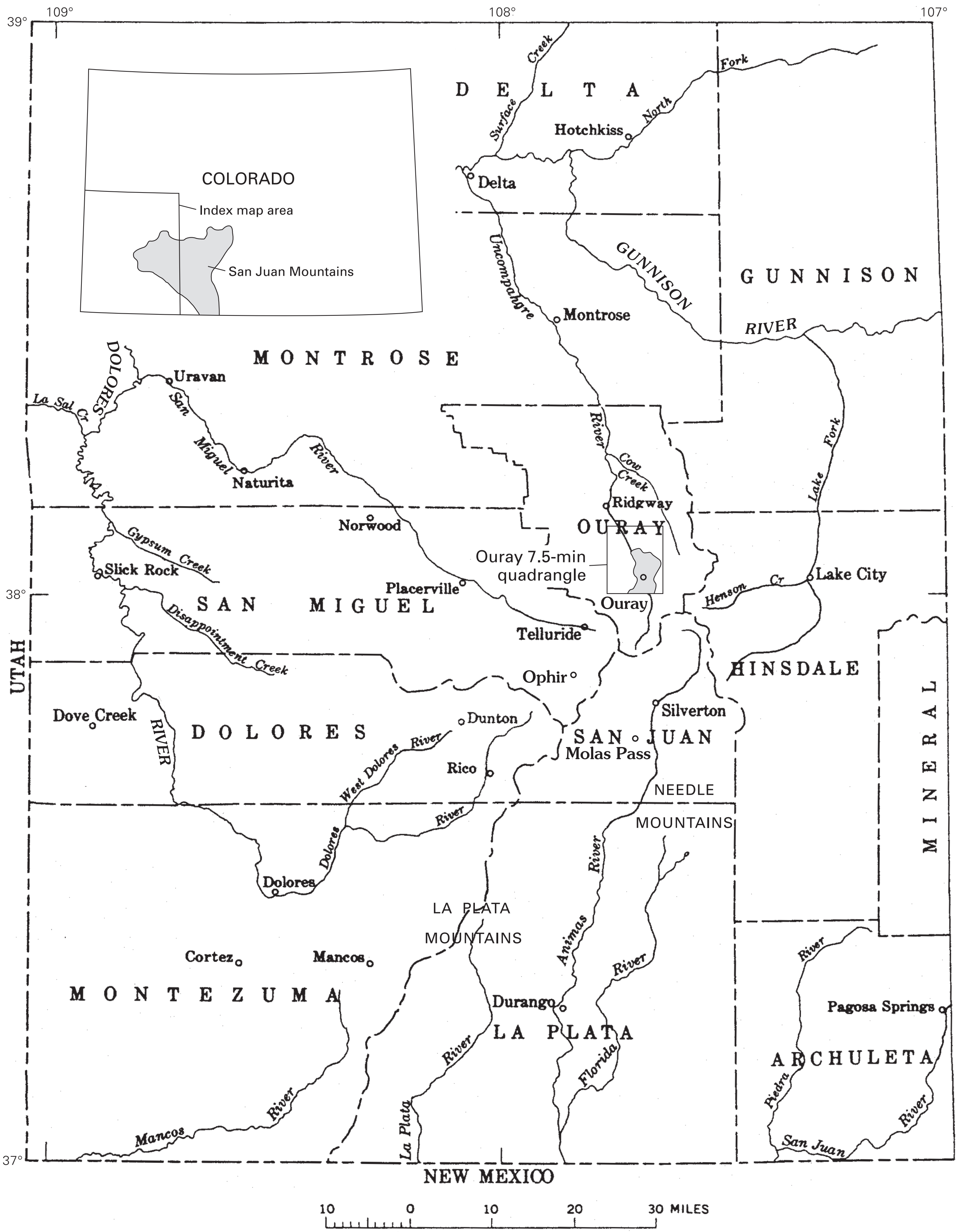

Figure 1. Index map showing the location of the Uncompahgre (Ouray) mining district (shaded) within the Ouray 7.5-min quadrangle and surrounding region in the western San Juan Mountains of southwestern Colorado.

Figure 2. View looking south at the town of Ouray (average altitude 7,800 ft) nestled in a mountain park at the base of Hayden Mountain and at the confluence of the canyons of the Uncompahgre River (left) and Canyon Creek (right). Rocks exposed at town level and on the lower slopes are predominantly sedimentary; those in the higher precipitous mountains surrounding the town site are mainly volcanic. Altitude of the mountain crests on the skyline ranges from 12,500 to more than 13,000 ft.

is about 5,000 ft. Altitudes just beyond the area to the west, south, and east reach 13,500 ft.

The district is subject to a wide variation in climatic conditions because of its location on the flank of the mountains and because of the considerable topographic relief within the region. Summers are short and relatively cool, whereas winters are long but seldom severe. Minimum temperatures of several degrees below 0°F may occur in winter months, but not for long duration, and maximum temperatures in the summer rarely exceed 90°F. Typical of mountainous areas, precipitation occurs as rain in the summer and snow, sometimes heavy, in the winter; afternoon thunderstorms are common in July and August and cease with the first heavy frost or snowstorm, which usually occurs before the end of September. Ice and snow in the winter, snowslides in early spring, and flash floods or debris flows (Jochim, 1986) in the summer are seasonal weather hazards.

Timber and vegetation growth vary as might be expected in accordance with variations of location and altitude. Scrub oak, piñon, and juniper are common on lower slopes of the district, especially in the northern part. Cottonwood and willow grow along the waterways, and aspen, pine, fir, and spruce on the higher mountain slopes. Most of the district is below timberline, which, depending upon exposure, averages about 11,500 ft in altitude.

Although limited geologic examinations of the region were made by the earlier Hayden Surveys, not until the late 1800s and early 1900s were more comprehensive geologic studies made. These include the Ouray 15-min quadrangle (Cross and others, 1907). The areal geology, with revisions and at a smaller scale, was incorporated into a preliminary report on the entire San Juan Mountains region (Cross and Larsen, 1935) and later into a more complete geologic and petrologic report on the same region (Larsen and Cross, 1956). A resurvey of the mineral resources in areas and (or) mining districts, including the Uncompahgre, of the western San Juan Mountains region was begun in the late 1920s by Burbank (1930, 1936, 1940, 1941, 1947), and in the late 1930s by Kelley (1946). Much of that material was included as part of a later study, begun in 1956, of quadrangle mapping in the northwestern part of the San Juan Mountains. The geologic map of the Ouray 7.5-min quadrangle at a scale of 1:24,000 (Luedke and Burbank, 1962) was the first of those maps prepared in cooperation with the Colorado State Metal Mining Fund Board. A more detailed geologic map of only the Uncompahgre mining district at a scale of 1:12,000 was subsequently completed and published (Luedke and Burbank, 1981). Copies of these two maps are recommended for at-hand reference, but if not available, the illustrations included herein should suffice in showing locations, distribution of major rock units, structure, and other features pertinent to the discussion. A later geologic and mineral resources appraisal of the mining district and surrounding Uncompahgre Primitive Area was made by Fischer and others (1968) and Steven and others (1977) to determine the area's suitability for incorporation into the National Wilderness Preservation System.

Acknowledgment is gratefully extended to property owners and mine operators for permitting access to mines and use of data, and to the many individuals in the area for their generous cooperation in providing information on previous and current mining operations. Assistance in the field was given by M.G. Barclay, F.G. Wells, R.A. Yund, and T.H. Foss. D. Paul Mathieux provided invaluable instruction and assistance in the digital preparation of the illustrations.

History and Production

Limited prospecting was done throughout the San Juan Mountains region beginning about 1860, but not until the spring of 1874, upon completion of negotiations of a treaty between the Ute Indians and the Federal Government, was the western part of the region officially opened to prospecting and settlement (Burbank and Luedke, 1968). In the rush to the western San Juans, prospectors came into the Ouray area supposedly not from the north along the more easily accessible Uncompahgre River valley but from the south through the rugged mountains. The lure of mineral wealth resulted in a rapid increase in population, so that the need for a community to service and supply the area was soon realized. A permanent mining camp was established in 1875, and within a very short time the camp became a town and was platted and soon incorporated. Aside from conflicting information concerning who founded the town, it was first called Uncompahgre City; the name was later changed to Ouray in honor of Chief Ouray, leader of the Uncompahgre Ute Indians. By 1880, the town of Ouray had about 900 inhabitants and was an important supply center to the adjacent mining regions (Strahan, 1881). The town continued to prosper and grow through its early years and, typical of most mining communities, had its "boom and bust" periods. Today, with mining activities at an ebb, it serves as an important hub for tourism. For more comprehensive discussions on the early history of the town and its environs, consult the accounts of Wolle (1949), Dorset (1970), Benham (1976), and Rice (1980).

Ouray County, organized in 1883 and reportedly the first county created following Colorado statehood (Dawson, 1954), is divided into several mining districts. The Uncompahgre mining district is part of the larger, all-inclusive Ouray district. The principal ore deposits of the Uncompahgre district have been found in the sedimentary strata exposed along the walls of the Uncompahgre River valley to a maximum altitude of about 10,000 ft, and east and west of the main valley in several tributary canyons; the more productive deposits have all been within 4 mi of town, mostly to the north. Most mine workings are entered by adits situated on the slopes or steep walls of the canyons. The local high relief favored this type of mine development and, also, the use of aerial tramways to transport ore to the valley bottoms from cliffy locations otherwise inaccessible except by pack-animal trails. The local physical relief, as it affected accessibility, as well as the regional climatic conditions were very important locally in the evaluation of a mine or prospect. Production data of precious and base metals for both Ouray County and the Uncompahgre mining district are given in tables 1 and 2, respectively, and are compared geographically in figure 3.

The Trout and Fisherman claim near Box Canyon, one of the earliest mining properties in the area, was staked by men who had come into the area with the original intent to hunt and fish. During the summer of 1875 (Henderson, 1926, p. 54), the Grand View claim north of Ouray was located, registered, and patented. Soon, other gold-bearing lodes were located in the canyon walls within sight of town, and, by 1877, silver-lead deposits were discovered in the limestone benches southwest of town. Although most prospecting was limited by weather to late spring and summer, many claims had been staked and mines started by the late 1870s and early 1880s. Progress associated with mining in the district was slow at first "…because of its remoteness from competing markets, want of local facilities for reduction of ores, and extravagantly high rates for freight. No ores yielding less than $150 to $200 per ton will pay for shipping…" (U.S. Bureau of the Mint, 1882, p. 419). Only a few mines were shipping because of the normally low grade of ore.

During the 1880s, a few deposits of high-grade gold and high-grade silver-lead ores were discovered and subsequently mined. Among mines in this group was the Calliope in the valley of Dexter Creek, which was brought into production in 1887 and, prior to 1890, yielded ore valued at several hundred thousand dollars. The discovery of very rich gold ore high on the north wall of The Blowout at the American Nettie mine in 1889 resulted in rapid development of this and adjoining gold properties, which together yielded subsequently the bulk of the gold production of the district. The principal body of silver ore within the Bachelor mine, also located in the valley of Dexter Creek, was not discovered until 1892, but by about 1895 at the peak of its activity, the production and profit over a period of about two years had exceeded that of any other mine in the district; during that period the mine had a total production of more than $3 million.

The mining industry in the Uncompahgre district kept pace with that of the neighboring districts in attempts to treat lower grade base-metal ores, and to search for additional shoots of high-grade gold- and silver-bearing ores. Gradual improvements in milling techniques through concentration and amalgamation and the operation of several local smelters all facilitated a more profitable handling of the lower grade ores. A number of mines had their own mills, but a considerable proportion of the base-metal ores of the district was treated at several different custom mills. One of the more important of these after 1930 was the 120-ton-per-day Banner American custom flotation mill north of Ouray, which permitted a continuous small production of silver-lead-zinc ore to be treated through the period of World War II.

In the early days of mining, pack animals were used to carry most of the equipment and supplies to the surrounding mines and the ore down to the smelters in Ouray. With time, trails were widened and a few roads were built that lowered transportation costs; because the ore was brought out by wagons instead of by pack animals, lower grade ores could be handled more profitably. By 1882, the narrow-gauge Denver and Rio Grande Western Railroad had been constructed to within 30 mi of Ouray and was expected to reach the town the following summer, but that extension was not completed until 1887. Otto Mears was responsible for extending the railroad

Table 1. Ouray County mine production of gold, silver, copper, lead, and zinc in terms of recovered metals, 1878–1986, inclusive.

[Production figures, some estimated, were calculated for 1878–1923 and are from Henderson (1926, p. 186); for 1924–1931 from "Mineral Resources of the United States" (U.S. Bureau of Mines, 1927–1934); and for 1932–1986 from "Minerals Yearbook" (U.S. Bureau of Mines, 1933–1988). No data for 1957; data for 1967, 1970, and 1979–1985 are withheld to avoid disclosing company proprietary data. s.t., short tons; --, zero]

Year	Gold		Silver		Copper		Lead		Zinc		Total value (dollars)
	Quantity[1] (ounces)	Value (dollars)	Quantity[1] (ounces)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	
1878	242	5,000	38,672	44,473	--	--	--	--	--	--	49,473
1879	411	8,500	38,672	43,313	--	--	99	8,150	--	--	59,963
1880	411	8,500	69,610	80,052	--	--	100	10,000	--	--	98,552
1881	2,661	55,000	85,078	96,138	50	18,200	115	11,040	--	--	180,378
1882	3,386	70,000	77,344	88,172	250	95,500	115	11,270	--	--	264,942
1883	967	20,000	386,719	429,258	200	66,000	585	50,310	--	--	565,568
1884	508	10,500	572,344	635,302	182	47,206	1,500	111,000	--	--	804,008
1885	484	10,000	900,000	963,000	200	43,200	2,200	171,600	--	--	1,187,800
1886	1,270	26,241	993,867	983,928	200	44,400	1,604	147,568	--	--	1,202,137
1887	1,106	22,853	952,255	933,210	333	91,908	1,334	120,066	--	--	1,168,037
1888	1,175	24,289	789,396	742,032	290	97,289	1,630	143,436	--	--	1,007,046
1889	1,279	26,436	913,254	858,459	199	53,704	2,352	183,466	--	--	1,122,065
1890	17,083	353,133	2,791,626	2,931,207	333	103,858	2,114	190,296	--	--	3,578,494
1891	23,160	478,750	2,273,054	2,250,323	433	110,726	2,084	179,262	--	--	3,019,061
1892	6,709	138,688	754,114	656,079	319	74,109	4,006	320,509	--	--	1,189,385
1893	9,136	188,854	1,221,155	952,501	300	64,800	4,000	296,000	--	--	1,502,155
1894	8,617	178,138	995,153	626,946	300	57,000	2,211	145,926	--	--	1,008,010
1895	8,355	172,697	1,515,693	985,200	300	64,200	2,874	183,904	--	--	1,406,001
1896	6,824	141,046	2,371,912	1,612,900	109	23,469	3,300	197,974	--	--	1,975,389
1897	26,746	552,840	2,776,394	1,665,836	1,093	262,210	3,892	280,232	--	--	2,761,118
1898	41,246	852,555	1,420,330	837,995	518	128,410	1,400	106,398	--	--	1,925,358
1899	82,000	1,694,940	2,346,194	1,407,716	153	52,185	3,778	340,037	--	--	3,494,878
1900	69,565	1,437,909	1,985,267	1,230,866	176	58,493	4,739	417,061	10	880	3,145,209
1901	74,810	1,546,323	1,633,725	980,235	326	109,040	3,952	339,903	--	--	2,975,501
1902	117,113	2,420,726	789,855	418,623	264	64,238	2,131	174,745	--	--	3,078,332
1903	105,056	2,171,508	417,343	225,365	190	52,116	1,675	140,724	--	--	2,589,713
1904	105,194	2,174,361	294,028	170,536	216	55,174	1,022	87,915	3	256	2,488,242
1905	112,882	2,333,282	758,107	462,445	262	81,775	2,674	251,368	24	2,848	3,131,718
1906	48,001	992,179	916,256	623,054	331	127,787	2,861	326,131	5	633	2,069,784
1907	116,838	2,415,049	352,519	232,663	454	181,735	1,803[2]	191,155	15	1,794	3,022,396
1908	98,147	2,028,698	415,070	219,987	510	134,584	1,517	127,401	--	--	2,510,670
1909	147,306	3,044,825	345,815	179,824	492	127,955	1,407	120,999	10	1,034	3,474,637
1910	106,234	2,195,847	414,250	223,695	310	78,770	2,002	176,208	--	--	2,674,520
1911	94,483	1,952,958	512,800	271,784	282	70,534	1,975	177,742	--	--	2,473,018
1912	50,778	1,049,590	545,177	335,284	200	66,091	1,495	134,507	70	9,706	1,595,178
1913	46,414	959,377	537,634	324,731	250	77,551	1,090	95,946	100	11,224	1,468,829
1914	58,635	1,211,993	594,289	328,642	427	113,587	1,060	82,663	22	2,275	1,739,160
1915	54,089	1,118,016	576,621	292,347	432	151,174	995	93,562	4	903	1,656,002
1916	23,763	491,175	803,461	528,677	222	109,244	1,170	161,393	35	9,248	1,299,737
1917	4,491	92,831	868,097	715,312	90	49,018	1,016	174,728	266	54,345	1,086,234
1918	5,208	107,645	801,359	801,359	77	37,820	1,294	183,742	20	3,576	1,134,142
1919	4,467	92,338	627,659	702,978	56	20,867	891	94,492	12	1,704	912,379

Table 1. Ouray County mine production of gold, silver, copper, lead, and zinc in terms of recovered metals, 1878–1986, inclusive.—Continued

[Production figures, some estimated, were calculated for 1878–1923 and are from Henderson (1926, p. 186); for 1924–1931 from "Mineral Resources of the United States" (U.S. Bureau of Mines, 1927–1934); and for 1932–1986 from "Minerals Yearbook" (U.S. Bureau of Mines, 1933–1988). No data for 1957; data for 1967, 1970, and 1979–1985 are withheld to avoid disclosing company proprietary data. s.t., short tons; --, zero]

Year	Gold		Silver		Copper		Lead		Zinc		Total value (dollars)
	Quantity[1] (ounces)	Value (dollars)	Quantity[1] (ounces)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	
1920	1,634	33,777	465,577	507,479	43	15,986	617	106,766	--	--	664,008
1921	3,543	73,229	730,970	730,970	43	10,970	604	54,378	--	--	869,547
1922	6,094	125,960	1,226,670	1,226,670	29	7,850	742	81,649	--	--	1,442,129
1923	2,864	59,207	840,044	688,836	22	6,497	769	107,662	--	--	862,202
1924	659	13,625	166,345	111,451	5	1,279	406	64,913	--	--	191,268
1925	675	13,962	35,934	24,938	100	28,258	191	33,234	42	6,308	106,700
1926	2,121	43,853	111,181	69,377	102	28,658	306	48,976	67	10,050	200,914
1927	1,311	27,106	79,291	44,958	43	11,228	145	18,315	47	5,952	107,559
1928	12,909	266,853	48,007	28,084	25	7,306	51	5,875	--	--	308,118
1929	17,831	368,598	20,683	11,024	27	9,358	51	6,478	--	--	395,458
1930	7,226	149,384	18,122	6,977	13	3,380	86	8,550	--	--	168,291
1931	9,760	201,764	40,586	11,770	37	6,673	184	13,618	--	--	233,825
1932	12,478	257,949	47,780	13,474	45	5,670	157	9,420	4	240	286,753
1933	9,255	191,323	53,323	18,663	81	10,336	140	10,375	--	--	230,697
1934	8,159	285,163	109,853	71,016	106	16,936	216	15,947	--	--	389,062
1935	12,520	438,201	226,183	162,569	127	20,999	429	34,288	11	968	657,025
1936	8,979	314,272	406,244	314,636	125	23,046	705	64,860	--	--	716,814
1937	19,176	356,167	182,389	141,078	242	58,443	481	56,758	13	1,625	614,071
1938	12,761	446,621	213,382	137,944	362	70,903	426	39,192	--	--	694,660
1939	12,586	440,510	158,798	107,790	179	37,274	327	30,757	7	676	617,007
1940	11,565	404,775	249,930	177,728	203	45,765	399	39,900	34	4,221	672,389
1941	10,790	377,650	159,186	113,199	128	30,208	319	36,309	19	2,850	560,216
1942	6,782	237,370	141,411	100,559	71	17,097	400	53,553	354	65,900	474,479
1943	4,937	172,795	91,679	65,194	72	18,720	540	80,925	327	70,632	408,266
1944	3,212	112,420	143,325	101,920	82	22,140	972	155,520	534	121,752	513,752
1945	3,126	109,410	176,926	125,814	84	22,680	896	154,026	572	131,560	543,490
1946	8,504	297,640	194,297	156,992	100	32,238	871	189,987	623	152,134	828,991
1947	4,536	158,760	150,886	136,552	135	56,658	1,092	314,539	642	155,485	821,994
1948	2,466	86,310	172,713	156,314	167	72,478	1,472	526,976	1,260	335,160	1,177,238
1949	2,824	98,840	206,667	187,044	173	68,162	1,521	480,636	1,374	340,752	1,175,434
1950	5,000	175,000	238,021	215,421	190	79,040	1,100	297,000	909	258,156	1,024,617
1951	2,168	75,880	129,216	116,947	256	123,904	1,211	419,006	1,101	400,764	1,136,501
1952	2,443	85,505	95,871	86,768	197	95,348	1,161	373,842	957	317,724	959,187
1953	3,224	112,840	91,975	83,242	254	145,796	1,360	356,320	864	198,720	896,918
1954	2,688	94,080	68,249	61,769	250	147,500	1,131	309,894	712	153,792	767,035
1955	3,266	114,310	48,450	43,850	181	127,566	639	190,422	465	114,390	590,538
1956	2,647	92,645	56,475	51,113	126	106,675	527	165,588	588	161,098	577,119
1958	201	7,035	1,866	1,689	1	579	9	2,153	--	--	11,456
1959	13	455	117	106	--	--	3	644	3	794	1,999
1960	185	6,475	17,763	16,076	35	22,181	260	60,758	222	57,173	162,663
1961	16,569	579,915	482,792	446,336	1,548	928,800	5,545	1,142,322	7,391	1,699,884	4,797,257
1962	12,560	439,600	339,886	368,776	1,356	835,235	4,363	802,773	5,924	1,362,647	3,809,031

Table 1. Ouray County mine production of gold, silver, copper, lead, and zinc in terms of recovered metals, 1878–1986, inclusive.—Continued

[Production figures, some estimated, were calculated for 1878–1923 and are from Henderson (1926, p. 186); for 1924–1931 from "Mineral Resources of the United States" (U.S. Bureau of Mines, 1927–1934); and for 1932–1986 from "Minerals Yearbook" (U.S. Bureau of Mines, 1933–1988). No data for 1957; data for 1967, 1970, and 1979–1985 are withheld to avoid disclosing company proprietary data. s.t., short tons; --, zero]

Year	Gold		Silver		Copper		Lead		Zinc		Total value (dollars)
	Quantity[1] (ounces)	Value (dollars)	Quantity[1] (ounces)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	Quantity[2] (s.t.)	Value (dollars)	
1963	10,154	355,390	313,453	400,944	1,141	702,548	4,043	873,375	5,499	1,264,713	3,596,970
1964	6,279	219,765	134,757	174,241	453	295,160	1,713	448,714	2,325	632,318	1,770,198
1965	6,009	210,315	119,537	154,561	413	292,510	1,833	571,818	2,436	711,210	1,940,414
1966	4,292	150,220	211,248	273,144	500	361,844	2,059	622,557	2,954	856,791	2,264,556
1968	2,689	105,570	194,036	416,130	525	439,561	1,976	522,085	2,773	748,616	2,231,962
1969	2,665	111,000	163,100	292,000	445	423,000	1,560	465,000	2,032	593,000	1,884,000
1971	2,400	99,001	129,484	200,181	579	601,952	3,079	849,788	3,997	1,287,147	3,038,069
1972	3,430	200,998	173,004	291,512	878	898,744	5,118	1,538,537	6,462	2,293,865	5,223,476
1973	2,701	264,185	157,853	403,789	842	1,001,907	4,041	1,316,676	5,684	2,348,737	5,335,294
1974	2,148	343,122	134,090	631,563	618	955,269	3,475	1,563,861	5,127	3,681,393	7,175,208
1975	1,764	284,868	214,145	946,521	779	999,840	3,516	1,511,754	5,510	4,297,620	8,040,603
1976	1,433	179,583	165,025	717,858	485	674,564	3,067	1,417,157	4,748	3,513,688	6,502,850
1977	1,259	186,722	69,115	319,311	183	244,849	1,286	789,441	2,151	1,479,849	3,020,172
1978	576	111,485	19,768	106,747	73	107,474	618	458,746	1,031	704,144	1,488,596
1986	576	212,106	644	3,523	1	977	3	1,287	--	--	217,893
Total	2,007,872	45,857,154	49,110,490	41,667,585	26,609	14,645,946	148,253	26,676,549	78,391	30,644,924	159,492,158

[1]Expressed as fine ounces for 1878–1957; as troy ounces for 1958–1986. [2]Figures in pounds recalculated to short tons for 1879–1948.

around the west side of the San Juan Mountains from Durango via Rico and Telluride to Ouray (fig. 1); he originally had intended to come to Ouray from the south as he had with a toll road in 1881, now U.S. Highway 550. This so-called Mears system of roads and railroads, built mostly in the 1880s and early 1890s throughout the San Juans, greatly facilitated development of the entire region. Over the years, improvement in transportation and in treatment of ores continued to reduce the costs of ore production.

The first recorded production of ores from Ouray County was in 1878 and consisted of gold and silver (table 1). Production of lead was first reported in 1879 and copper in 1881. Zinc was not recovered by local smelters, and its presence in ores resulted in a penalty charge during the early years of mining. Its first reported production was in 1900; it was reported again in 1904 and then sporadically until the late 1930s, after which production was reported almost every year. County production figures for gold, silver, copper, lead, and zinc for the years prior to 1904 were obtained from agents' reports, Director of the Mint reports, and smelter and mint receipts, and for the years 1904 through 1923 from mine reports to Federal and State agencies (Henderson, 1926); production figures for 1924 through 1931 are reported in the annual volumes in "Mineral Resources of the United States" (U.S. Bureau of Mines, 1927–1934) and for 1932 to 1986 in "Minerals Yearbook" (U.S. Bureau of Mines, 1933–1988). Production figures for these five metals from the Uncompahgre mining district were reported separately only for the years 1905–24 and 1932–55 (table 2). The total production for the district compared with that for Ouray County for the years 1905–55 is shown in figure 3. During that time, the combined values for gold and silver accounted for most of the district's total except for the periods 1916–18 and particularly 1944–51, when the values of base-metal production far exceeded that of the precious metals. Production figures for the county obtained during the period from 1878 to about 1980, for gold, silver, copper, lead, and zinc, were mostly from ore deposits of late Tertiary age and from other districts within the county. The Uncompahgre district's total value, gained from Late Cretaceous to early Tertiary ores, is estimated to have accounted for 8 to 10 percent of the county total, or about $14–15 million. The exact value is not known because the early records are incomplete. Almost all of the gold and silver produced in the district came from lode deposits; the very small amount obtained from placer operations in the Uncompahgre River valley was of little economic significance.

Several siliceous travertine deposits containing iron, manganese, tungsten, and other metals in trace amounts are associated with hot springs within the city limits of Ouray. The travertine apron at Ouray Hot Spring (also called Pavillion Spring) near Box Canyon in the southwest corner of town was quarried for its manganese content during World War II. Waters from the several hot springs have been utilized for heating and in local bathing and recreational establishments.

Table 2. Uncompahgre district mine production of gold, silver, copper, lead, and zinc in terms of recovered metals, 1905–1924 and 1932–1955, inclusive.

[Source: "Mineral Resources of the United States" (U.S. Geological Survey, 1906–1927, and U.S. Bureau of Mines, 1927–1934) and "Minerals Yearbook" (U.S. Bureau of Mines, 1933–1988). lb, pounds avoirdupois; oz, fine ounces; --, zero]

Year	Producing lode mines	Ore sold or treated (short tons)	Gold[1] (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)	Total value (dollars)
1905	6	--	1,484	26,569	16,972	66,195	46,767	55,237
1906	11	--	1,064	178,994	47,819	265,105	10,377	166,902
1907[2]	--	--	--	--	--	--	--	--
1908[3]	--	--	--	--	--	--	--	67,499
1909	15	2,646	1,936	38,548	47,454	61,605	19,148	69,922
1910	12	3,482	1,664	30,257	18,750	70,946	--	56,230
1911	16	22,154	6,616	48,049	128,421	211,844	--	187,802
1912	26	23,021	9,890	135,071	61,618	192,356	45,262	309,434
1913	22	27,601	10,691	115,624	124,535	90,387	68,553	317,942
1914	30	40,241	17,118	154,362	563,631	160,589	14,962	521,174
1915	27	37,860	7,981	155,607	552,114	43,659	7,282	343,435
1916	31	6,060	869	101,748	156,809	507,623	41,090	164,016
1917	28	5,708	381	137,273	26,055	496,500	--	170,809
1918	24	3,787	947	124,790	19,449	468,338	--	183,445
1919	11	1,618	196	62,634	3,091	120,848	--	81,189
1920	12	751	287	35,554	2,402	21,538	--	46,856
1921	5	170	4	21,676	1,667	4,088	--	22,149
1922	8	5,310	2,501	14,087	6,459	23,693	--	67,955
1923	4	239	129	7,695	1,470	31,127	--	11,373
1924	4	120	159	4,609	1,152	10,788	--	7,381
1932	3	1,588	753	13,305	1,300	35,000	8,000	20,694
1933[4]	6	990	1,206	7,286	1,400	15,300	--	28,129
1934	6	10,895	619	49,144	7,700	111,350	--	58,137
1935	6	16,348	1,083	144,836	26,400	422,700	16,000	161,810
1936[5]	5	19,604	552	340,793	44,500	1,046,000	--	335,482
1937	6	7,676	257	86,892	18,600	356,600	--	99,487
1938	8	6,784	543	83,479	13,500	168,300	--	82,036
1939	6	4,159	751	68,120	16,700	204,100	--	83,854
1940	6	7,721	549	122,815	26,200	325,600	57,000	129,382
1941	11	6,227	368	38,167	13,400	176,000	34,000	54,184
1942	8	3,369	159	27,997	6,000	85,700	--	31,942
1943	4	2,044	66	5,362	3,900	160,000	37,000	22,626
1944	5	4,251	139	27,197	12,800	652,200	143,000	94,411
1945	3	6,443	89	72,038	17,000	624,500	244,000	138,404
1946[6]	--	--	--	--	--	--	--	--
1947[6]	--	--	--	--	--	--	--	--
1948	4	9,501	113	57,042	36,000	1,004,000	547,000	315,860
1949	4	3,365	72	17,555	18,000	529,000	244,000	135,792
1950	5	2,136	23	8,268	14,600	281,700	107,600	64,633
1951	4	428	9	2,022	2,000	80,000	11,200	18,507
1952	3	856	28	4,886	3,000	132,000	52,600	36,112
1953[2]	--	--	--	--	--	--	--	--
1954	1	22	3	292	300	6,400	--	1,334
1955[2]	--	--	--	--	--	--	--	--

[1]Figures were calculated for 1909–1924. [2]No production recorded. [3]Total value, only, reported in 1909. [4]Includes two placer operations with 7 oz gold and 1 oz silver. [5]Includes two placer operations with 27 oz gold and 80 oz silver. [6]Combined with Sneffels district production.

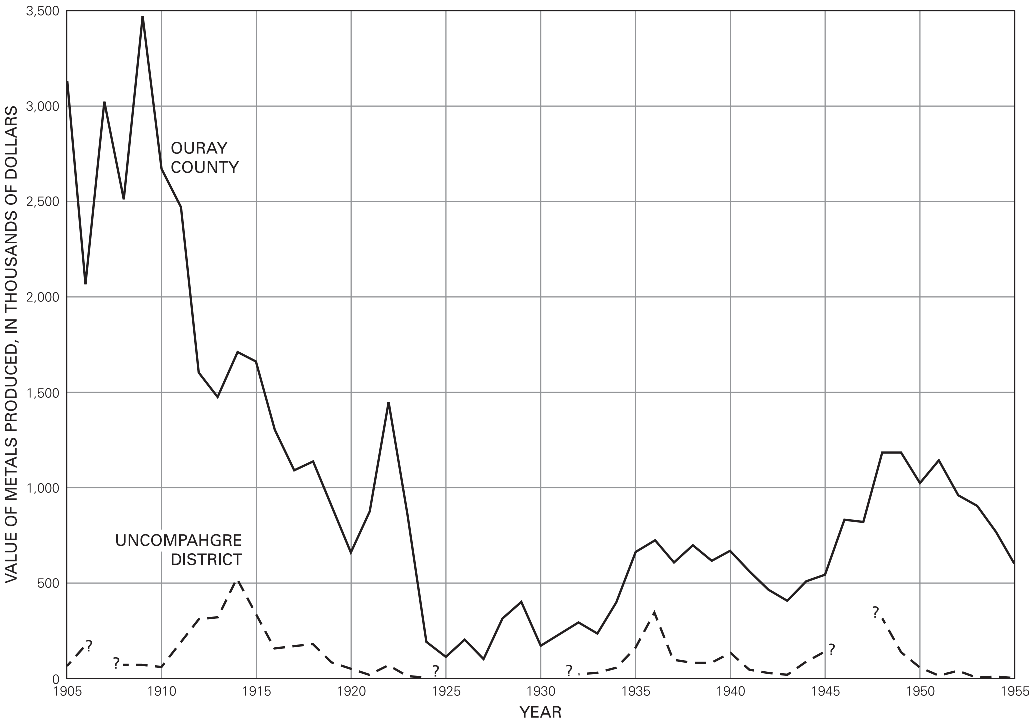

Figure 3. Graph of metal-production values (gold, silver, copper, lead, and zinc) for the Uncompahgre mining district compared with that for Ouray County, 1905–1955, inclusive.

Stratigraphy

The Uncompahgre district is underlain by a great variety of metamorphic, sedimentary, and volcanic rocks ranging in age from Proterozoic to Tertiary (fig. 4). Much of the area is blanketed by surficial deposits of Quaternary age.

The stratigraphy in the western San Juan Mountains has been discussed in the literature over the past 40 years so that an extensive description of the local units is not deemed necessary. However, the strata are briefly described and discussed here in order to consolidate and update pertinent literature, to establish a base for understanding the structural features, and to present the close relation of the rocks to alteration and ore deposition. Detailed measured sections of the different formations are available elsewhere (Armstrong and Mamet, 1976; Burbank, 1930; Franczyk, 1993; Luedke and Burbank, 1994; O’Sullivan, 1992).

Proterozoic Metamorphic Rocks

Only limited exposures of metasedimentary rocks of late Paleoproterozoic (Proterozoic Y) to early Mesoproterozoic (Proterozoic X) age (Plumb, 1991) are found in the southern part of the Uncompahgre district (fig. 4). Other metamorphic and igneous rocks similar to those in the Needle Mountains region to the south (fig. 1), although not exposed in this area, may underlie the northern and eastern parts of the district. Metasedimentary gneisses and schists were reported at moderate depths in several wells only 15 to 20 mi to the north (O’Sullivan, 1992; Tweto, 1987, pl. 1).

Uncompahgre Formation

The Uncompahgre Formation of Proterozoic age, named for the exposures in the Uncompahgre River gorge south of Ouray, was described by Cross, Howe, and Ransome (1905, p. 3), Cross and others (1907, p. 2–3), and Kelley (1946, p. 296–297, 305–306). Exposures of the formation in the Needle Mountains were described in detail by Barker (1969), who determined its age to be between 1,720 Ma and 1,460 Ma. Further extensive stratigraphic revision and structural reinterpretation of the Proterozoic complex has been done by Tewksbury (1985, 1989), Harris (1990), and Harris and Eriksson (1990).

The metasedimentary rocks in the Uncompahgre Formation consist of interlayered units, each several hundreds of feet thick, of quartzite or slate; quartzite is the dominant rock type. Within the mining district, the formation is estimated to have a minimum thickness of 3,000 ft in an exposed area of less than a square mile (fig. 4) that is terminated on the north by a major (Ouray) fault. Cumulative exposures of the formation within the district and in the river canyon for about 2 mi south of the district indicate the formation has a probable thickness in excess of 7,800 ft, with neither the bottom nor the top of the formation exposed.

The quartzite is massive to thin bedded, strongly jointed, and white to gray but locally red or black from the presence of minute flakes of iron oxides; weathered outcrops are commonly buff colored. The quartzite beds have some thin partings of argillaceous material. No definite progression was recognized in the nature of the commonly well-defined quartzite bedding within any one unit, but in some units, individual beds appear to be thinner near the top or bottom of the unit rather than in the middle. For the most part, the beds are composed of well-indurated, fine- to medium-grained quartz relatively free of impurities; minor amounts of mica and carbonaceous material occur locally. Within the thick unit of quartzite near the south edge of the district are a few pink to brown beds composed of subangular to rounded, closely packed quartz grains, 0.5 to 3.0 millimeters (mm) in size, cemented by iron oxide; this rock tends to fracture on grain boundaries, with the larger clear to blue quartz grains appearing to have a frosted surface. A few beds are conglomeratic and contain well-rounded quartz, jasper, and chert pebbles averaging about a centimeter in diameter. However, the quartzite is characterized by the sparseness rather than the abundance of conglomerate. Just south of and adjacent to the Ouray fault, the quartzite grades into a narrow belt or zone of finely contorted mica schist. Crossbedding and ripple marks are common, and aid in the determination of tops and bottoms of beds where involved in complex structure. A few thin beds of quartzitic sandstone occur locally near the contact of the quartzite and slate units. The lower contact of quartzite with slate is generally even and sharp, whereas the upper contact is gradational through several feet, which also shows the younging direction.

The slate units are dark green, brown, and gray to black and consist of laminated thin to thick beds that in a few places grade either into argillite or phyllite. Thin, lenticular metasiltstone to fine-grained quartzite layers commonly are interbedded in the lower part of the slate units. Although locally the slate beds are contorted, the beds in many places are readily cleavable into sheets about 0.25 inch (in.) thick; where slaty cleavage is less perfectly developed an irregular jointing produces blocky fracturing. Prominent cleavage surfaces often are coated with fine mica. Mud cracks and ripple marks, the latter often with considerable amplitude, are common in some beds. The slates are dense, very fine-grained aggregates of quartz, sericite, iron oxides, opaque matter, and chlorite, with accessory rutile, apatite, and tourmaline; sparse andalusite and staurolite were noted as imperfect grains.

The upper contact of the Uncompahgre Formation is everywhere a profound angular unconformity (fig. 5). Following an erosional period of long duration, the surface upon which the Paleozoic rocks lie is remarkably even with very gentle undulations, as shown by the trace of the erosion surface where the Paleozoic rocks wedge out south of Ouray on the west side of the Uncompahgre River canyon. However, after the early Tertiary regional erosion, the Tertiary rocks overlap exposed basement rocks with a more marked unevenness. On the east side of the river gorge, local relief on this erosion surface is as much as 350 ft.

The Uncompahgre Formation as a whole has yielded less in mineral wealth in proportion to its areal extent than the younger rocks. Generally north- and west-oriented joints and fractures, probably related to Late Cretaceous to early Tertiary deformation (Laramide orogeny), are small and usually carry only barren quartz veins. Mineral deposits of minor economic interest may occur in the veins of late Tertiary age.

Paleozoic Sedimentary Rocks

Sedimentary rocks of Paleozoic age constitute a large amount of the rocks cropping out within the district (fig. 4), but they have been the source of only a minor proportion of the mineral wealth of the district. These rocks form the base and lower slopes of the river valley throughout the area except south of the Ouray fault. They singularly and collectively were subjected to folding, faulting, and erosion prior to deposition of the overlying Mesozoic rocks. The Ignacio Quartzite of Late Cambrian age, present elsewhere in the western San Juan Mountains region, and reported in the Cow Creek area to the northeast (Cross and others, 1907, p. 3), is thought to have been deposited locally but later eroded from the Ouray area prior to Late Devonian time. No Ordovician, Silurian, or Lower and Middle Devonian rocks have been recognized in the western San Juans. Paleozoic rocks, deposited during the Late Devonian through Permian, rest upon the erosion surface of the Proterozoic rocks and total more than 3,900 ft in thickness. The lower part of the exposed Paleozoic section consists mostly of marine carbonate rocks that grade upward into marine clastic rocks and minor carbonate rocks. The upper part of the section consists of dominantly terrestrial clastic rocks.

Elbert Formation

The Elbert Formation, of Late Devonian age, is exposed only south of the Ouray fault from Box Canyon southward along the benches west of the river gorge and is considered to be representative of the formation. A very small exposure occurs also south of the fault on the south side of The Amphitheater just beneath the base of the Tertiary volcanic rocks.

The formation is green, buff, and gray and consists of thin-bedded calcareous shales, dense sandy limestones, and impure sandstones. The limestones have thin shaly partings and are sandy and dolomitic, as indicated by the silica and magnesia contents, determined by rapid-rock methods (Shapiro, 1967), of a typical limestone bed from the Elbert (table 3, sample no. 1). In general, the carbonate beds are lenticular and wedge out or grade laterally into calcareous shales or sandstones. The sandstones are fine to coarse grained and have thin shale and limestone partings. Locally interbedded in the lower part of the formation are a few thin lenticular conglomeratic beds. Occasional casts after salt crystals are found within the shaly beds. Lateral lithologic changes in the Elbert occur within short distances throughout the formation. The local rock types differ from those at the type locality in the southern San Juan Mountains (Cross, 1904) in the amount of contained detrital material and the lack of fossils.

The Elbert Formation ranges in thickness from 30 to 50 ft, and appears to grade into the overlying Ouray Limestone. At some places, the contact between these formations is difficult to pick, but at others is marked by a thin sandy or conglomeratic limestone at the base of the Ouray Limestone.

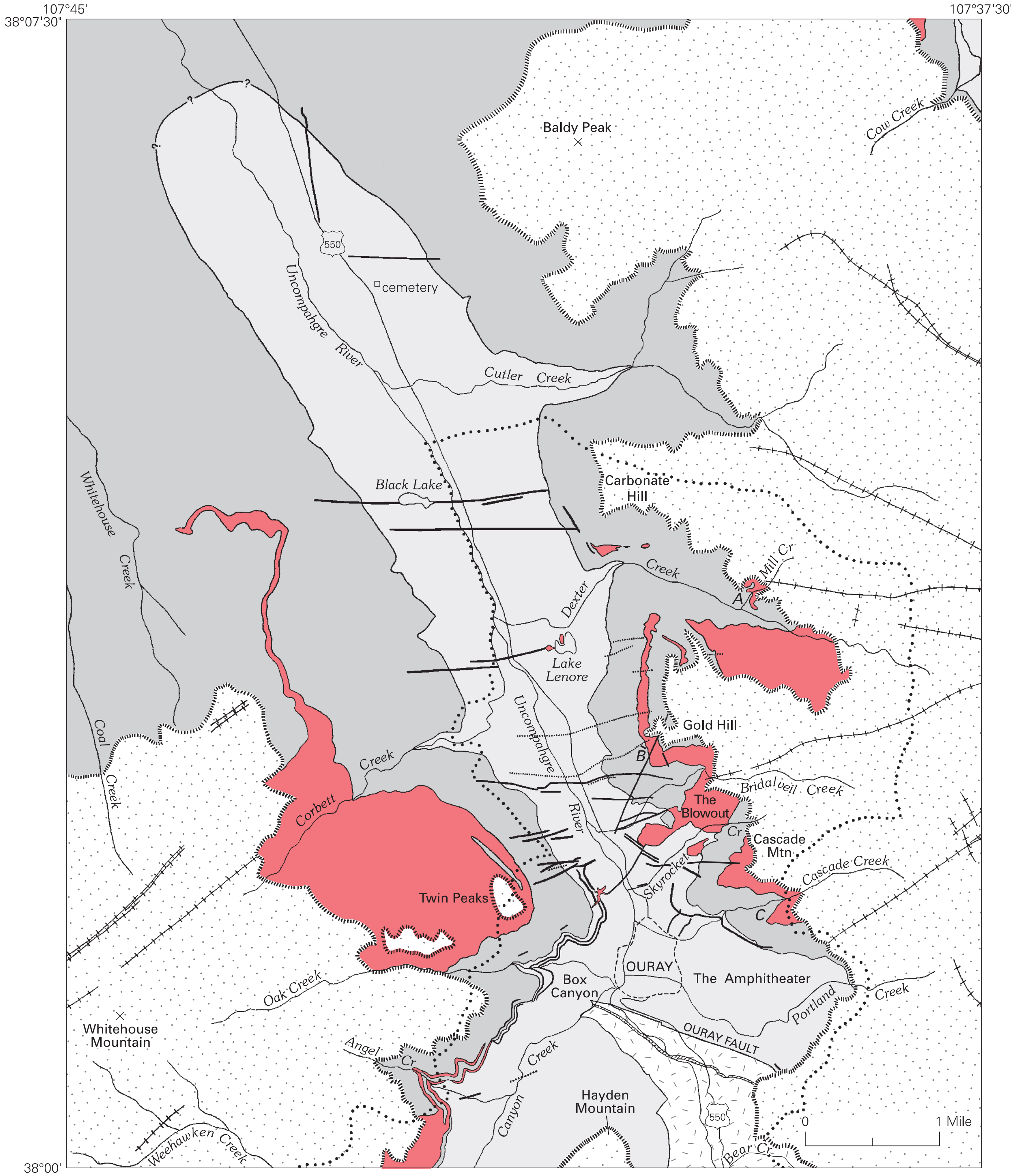

Figure 4. Generalized geologic map, excluding surficial deposits, of the Ouray 7.5-min quadrangle and the Uncompahgre mining district, southwestern Colorado (modified from Luedke and Burbank, 1962, 1981).

EXPLANATION FOR FIGURE 4 (FACING PAGE)

- Tertiary rocks
- Mesozoic sedimentary rocks
- Paleozoic sedimentary rocks
- Proterozoic metamorphic rocks
- Cretaceous to Tertiary igneous rocks
- Limit of volcanic rocks
- Tertiary igneous dikes
- Cretaceous to Tertiary igneous sills and dikes
- Cretaceous to Tertiary clastic dikes
- Proterozoic(?) diabase dike
- Contact; queried where uncertain
- Boundary of Uncompahgre mining district as shown in Luedke and Burbank (1981)
- *A* Approximate location of Dakota Sandstone sections *A*, *B*, and *C* shown in figure 8

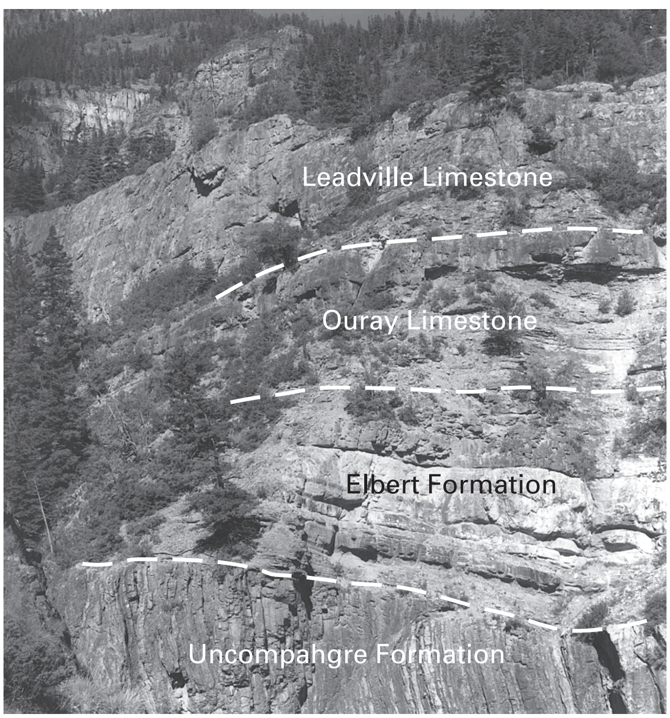

Figure 5. Angular unconformity between the underlying nearly vertical Proterozoic metamorphic rocks of the Uncompahgre Formation and the overlying nearly horizontal Paleozoic sedimentary rocks of the Elbert Formation, Ouray Limestone, and Leadville Limestone at Box Canyon (see fig. 4 for location) near the southwest corner of the town of Ouray. Photograph by A.K. Armstrong.

Table 3. Chemical analyses of carbonate rocks in the western San Juan Mountains region, southwestern Colorado.

[Analyses by U.S. Geological Survey. Major-oxide data, in weight percent, from rapid-rock methods by Samuel Botts; selected trace-element data, in parts per million, from semiquantitative spectrographic methods by J.L. Harris. N, not detected at limit of detection; ls., Ls., limestone]

Sample no.	1	2	3	4	5	6
Field no.	69S10	69S11	69S12	69S13	69W1	69S14
Lab no.	W173383	W173384	W173385	W173386	W173388	W173387
SiO_2	10.30	6.00	3.00	1.60	0.78	13.00
Al_2O_3	1.50	1.30	0.46	0.10	0.08	0.54
Fe_2O_3	0.50	0.31	0.52	0.11	0.08	0.22
FeO	1.00	0.44	0.16	0.08	0.00	0.20
MgO	18.00	18.40	17.40	0.54	0.32	0.83
CaO	29.60	30.70	33.00	53.60	54.90	46.80
Na_2O	0.10	0.00	0.00	0.03	0.33	0.00
K_2O	0.10	0.26	0.16	0.10	0.10	0.13
H_2O^+	1.50	0.95	0.61	0.42	0.48	0.51
H_2O^-	0.20	0.15	0.03	0.00	0.00	0.04
TiO_2	0.08	0.06	0.00	0.03	0.00	0.02
P_2O_5	0.02	0.00	0.00	0.00	0.00	0.02
MnO	0.20	0.04	0.00	0.08	0.00	0.04
CO_2	37.30	42.30	46.00	43.50	43.50	38.20
Total	100	101	101	100	101	101
Powder density	2.84	2.88	2.88	2.72	2.72	2.72
Bulk density	2.78	2.8	2.76	2.7	2.69	2.69
Ba	30	30	7	7	3	30
Cu	20	3	2	5	1	5
Pb	1	1	5	1	3	N
Sr	100	70	70	100	100	700
V	10	10	5	5	3	7

Sample descriptions and locations:

1. Gray sandy dolomite, Elbert Formation, Molas Pass area; 37°45’46” N., 107°40’38” W.
2. Gray dolomite, Ouray Ls., Molas Pass area; 37°45’46” N., 107°40’40” W.
3. Gray impure dolomitic ls., Leadville Ls., Molas Pass area; 37°45’45” N., 107°40’42” W.
4. Gray ls., Leadville Ls., Molas Pass area; 37°45’08” N., 107°40’32” W.
5. Gray ls., Leadville Ls., Cow Creek area; 38°06’03” N., 107°36’42” W.
6. Gray sandy ls., Hermosa Formation, Molas Pass area; 37°44’57” N., 107°41’38” W.

No ore deposits of commercial importance are known to exist in the formation in the Ouray area. The few veins that cut the formation near the south edge of the district contain hematite, chlorite, rhodochrosite, and quartz; those minerals have locally replaced some beds, as have minor amounts of pyrite, sphalerite, and galena.

Ouray Limestone

The Ouray Limestone of Late Devonian age was named for exposures on the benches southwest of the town of Ouray, but as originally defined, included rocks of both Devonian and Mississippian ages (Spencer, 1900). Kirk (1931) restricted the name Ouray Limestone to the lower thin- and medium-bedded sequence (Devonian age), and assigned the upper massive part to the Leadville Limestone (Mississippian age).

The Ouray Limestone, with the same distribution as the underlying Elbert Formation, consists predominantly of gray, buff, and white dense to medium-grained limestone, locally dolomitic, and dolomite, and has a few thin shaly partings. Dolomite constitutes the bulk of the formation, ranges in texture from sublithographic to crystalline, and is nonfossiliferous. Some of the more earthy, fine-grained beds consist of calcareous cemented dolomite rhombs, 0.02 to 0.06 mm in size, as well as minor quantities of insolubles including quartz and clay (table 4, sample no. 2). About 15 to 20 ft above the base of the formation in the cliffs about a mile southeast of Box Canyon, a pink crystalline limestone bed, 4 ft thick, contains numerous invertebrate fossils characteristic of Late Devonian fauna (Burbank, 1930, p. 159). A chemical analysis of a typical dolomitic limestone from this formation is given in table 3 (sample no. 2). Most beds, particularly those of limestone, cannot be traced throughout the district. Within the district, however, the formation has a fairly uniform thickness of about 60 to 70 ft.

The base of the Ouray Limestone is marked in a few places by a sandy or conglomeratic limestone containing crinoid fragments (table 4, sample no. 1), but in other places it was determined by the amount of contained sandstone and shale (rocks that are more characteristic of the underlying Elbert). The top of the Ouray is marked in a few places by a sharp change of lithic type that perhaps indicates a time of some erosion, but otherwise appears to grade into the overlying Leadville Limestone. This contact was placed arbitrarily at the base of a bluish-gray, non-magnesian, fine-grained, thin-bedded limestone that commonly contains black chert nodules. In places this chert-bearing limestone gives way to an inconspicuous limestone breccia or, as at Box Canyon, to thin calcareous sandstone layers. Difficulty in determining the upper contact, not only here but throughout the western San Juan Mountains, was noted by others (Armstrong and Mamet, 1976; Baars and See, 1968).

The Ouray Limestone does not host ore deposits in the Uncompahgre district. Small scattered blebs of base-metal sulfides were seen in the more limy beds on the benches and along the cliffs overlooking Uncompahgre Canyon and lower Canyon Creek, but nowhere did they show more than an extremely feeble mineralization. Dolomitic beds were even less favorable to replacement.

Leadville Limestone

The Leadville Limestone of Early Mississippian age (Kirk, 1931) constitutes the upper massive part of the former Ouray Limestone of Spencer (1900). Knight and Baars (1957) divided the formation into two members: the lower dolomitic

Table 4. Partial chemical analyses of carbonate rocks from the Uncompahgre mining district, Ouray County, southwestern Colorado.

[Analyses by U.S. Geological Survey. Chemical data, in weight percent, by standard rock methods. Analyses by J.J. Fahey. --, zero]

Sample no.	1	2	3	4	5	6
Field no.	O–3602	O–36205–9	O–36203–8	O–36203–D	O–2613	O–2610
Insolubles	3.10	[1] 13.00	2.02	0.42	0.36	[2] 36.66
$CaCO_3$	96.61	53.43	97.07	99.68	99.54	61.74
$MgCO_3$	0.54	31.66	1.07	0.42	0.42	0.52
$FeCO_3$	--	1.32	--	--	--	0.97
$MnCO_3$	--	--	--	--	--	--
Total	100.25	99.41	100.16	100.52	100.32	99.89

[1]Includes 7.76 percent SiO_2 and 2.28 percent Al_2O_3

[2]Includes 30.58 percent SiO_2 and 3.86 percent Al_2O_3

Sample descriptions (sample locations are on sedimentary benches south of Ouray):

1. Ouray Limestone: Coarse crystalline crinoid-bearing limestone bed near base of formation.
2. Ouray Limestone: Impure dolomitic limestone bed about 49 feet (ft) above base of formation.
3. Leadville Limestone: Dense black limestone near base of formation.
4. Leadville Limestone: Limestone bed in middle of formation.
5. Leadville Limestone: Limestone about 150 ft above base of formation.
6. Leadville Limestone: Impure limestone bed at top of formation.

beta member, which is absent at Ouray, and the upper alpha member, a limestone. South of the Ouray fault the Leadville Limestone has the same distribution and general attitude as the underlying Devonian formations. North of the fault, it crops out south of the town of Ouray, along the south edge of The Amphitheater, and at the east edge of town. The Leadville also occurs in the workings of the Portland mine near the head of The Amphitheater.

The formation locally ranges from 180 to 235 ft in thickness and may be roughly divided into two parts: a lower massive, cliff-forming part and an upper step-like, bench-forming part consisting of interbedded layers of crystalline limestone and more easily eroded shale. Reported thicknesses vary dependent upon placement of the contacts and assignment of bedded units to the Ouray, Leadville, or Molas formations. Armstrong and Mamet (1976) measured a thickness of 214 ft in their section near Box Canyon, whereas Kindle (1909) measured only about 75 ft in the same locality.

In general, the lower 55 ft of unfossiliferous locally dolomitic limestone (table 3, sample no. 3) is massive to evenly bedded and dark bluish-gray or brown, and contains some interbedded gray crystalline limestone and sandy limestone layers. Chert-bearing limestone, limestone breccia, or calcareous sandstone is locally present at the base. Sample no. 3 (table 4) from a dense limestone within 8 ft of the base of the formation contains only a small amount of insolubles. This unfossiliferous lower part is included in the Leadville because the beds are similar lithologically to the overlying fossiliferous strata rather than to that in the underlying Ouray.

The generally thicker upper part of the formation consists of gray to brownish-gray, coarsely crystalline limestone in thick beds, which commonly contain poorly preserved fossils. Near the top of this upper part a few of the beds are composed almost entirely of fossils or fossil fragments. The purest limestones of the formation occur in this part (table 4, sample nos. 4, 5). Alternating with these massive beds in the upper part of the formation are limestone breccias; these breccias, containing red shaly seams, become more abundant upward. Also, some of the limestone beds are more siliceous and contain thin layers or stringers of chert nodules. Insolubles, particularly quartz sand, increase in the uppermost beds as indicated by sample no. 6 (table 4). On the whole, chemical analyses (tables 3 and 4) from the Ouray area, from the Molas Pass area about 4 mi south of Silverton (fig. 1), and from the Cow Creek area about 6 mi north-northeast of Ouray, indicate that the Leadville in the western San Juan Mountains consists dominantly of limestone.

The uppermost beds, included in the Leadville but quite similar to beds in the overlying Molas Formation, illustrate the greatest lateral compositional change in the formation. This sequence of beds, 50 to 75 ft thick, consists of siliceous and dolomitic limestones that grade laterally into clastic limestones separated by thin red shale partings and limestone breccias, or into ferruginous limy shale and thinly layered chert. In most exposures this uppermost shaly part, particularly above Box Canyon, appears to have been eroded before deposition of the overlying Molas Formation. The upper contact is everywhere a very irregular erosional unconformity.

No deposits of commercial importance are known to occur in the lower unfossiliferous beds of the Leadville Limestone. Manto-type orebodies formed at the time of the Laramide orogeny, known principally at the Mineral Farm mine located on the benches southwest of Ouray, appear to occur about equally in the very uppermost beds of the Leadville and in the basal chert conglomerates and red shales of the overlying Molas Formation. In the Portland mine near the head of The Amphitheater, there has been some replacement of the brecciated limestone walls immediately adjacent to the late Tertiary vein. The greater part of the massive beds in the Leadville, however, probably was unfavorable to easy replacement.

Molas Formation

The Molas Formation of Early and Middle Pennsylvanian age has about the same distribution in the district as the underlying Leadville Limestone. It is poorly exposed in most places because of its rock type and its clayey cementing material. Merrill and Winar (1958) divided the Molas Formation into three members in the Needle Mountains area (fig. 1). Baars and others (1967) suggested that particularly the lower part of the formation was in part an ancient regolith or paleosol of possibly Late Mississippian to Early Pennsylvanian age, and that it formed a karst surface on the Leadville Limestone. Only the middle member and a small thickness of the lower member crop out in the Ouray area.

The formation is composed of thin to thick lenticular beds of reddish-brown and red shale and conglomerate containing minor amounts of red sandstone and green and gray shale. All of the sandstones and shales are calcareous. The conglomerates contain black and gray chert fragments, ranging from 0.25 to 6 in. in diameter, cemented in a reddish clay and sand matrix. Just north of Canyon Creek, downstream of Box Canyon, the formation rests upon the uppermost shale in the Leadville Limestone, which appears to have been removed by erosion elsewhere in the district.

Throughout the district the formation ranges from 40 to 60 ft in thickness. The differences in thickness probably are the result of irregularities on the underlying erosion surface. Deposition of the Molas beds was preceded by considerable erosion, as shown by the many chert and limestone clasts derived from the Leadville Limestone that are included in the basal beds of the Molas Formation. The upper contact of the Molas is conformable and apparently gradational with the overlying Hermosa Formation.

The uppermost part of the Leadville and the lower chert-bearing shales and conglomerates of the Molas constitute the horizon within which most of the ore was deposited at the Mineral Farm mine. Also, the lower beds of the Molas, at a few places in The Amphitheater, seem to have influenced the localization of ore adjacent to fractures of Tertiary age.

Hermosa Formation

The Hermosa Formation of Middle and Upper Pennsylvanian age crops out as a series of greenish-gray and red ledges and cliffs west of Ouray and in the valley of Canyon Creek, north from within The Amphitheater around into Skyrocket Creek, and in the lower slopes above the benches at the north end of Hayden Mountain south of Ouray. One small block is exposed north of the Ouray fault on the south side of The Amphitheater. No attempt was made to separate or to correlate the formation as mapped here to the units or subdivisions proposed by Wengerd and Matheny (1958), Wengerd (1962), Baars and others (1967), and Spoelhof (1976) for nearby areas to the south and west.

The Hermosa Formation is composed of thin to massive beds and is about 1,450 ft thick. Throughout the district, correlation of individual beds was found to be impracticable because of the lenticularity of beds or lateral lithologic gradation. For descriptive purposes only, the Hermosa Formation here is divided into three parts.

The lower part, about 450 ft thick, consists predominantly of green, gray, and red calcareous sandstone, siltstone, and shale and contains interbedded greenish-gray sandy limestone. A chert-pebble conglomerate is at the base. The sandstones, many of which are pink grits, are fine to coarse grained; some of the sandstones are conglomeratic. Most of the siltstones and shales are micaceous, and some of the shales are fossiliferous. Thin black carbonaceous shale is interbedded with dark, dense limestone near the base. The limestones are dense, but locally may be gnarly and contain siliceous concretions; many of the limestones are fossil bearing. Sample no. 6 (table 3) from the Molas Pass area, about 4 mi south of Silverton, is an example of dense sandy limestone from the lower part of the formation. The limestones occur in beds that typically are 1 to 5 ft thick but that may be as much as 25 ft thick.

Pink to red grit, sandstone, siltstone, and sandy shale, in 50- to 80-ft-thick massive beds, constitute the 700-ft-thick middle part of the Hermosa Formation, and are interbedded with thin red and gray, fossiliferous shale and gnarly limestone. Many of the sandstones are feldspathic and conglomeratic, and some of the shales are very micaceous.

The thin- to thick-bedded upper part of the Hermosa is composed of about 300 ft of pink to red arkosic coarse-grained sandstone and conglomerate containing intercalated shale and limestone. The shale is gray to red, micaceous, and generally silty or sandy; the limestone is gray, dense, and fossiliferous. The upper part of the Hermosa Formation more closely resembles lithologically the overlying Cutler Formation than the underlying lower and middle parts of the Hermosa in having more conglomeratic lenses and a greater content of feldspathic material in the sandstones. However, the shales in this upper part are not sandy like the shales in the immediately overlying beds of the Cutler. The upper part also contains fossil-bearing beds that have a greater proportion of mollusks to brachiopods as compared to fauna in the lower and middle parts of the formation. A similar ratio of mollusks to brachiopods is typical of the Rico Formation of Pennsylvanian age, a transitional unit between marine Hermosa below and continental Cutler above, as mapped in the Rico area about 25 mi to the southwest (McKnight, 1974). Comparison of the fauna from the two areas found that each contained a considerable number of species in common, but also that each had a considerable number of species peculiar to itself (Burbank, 1930, p. 165). The similar faunal ratio and the similar lithology suggest, however, that the upper part of the Hermosa Formation at Ouray may be an approximate equivalent of the Rico Formation.

The Hermosa Formation apparently grades into the conformable overlying Cutler Formation. The upper contact was placed arbitrarily about 130 ft above the uppermost fossiliferous horizon where the succeeding beds are unfossiliferous and correspond more closely in lithologic character to the red beds in the thick Cutler Formation above. There is little assurance that the contact is everywhere at the same horizon.

In the vicinity of Ouray the Hermosa Formation does not contain replacement deposits of the blanket type. Some thin limestones and associated black limy shales, however, contain small pyritic replacement deposits along some mineralized fractures or veins near the stock in The Blowout. These deposits have not proved commercially valuable except where they were later enriched by late gold-bearing solutions that formed small ore shoots. The lack of large replacement deposits in this formation is due either to unfavorable lithic characteristics of its beds or to some unfavorable structural conditions. It is significant, however, that the major massive-sulfide replacement ore deposits characteristic of the middle Hermosa in the Rico mining district are not present at Ouray (Ransome, 1901; McKnight, 1974).

Cutler Formation

The Cutler Formation of Early Permian age was named for the red beds that crop out at the mouth of Cutler Creek (Cross and others, 1907, p. 5) and along the Uncompahgre River valley from the town of Ouray northward. The formation crops out typically as benches and cliffs because of the variation in resistance of the beds to erosion. It consists of thin to massive beds that are commonly lenticular and exhibit distinct vertical and lateral gradations in lithology; many of the beds are cross-stratified and show cut-and-fill deposition. For descriptive purposes only, this formation is divided into two parts.

The lower part consists of interbedded shale, siltstone, and sandstone. The rocks are generally pink, red, and reddish brown, but a few are gray. Selective bleaching has altered the color of some beds to white, yellow, or green, and has imparted a mottled appearance to others. The shales and siltstones are calcareous, sandy, and micaceous, and some shale contains limestone nodules. The sandstones are micaceous and arkosic and are fine to very coarse grained; many are slightly to very conglomeratic, containing rounded pebbles and cobbles as much as 4 in. in diameter. These fragments were derived from all the underlying rocks, but fragments of Precambrian granite, gneiss, schist, slate, and quartzite predominate. Conglomeratic beds increase in number upward. The thickest measurement obtained in the area for the lower part of the formation was about 1,450 ft.

The upper part of the Cutler Formation is sandstone that contains subordinate shale and mudstone, as well as several very coarse conglomeratic beds as much as 40 ft thick. These conglomeratic beds, which contain very little interstitial material, are composed of well-rounded pebbles, cobbles, and boulders that are as much as 10 in. in diameter but which average about 4 in. Some conglomerates consist of predominantly metamorphic and igneous rock fragments, whereas others consist mainly of limestone fragments. Especially in the upper part of the formation, beds cannot be traced laterally for any great distance, in part because of the gradation between rock types and in part because of slope cover. The thickest measurement obtained in the area for the upper part of the formation was about 550 ft.

The upper contact of the Cutler Formation with the overlying Dolores Formation is everywhere an angular unconformity; this angular contact is particularly evident on the north wall of The Amphitheater (fig. 6) where the Dolores Formation transgresses the Cutler Formation to lie on beds of the Hermosa Formation. Therefore the total thickness of the Cutler Formation ranges from zero to about 2,000 ft.

Very few beds in the Cutler Formation were favorable to mineral deposition. Most of the sandstones consist of poorly sorted grains and are too shaly or micaceous to be permeable. A few thick, presumably more permeable, sandstone beds near the center of mineralization (in the area of The Blowout) contain small gold-bearing replacement veins where the ore shoots were restricted mainly in the sandstone walls. The same veins in the more shaly beds commonly had little or no value.

Mesozoic Sedimentary Rocks

Sedimentary rocks of Mesozoic age constitute only a small part of the rocks exposed within the district (fig. 4), but account for a major proportion of the district's ore deposits. The strata have been subjected to folding and faulting both separately as an age group or together with the underlying

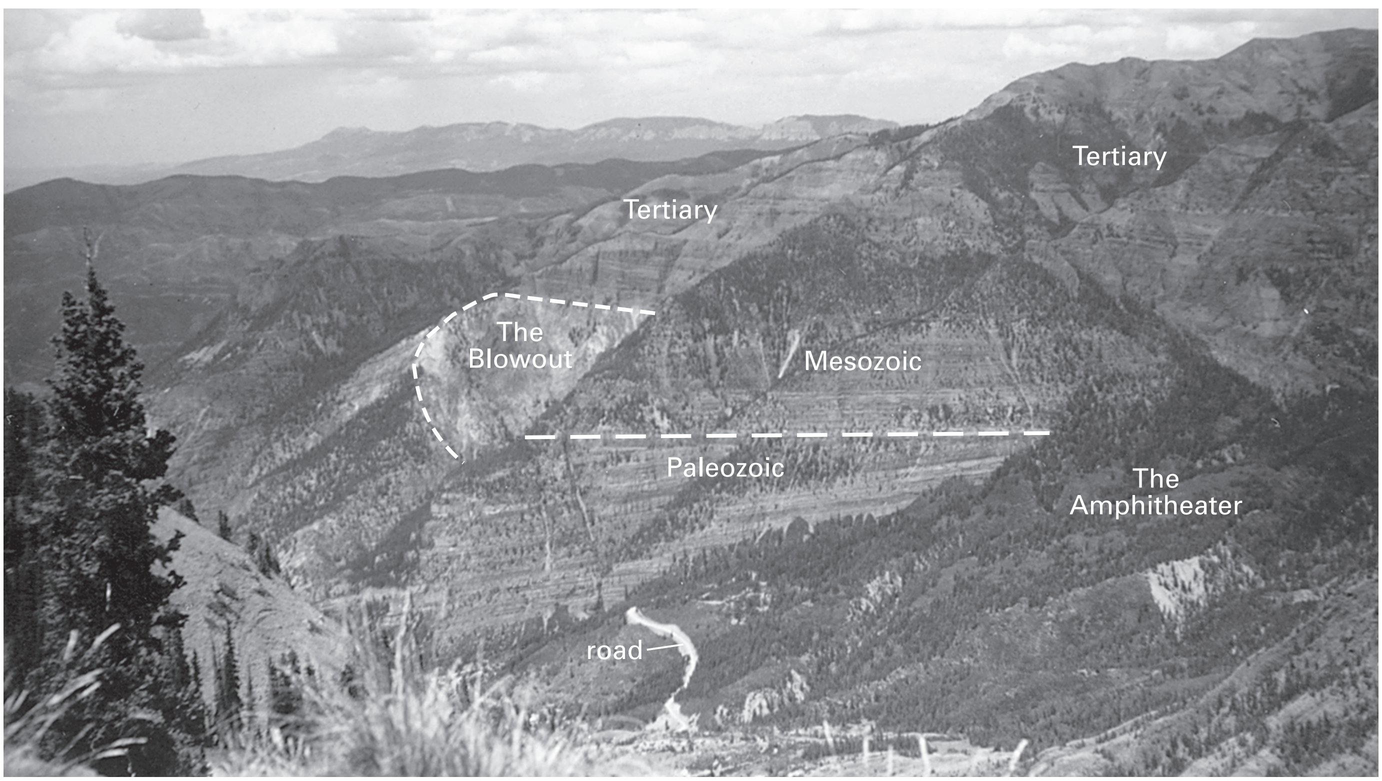

Figure 6. View looking northeast from Hayden Mountain at cliffs on the north side of The Amphitheater, east of the town of Ouray, showing the angular unconformity (marked by the long-dashed line) at the base of the nearly horizontal Mesozoic beds overlying inclined northwest-dipping Paleozoic strata. The back of The Amphitheater (to the right) and the upper slopes behind are Tertiary volcaniclastic rocks; its floor in the foreground and mostly to the right of the road (bottom center) is covered by glacial and landslide debris. The light-colored, somewhat circular area in the next gulch to the north, known as The Blowout (outlined by short-dashed curved line), consists of extremely altered Paleozoic and Mesozoic sedimentary rocks surrounding an intruded, partly altered igneous stock; the top of the altered rocks and the base of overlying unaltered Tertiary volcanic rocks (indicated by the straight segment of the short-dashed line) was a factor in recognizing and defining this alteration-and-mineralization episode (related to the Laramide orogeny) within the Uncompahgre mining district.

Paleozoic units. The entire stratigraphic section was eroded extensively prior to deposition of the Cenozoic rocks. The Mesozoic rocks, of Triassic through Cretaceous age, total more than 2,000 ft in thickness and are composed dominantly of terrestrial clastic rocks.

Dolores Formation

The Dolores Formation of Late Triassic age generally crops out in steep rubble-covered slopes or cliffs and benches along the west side of the Canyon Creek and Uncompahgre River valleys as well as along the east side of the Uncompahgre and its tributary canyons from The Amphitheater northward. The formation is extremely variable in rock type both horizontally and vertically and consists predominantly of sandstone and siltstone and minor amounts of mudstone, limestone, and conglomerate. For the most part it consists of thin to massive even beds, but in places it is irregularly bedded, lenticular, and cross-stratified; locally it shows cut-and-fill structures. The upper one-half to two-thirds of the formation generally is thin bedded, whereas the lower part consists of thick and massive beds; the latter commonly weathers to a knobby surface and contains hackly or subconchoidal fractures. Poorly preserved bone, teeth, and plant fragments have been found locally.

The sandstone is very fine to coarse grained and contains mudstone partings and pebble-size conglomerate streaks. Laminated thin beds of sandstone and siltstone are generally reddish brown, but thick or massive beds are often mottled red and white. The mudstone, in places fissile, is red, reddish brown, green, and yellow. Everywhere at the base of the formation is a pebble conglomerate ranging in thickness from 6 in. to 8 ft. At most places this conglomerate is white, pinkish white, or light gray, but locally, near Ouray, it is reddish brown. The subangular to rounded pebbles are set in a calcareous sandy matrix and consist of quartz, quartzite, chert, mudstone, and limestone as much as 2 in. across. A few red, white, or gray dense or silty limestone and limestone-pebble conglomerate beds, averaging about 1 ft thick, occur in the middle and upper parts of the formation. Pebbles of the limestone and calcareous mudstone, often slightly flattened, are as much as an inch across; a few quartz and quartzite pebbles occur sporadically. Locally, the uppermost 2 or 3 ft of the formation is altered greenish gray and yellow. Alternating thin beds of mottled, limy mudstone and fine-grained sandstone occur within a scour at the top of the formation, west of Black Lake at the northwest edge of the mining district (fig. 4). These beds are similar to and are believed to be an erosional remnant of formerly extensive beds more characteristic of the Chinle Formation and the Wingate Sandstone, both of Late Triassic age, in the Colorado Plateau region to the west.

As previously stated, the base of the Dolores Formation is marked by a very important angular unconformity. At the east side of The Amphitheater the Dolores rests directly upon the Hermosa; contact with older formations was not seen at that locality, but structural conditions suggest that the Dolores possibly may have lain across the entire section of Paleozoic beds. The contact with the overlying Entrada Sandstone is an erosional unconformity. Erosion preceding and following deposition of the Dolores, as well as possibly intra-formational erosion, accounts for the variance in thickness of the formation, which ranges from 40 to 130 ft and averages about 80 ft.

Few beds in the Dolores Formation appeared favorable to mineral deposition. Locally some beds do contain minor vein deposits.

Entrada Sandstone

The white to buff Entrada Sandstone of Middle Jurassic age crops out in a steep to rounded cliff along the Uncompahgre River valley walls. It is thick bedded to massive and typically characterized by sweeping crossbeds. At a few places, however, the upper part is evenly bedded.

The friable and calcareous sandstone is fine grained and consists of rounded clear and frosted quartz grains. Characteristic of and scattered throughout the sandstone are larger single, rounded, frosted quartz grains (so-called “Entrada berries”) averaging 1 mm in diameter. Red angular fragments of the underlying Dolores Formation are locally incorporated near the base of the sandstone. Thin streaks of very fine-laminated black shale or mudstone are common near the top of the unit.

The Entrada Sandstone ranges from 45 to 80 ft in thickness. The difference in thickness primarily is due to the erosional unconformity at its base. The lower and upper contacts are sharp because of the contrasting composition of the Entrada and the underlying and overlying formations. To all appearances, the upper contact is even and in a few places appears to grade into the overlying formation, but in other places it is somewhat irregular.

The Entrada Sandstone is made up mostly of windblown sand of relatively fine grain size and consequently is not highly permeable; the formation was not a favorable host to ore deposition. However, locally there are a few vein deposits of minor value.

Wanakah Formation

The Wanakah Formation of Middle Jurassic age crops out along the walls of the Uncompahgre River valley and generally forms a cliff in the lower part and a mostly covered gentle to steep slope, with some ledges, in the upper part.

Named for exposures at the Wanakah mine north of Ouray (Burbank, 1930, p. 172), the Wanakah Formation consists of three distinct units: a lower limestone and breccia unit (Pony Express Limestone Member), a middle sandstone unit (Bilk Creek Sandstone Member), and an upper limy mudstone and siltstone unit (unnamed marl member). The unnamed upper unit, generally referred to as the “marl” member (Bush and others, 1959; Vhay, 1962; Bromfield, 1967), is now informally called “beds at Sawpit” (O’Sullivan, 1992, p. 11). The formation ranges from 85 to 125 ft in thickness.

Pony Express Limestone Member

The Pony Express Limestone Member, known from its occurrence at the Pony Express mine, consists generally of two parts: a lower limestone and limy shale and an upper, not always present, calcareous shaly breccia, hereinafter referred to as limestone breccia. At only a few localities along the Uncompahgre River valley north of the district, the Pony Express consists of a lower limestone and shale, a middle thin breccia, and an upper shaly mudstone containing interstitial gypsum nodules. Underground in some mines, the Pony Express consists entirely of thin layers of shaly sandstone.

The lower part of the member, ranging from 1 to 5 ft in thickness, is predominantly laminated to thin-bedded, dark-gray to black, dense limestone interbedded with black bituminous shale. At one locality the lower part consists of a single limestone bed about 1 ft thick. The limestone beds are contorted, crumpled, or crinkled and somewhat broken (pseudobreccia) but healed by coarse crystalline calcite or by white fibrous gypsum. A freshly broken exposure of the limestone emits a petroliferous odor. This lower part is present wherever the Pony Express is exposed.

The upper part ranges from zero to 20 ft thick and usually consists of a very porous breccia composed of grayish-black, very thin but angular shale and limestone fragments cemented by calcium carbonate. The contact between the Pony Express Limestone Member and the overlying member is commonly sharp and conformable, but at a few places appears to be uneven.

A few localities on both the west and east sides of the Uncompahgre River valley north of the mining district are particularly instructive as to the origin of the breccia in the upper part. At these localities, the upper part contains somewhat flattened, oval to round white gypsum nodules surrounded by thin layers of dark calcareous mudstone. This part may reach a maximum of 70 ft in thickness, but laterally thins rapidly to a porous breccia. Upon dissolution of the gypsum by circulating ground waters, the layers of mudstone sagged, broke into fragments or small plates, and were gradually compacted to form the porous breccia of a much lesser thickness (fig. 7).

Dissolution of most of the gypsum probably occurred in Late Jurassic time; several sections measured near one of the gypsum localities indicate that the overlying Bilk Creek Sandstone Member is of uniform thickness whereas the uppermost part of the Wanakah Formation and lower part of the Morrison Formation are thinned and arched slightly over the remaining gypsiferous mass.

The Pony Express Limestone Member, including all the beds, was known locally to the miners as the “Pony Express beds,” “Pony Express contact,” or “Iron Clad contact;” it was an important ore-bearing horizon in the sedimentary sequence and of considerable economic interest. Where cut by veins, the breccia was mineralized, and bedded deposits were formed along many of the ore channels throughout the district and in adjacent areas particularly to the north and west.

Bilk Creek Sandstone Member

The Bilk Creek Sandstone Member, named by Goldman and Spencer (1941, p. 1750) for exposures at Bilk Creek to the west, is rarely well exposed. It is a greenish-gray to buff, silty, very fine- to fine-grained, calcareous sandstone and is very soft and friable. In a few of the better exposures, some thin greenish-gray shale partings were seen in the upper part. The beds are mostly thin to thick and planar but locally are somewhat irregular and lenticular. This member ranges from 14 to 25 ft in thickness.

The uppermost part of the Bilk Creek is marked by a 1-ft-thick, comparatively hard and resistant, greenish-gray, medium-grained sandstone bed containing grains of jasper or red chert. This bed is the “carnelian sandstone” described in neighboring areas (Goldman and Spencer, 1941). O’Sullivan (1992, p. 10) suggested this sandstone marker bed could be a reworked zone and should be considered the basal part of the overlying strata, but he retained it (fig. 3B; p. 22) as the capping, uppermost part of the Bilk Creek Sandstone Member. The upper contact of this member where seen is sharp and even.

Although not of major importance, the sandstone in the Bilk Creek is generally mineralized where the underlying Pony Express Limestone Member is mineralized. Ore deposits in the sandstone exist both as fracture fillings and as bedded replacement types. The latter often were associated with deflections in the dip of a vein, locally known as “rolls” in a vein, where the vein broke through the underlying Pony Express.

Unnamed Upper Member

The upper unit, or marl member, of the Wanakah Formation is lithologically not marl, but consists of irregular, thin-bedded, reddish-brown calcareous mudstone and siltstone ranging from 40 to 75 ft in thickness. Interbedded with the mudstone and siltstone are a few thin, lenticular, gray and brown, very fine-grained sandstone and nodular limestone beds. The limestone is finely crystalline, locally dolomitic, and commonly vuggy. The sandstone, locally, and a very silty limestone near the top of the member contain grains of jasper and a green chert or chalcedony. Stratigraphic and lateral gradations are common among the lithic types that throughout the unit are laced with seams and stringers of crystalline calcite. Typically the uppermost 1 to 2 ft is bleached olive to yellowish gray. The upper contact everywhere is sharp and apparently flat, but locally is irregular, having a few inches of relief. This member is commonly void of mineralization.

Morrison Formation

The Morrison Formation of Late Jurassic age crops out in cliffs, ledges, and steep slopes high along the walls of Canyon Creek and the Uncompahgre River valley. Although mapped as a single unit, the formation within the district was recog-

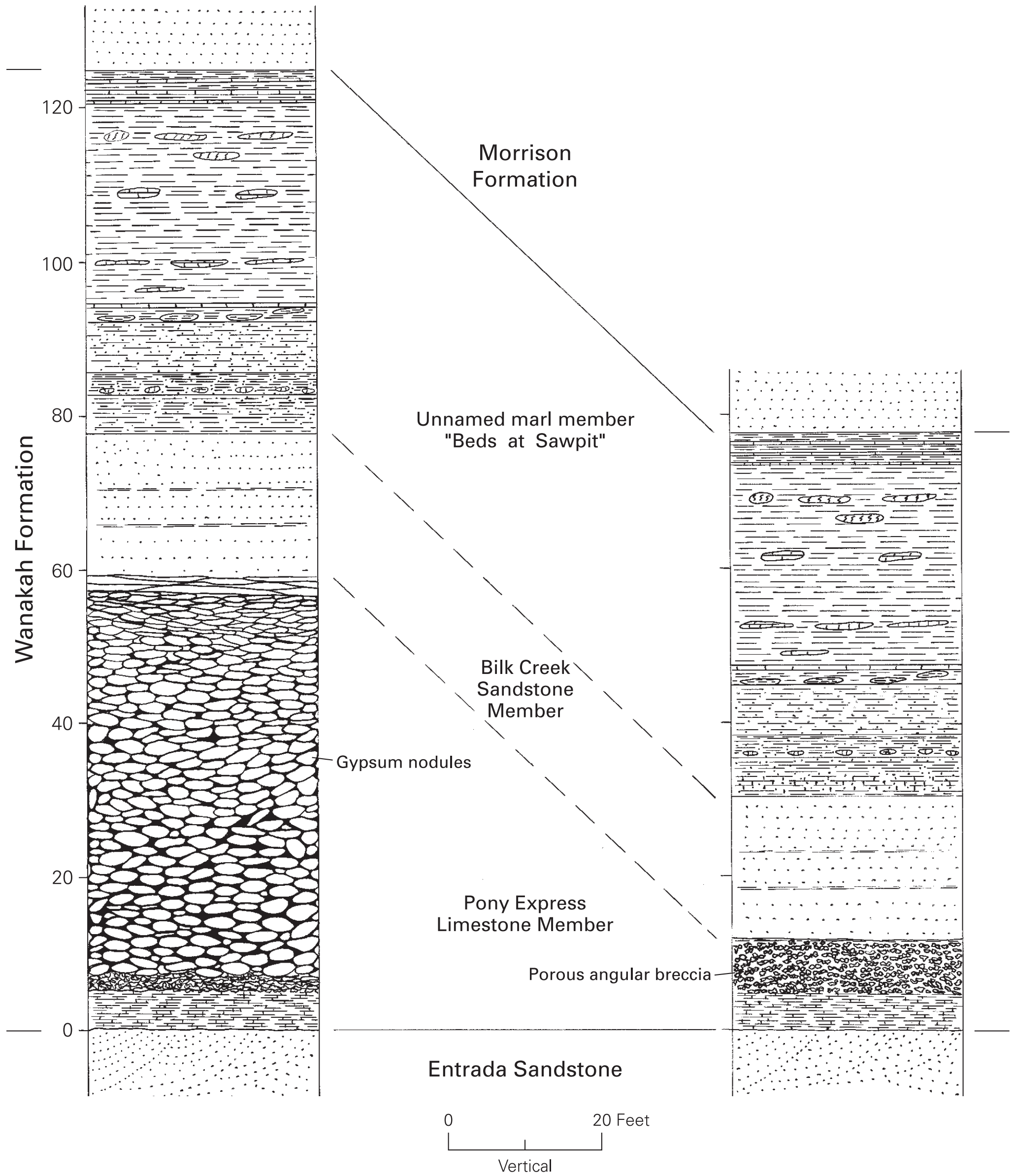

Figure 7. Generalized sketch of two nearby separate measured sections of the Wanakah Formation high on the east side of the Uncompahgre River valley, about 1.5 mi north of the mining district in the vicinity of Ouray's Cedar Hill Cemetery (see fig. 4), where the thicknesses and compositions of the Pony Express Limestone Member of the Wanakah Formation are exposed. The thicker section, representing the unit as originally deposited and containing gypsum nodules, is compared with the common, normally exposed thinner section consisting of porous, angular breccia resulting from the dissolution of the gypsum and the subsequent collapse, breakage, and cementation of the thin calcareous mudstone sheaths that had surrounded individual gypsum nodules.

nized to consist of two members, the lower Salt Wash Member and the upper Brushy Basin Member (Burbank, 1930; Craig and others, 1955; Luedke and Burbank, 1962, 1981). The contact between the members is neither sharply defined nor everywhere at the same horizon. Subsequent to these studies, O'Sullivan (1992) recognized and correlated a third member within the Morrison Formation throughout western Colorado and eastern Utah. He subdivided the Salt Wash Member by restricting the upper part to the Salt Wash Member and the lower part to the Tidwell Member of the Morrison Formation.

As a whole, the Morrison Formation consists of mainly sandstone and some interbedded mudstone in the lower part, and mostly mudstone and siltstone containing minor amounts of sandstone in the upper part; also, throughout the formation are minor amounts of limestone and conglomeratic sandstone. The character of the beds varies laterally, with few of the beds persistent for any distance other than the prominent basal sandstone. The Morrison Formation ranges from 620 to 750 ft in thickness; it averages about 700 ft thick.

A few ostracodes (Steele, 1985, p. 12) and other poorly preserved and indeterminable invertebrate fossils have been found in limestones near the base, and, in addition, fragmentary plant and bone specimens were found in mudstones and sandstones stratigraphically higher in the formation. A fossilized dinosaur footprint is exposed in the prominent basal sandstone near the boarding house of the American Nettie mine.

Other than the basal sandstone unit, most of the Morrison Formation consists of relatively impermeable rock types and was not mineralized except where some veins cutting through sandstone layers formed small, locally productive deposits.

Tidwell Member

The Tidwell Member is 49 to 72 ft thick and consists of a prominent light-colored, ledge-forming sandstone unit at the base that is overlain by slope-forming red and gray siltstone and limestone interbedded with some mudstone and sandstone. The dense to crystalline limestone beds, averaging 1 to 1.5 ft thick, are not everywhere present, nor are they persistent laterally.

The resistant, mostly evenly bedded to massive quartzitic sandstone at the base, "bed A" of O'Sullivan (1992, p. 12), here ranges from 14 to 29 ft in thickness and averages 20 ft. It is yellowish white to buff, usually speckled with limonite, and locally stained by desert varnish. The sandstone consists of fine to medium, subangular to well-rounded, frosted and clear quartz grains cemented generally by carbonate or, near intrusive and mineralized zones, by silica. Because of its original permeability and susceptibility to mineralization, the sandstone has been altered to quartzite in the central part of the district. This sandstone unit, an important horizon marker in the stratigraphic section, contains a large number of small bedded ore deposits and was known locally to the miners as the "lower quartzite" to distinguish it from the "upper quartzite" (Dakota Sandstone of Cretaceous age) about 700 ft stratigraphically above. Locally the unit is capped by a limy mudstone or limestone bed seldom as much as 3 ft thick; this limestone bed, which has been replaced and mineralized in and near the Wanakah mine, was known to the miners as the "Bright Diamond contact" or "upper contact" in that area.

Salt Wash Member

The Salt Wash Member consists predominantly of light-colored, fine- to medium-grained sandstone interbedded with red and gray mudstone. The sandstones are yellowish white, yellowish brown, buff, and pink, and locally are speckled with limonite; at places, the surfaces are stained by bluish-black desert varnish. Composed mainly of quartz but including some chert and feldspar, the subangular to well-rounded grains are cemented by calcareous or siliceous material. The sandstones form lenticular thin to thick beds that pinch and swell along strike. Bedding locally is accentuated by included flakes or semi-flattened pellets of mudstone. Crossbedding is common in individual sandstone beds, and occasionally ripple marks are seen. The tops of individual sandstone beds are gradational, whereas the bottoms are typically sharp and irregular. Joint surfaces are commonly coated with carbonate. A few streaks or thin lenses of pebble-size conglomerate occur throughout the sandstones. Interstratified with the sandstones are a few sandy shale partings and thin- to thick-lensing beds of gray, red, green, and variegated sandy and silty mudstone.

The Salt Wash Member ranges from about 225 to 400 ft in thickness. The number and thickness of mudstone layers increase upward everywhere in the formation, thus making it difficult to pick a contact between this and the overlying Brushy Basin Member. Although not shown on the map, this arbitrary contact, not always at the same horizon, was usually placed at the top of a massive cliff-forming sandstone 20 to 30 ft thick wherever that sandstone was present.

Brushy Basin Member

The Brushy Basin Member consists predominantly of variegated, generally calcareous, well-indurated mudstone and subordinate amounts of sandstone and limestone. The calcareous sandstone and silty limestone are similar to those described in the Tidwell Member.

The Brushy Basin Member averages about 275 ft in thickness. Although generally covered by slide rock, the contact between this member and the overlying Dakota Sandstone locally appears sharp and conformable. However, the contact is undoubtedly an erosional unconformity as indicated by ancient scours—as much as 25 ft deep and 100 ft wide and filled with yellowish-brown sandstone and conglomerate—that are exposed in the west wall of the Uncompahgre River valley northwest of the district, and that are interpreted to be erosional remnants of the Burro Canyon Formation of Early Cretaceous age, found in the Colorado Plateau region to the west.

Dakota Sandstone

The Dakota Sandstone of Early(?) and Late Cretaceous age forms prominent cliffs high on the walls of the Uncompahgre River valley and tributary valleys, and ranges from about 140 to 175 ft in thickness except where extensively eroded in early Tertiary time. It consists locally of one to three different lithologic units throughout the area, each unit having differing physiographic expression and varying compositions of quartzite and shale layers (fig. 8). The quartzose sandstones within the Dakota are commonly well indurated so that the term quartzite is locally appropriate, especially in the vicinity of metalliferous deposits.

The lower unit of the Dakota Sandstone consists of interbedded quartzite and shale above a basal chert-pebble conglomerate. This basal bed and some overlying shale beds may be absent locally or may not be recognized because of lateral facies changes, nondeposition, or intraformational erosion.

The middle unit of the Dakota, consisting of thick permeable quartzite, some quartzitic sandstone, and a few shale partings of variable thickness, is persistent throughout the area. Quartzite in the middle unit occurs as thin to massive lenticular beds that have both graded bedding and torrential cross-stratification, and contains some 2- to 4-in.-thick partings of mudstone and shale, and lenses or streaks of pebble conglomerate. These beds are gray, yellowish tan, white, and buff, and commonly are freckled by limonite specks or stained by bluish-black desert varnish. The sandstone is quartzose, fine to coarse grained, and consists mainly of clear and etched subangular to well-rounded grains mostly cemented by silica but locally by clayey or calcareous material. Shale in the middle unit is gray to black, thin bedded, somewhat calcareous, and very carbonaceous; also, the proportion of shale to quartzite increases upward in this unit. Pebbles in the conglomerate lenses consist of chert, quartz, quartzite, and clay, and may be as much as 1 in. in diameter

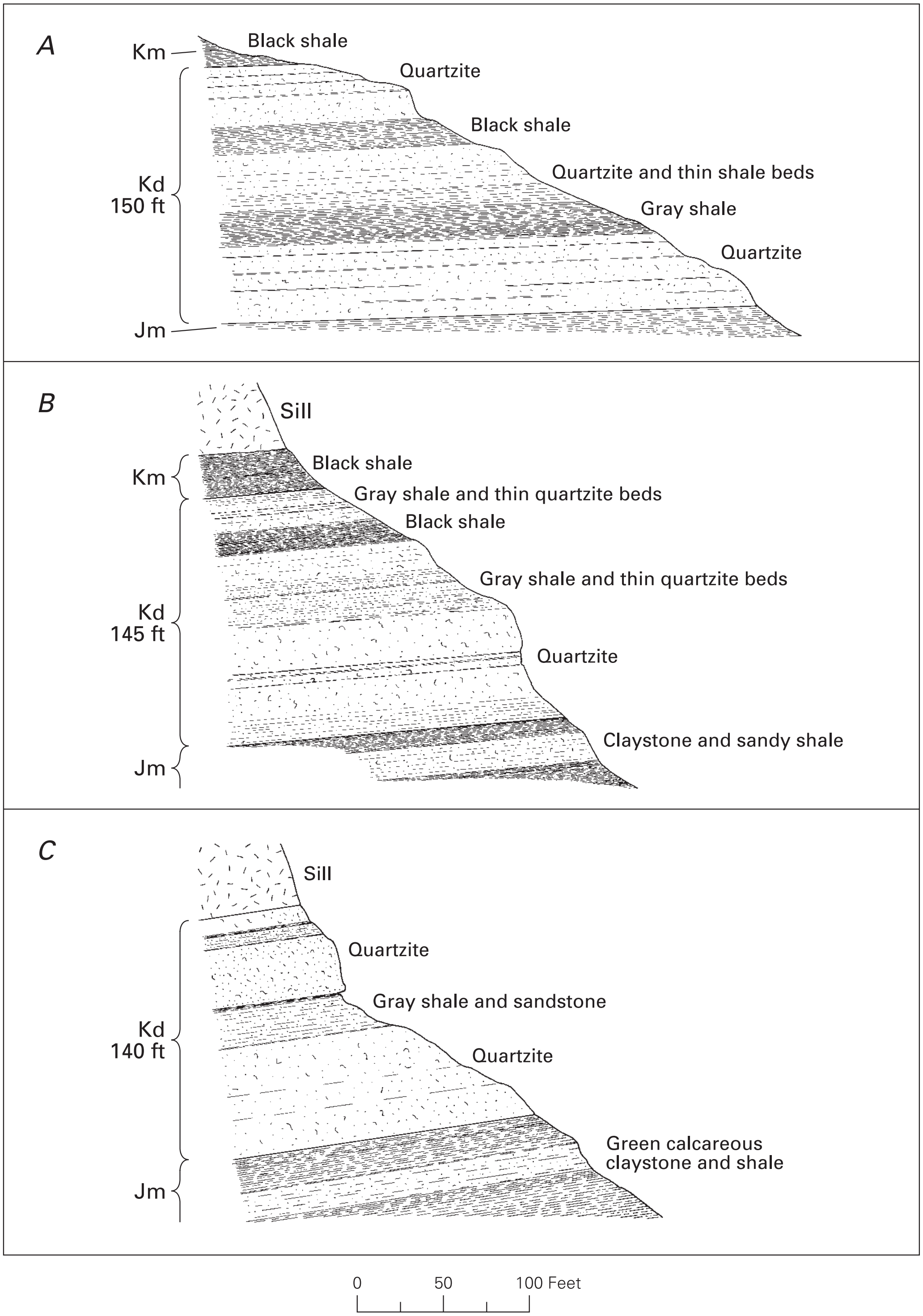

Figure 8. Generalized diagrams showing lithic variations in the Dakota Sandstone and their respective topographic expressions. See figure 4 for approximate locations of sections. *A*, Mill Creek section in the valley of Dexter Creek; *B*, Gold Hill section north of Ouray; *C*, Cascade Creek section east of Ouray and north of The Amphitheater. Km, Mancos Shale (Upper Cretaceous); Kd, Dakota Sandstone (Upper and Lower (?) Cretaceous); Jm, Morrison Formation (Upper Jurassic).

but usually average 0.25 in. The formation contains a few carbonized plant remains.

The upper unit of the Dakota consists of gray carbonaceous shale interbedded with dark-colored quartzite and is compositionally similar to the lower unit. This upper unit is not everywhere present because of erosion in early Tertiary time.

The contact between the Dakota Sandstone and the overlying Mancos Shale is poorly exposed. It is conformable and gradational except near Ouray, where the Mancos appears to lie unconformably on the Dakota. Although not everywhere at the same horizon, this contact was arbitrarily picked either at the top of the uppermost prominent quartzite bed or at the change from carbonaceous shale to calcareous shale.

The Dakota Sandstone was known to the miners as the "upper quartzite." Several important ore-bearing horizons or "contacts" occur within the formation. As previously stated, near mineralized zones the sandstone was converted to quartzite, and, near the larger ore channels, beds were completely recrystallized, hydrothermally leached, and replaced by rich ore in the resulting cave-like open spaces.

Mancos Shale

Small erosional remnants of Mancos Shale of Late Cretaceous age are exposed within the district in small patches high on the cliffs west of Ouray and between The Blowout northward into the canyon of Dexter Creek. Most of the Mancos and younger formations of Cretaceous age that originally covered the area were removed by erosion probably during the later phases of the Laramide orogeny. Within the district, the Mancos ranges from zero to about 325 ft in thickness, but in the ridges to the west and northwest, it is about 2,000 ft thick.

The Mancos consists dominantly of marine, dark-gray to black, fissile shale and platy mudstone and contains a few thin buff sandstone and gray limestone lenses in the lower part. Locally the shale is sandy, carbonaceous, calcareous, or a knobby aggregate of shale concretions. In places, the shale has seams and crosscutting veinlets of coarsely crystalline calcite as much as 0.5 in. thick. Near igneous intrusive bodies, the shale has been metamorphosed to argillite and slate, and may be impregnated with pyrite. Limy parts of the Mancos contain numerous invertebrate fossils, and the basal sandy shale contains many shark teeth.

Shale in the lower part of the Mancos, and possibly shale in the underlying upper part of the Dakota, where present, forms the cap that essentially marks the upper limit of mineralized sedimentary beds in the district. This horizon in the section also had considerable influence upon the igneous intrusive activity related to the Laramide orogeny, because at or near this horizon the magma intruded outward to form sills and laccoliths away from the intrusive center in The Blowout. The blanketing effect of the shale is clearly reflected in the character of the ore deposits related to that intrusive activity.

Tertiary Rocks

Rocks of Tertiary age throughout the district rest upon a profound erosional surface and, except for limited outcrops of an early Tertiary sedimentary unit, consist principally of a thick section of extrusive rocks. There are also a few intrusive dikes of mid-Tertiary age (fig. 4).

The volcanic rocks within the district are part of the so-called early intermediate-composition volcanic rocks (Steven and Hail, 1989) as mapped throughout much of the western San Juan Mountains. These rocks are composed of and characteristic of outflow rocks (volcaniclastic facies) that accumulated as coalescing marginal aprons of numerous scattered stratovolcanoes rather than as the near-source rocks (vent facies). Extensive younger Tertiary lava flows and welded ash-flow tuffs occur to the west, south, and east of the district but are not pertinent to the discussion herein.

There are abundant Pleistocene and Holocene surficial deposits of considerable extent and variety throughout the district.

Telluride Conglomerate

The Telluride Conglomerate of Eocene age (Steven and Hail, 1989) is exposed within the Uncompahgre district only on Hayden Mountain south of the town of Ouray, at the back of The Amphitheater, and at two localities high on the canyon wall southeast of Ouray. These few scattered remnants are preserved in shallow depressions on the underlying erosional surface. The formation formerly overlay a broad erosional surface that transgressed all older metamorphic, sedimentary, and igneous rocks and covered or lapped onto hills formed by the more resistant granodioritic intrusive bodies that existed on the surface in the current vicinity of Ouray. Post-depositional erosion of the formation accounts for the paucity of outcrops. Known to have a thickness in excess of 200 ft elsewhere in the western San Juan Mountains, it here is less than 50 ft thick.

In general, the Telluride is composed of gray to red, well-indurated conglomerate having a silty to sandy matrix. The rounded cobbles and boulders of the conglomerate vary in size but have a maximum diameter of about 1 ft. They consist of metamorphic and igneous rocks mostly from the Needle Mountains area to the south (fig. 1); they also consist of numerous angular to rounded fragments of granodiorite derived locally. Fragments of some of the more resistant sedimentary rocks are commonly incorporated within the lower few feet of the formation. One of the two mentioned small outcrops on the east side of the Uncompahgre River canyon southeast of Ouray, located east of U.S. Highway 550 and just north of Bear Creek (fig. 4), differs from the other exposures of the Telluride in consisting of alternating thin beds of very limy siltstone and conglomerate composed mainly of small plates of slate in a silty matrix.

San Juan Formation

The San Juan Formation of Oligocene age forms steep rounded slopes and cliffs and is prominently exposed high on the valley walls east and west of the Uncompahgre River. Its thickness varies within and near the map area in part because of pre- and post-depositional erosion and in part because of presumed distances from volcanic sources for the debris. At the back of The Amphitheater the formation is more than 3,000 ft thick. Based upon a few radiometric ages determined elsewhere in the western San Juan Mountains region, the rocks of dominantly volcanic origin were deposited probably between 35 and 30 Ma (Lipman and others, 1970).

Southwest of the map area in figure 4, along the valley of Canyon Creek, a twofold division by Burbank (1930) of the formation into the lower Canyon Creek Member and the upper Sneffels Member can be extended into the map area only with some uncertainty. In general, the lower part of the formation is from 300 to 1,200 ft thick, comprises the most important cliff-forming part of the formation, and differs from the upper part in being a more heterogeneous mixture of volcanic debris with interbedded conglomerate beds; the conglomeratic layers are characterized by containing distinctly rounded, water-worn volcanic fragments that impart a crude layering or bedding to the formation when viewed from a distance. The lower hundred feet also includes foreign fragments of pre-Tertiary rocks similar to those in the underlying Telluride Conglomerate. The upper part of the formation is about 1,500 ft thick, is more uniform in textural composition (more finely porphyritic lava containing numerous feldspar phenocrysts), and with fewer conglomeratic beds than in the lower part.

The San Juan Formation has been propylitically altered and thus is characteristically gray to greenish gray, grading locally to shades of red and purple depending on the degree of alteration. The formation consists of a chaotic accumulation of moderately indurated, mostly water-reworked sandy tuffs or air-fall ash beds, tuff conglomerates, tuff breccias (fig. 9), some agglomerates, flow breccias, and a few lava flows. The fragments range in size from microscopic to blocks several inches, locally a foot or more, across. Mudflow (lahar) deposition probably accounts for the major part of the pyroclastic detritus constituting the San Juan Formation where exposed in the district. Sources of the debris are not fully established, but most of it within the district probably came from a volcano or cluster of volcanoes to the east or south.

Volcanic rocks in the San Juan Formation are predominantly intermediate in composition (table 5), as classified according to the International Union of Geological Sciences (IUGS) system (Le Bas and others, 1986), and range in composition from basaltic andesite to dacite and trachyte (fig. 10). Most of the available chemical rock analyses (table 5) show that the composition of the volcaniclastic rocks clusters on the boundary of the trachyandesite-andesite fields, and that the rocks are dominantly subalkaline according to Irvine and Baragar (1971). The two samples that plot within the basaltic andesite field are from lava flows. Most of the rock fragments are finely porphyritic; the phenocrysts average 1 mm in size, and consist of plagioclase, hornblende, pyroxene, and sparse biotite in an aphanitic groundmass. Labradorite or andesine phenocrysts predominate; they are euhedral to anhedral and commonly zoned and twinned, and have an anorthite content averaging about An_{40}. Hornblende phenocrysts are more common than either those of pyroxene or biotite; however, pyroxene is the principal ferromagnesian mineral in the lava flows. The groundmass is cryptocrystalline, fine-grained or felted, and consists of quartz, potassic feldspar or sodic plagioclase, apatite, and specks of iron ore; where felted, the microlites are sanidine. Relict perlitic structure in the fine-grained felsitic mixtures of quartz and orthoclase indicates that some of the rocks were originally glassy. The mafic minerals typically are altered, whereas the plagioclase may or may not be. Alteration products are carbonate minerals, chlorite, epidote, sericite, clay, secondary silica, iron oxides, and pyrite. In addition to the formation having been weakly to moderately propylitized throughout

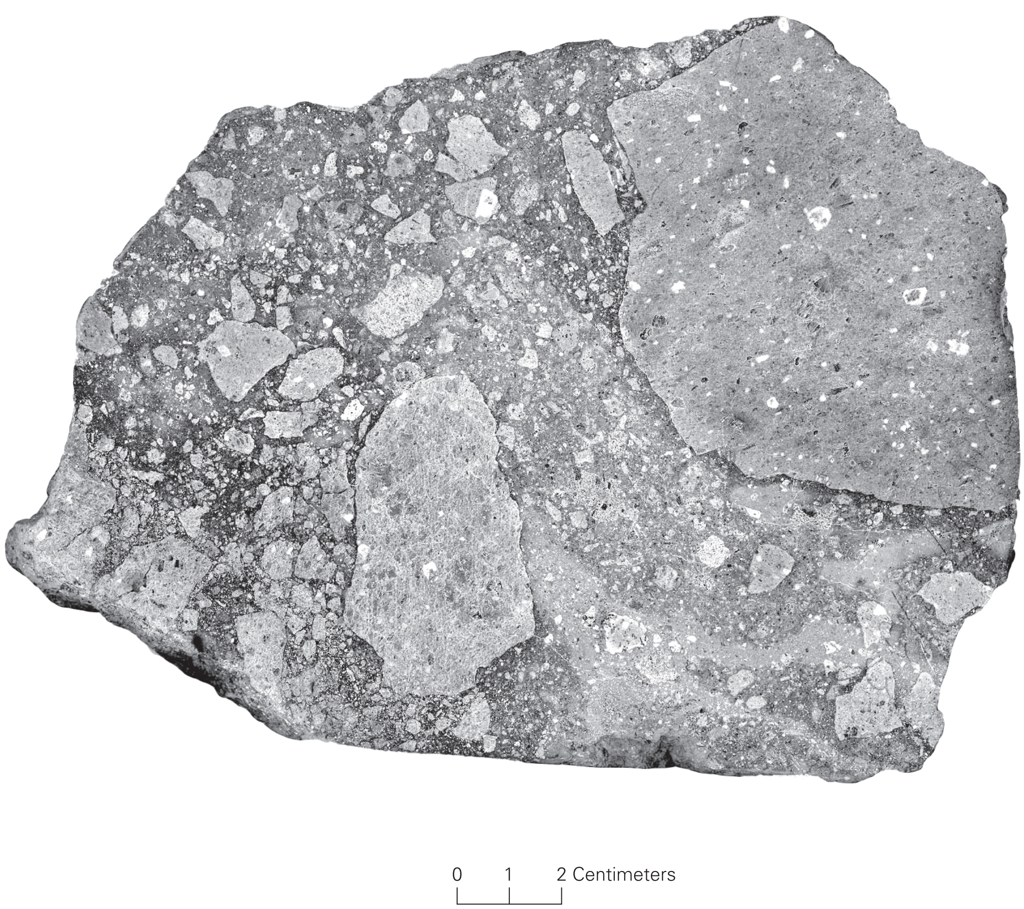

Figure 9. Photograph of polished rock slab of tuff breccia from the San Juan Formation showing the typical chaotic texture of subrounded to angular, porphyritic volcanic rock fragments in a dense matrix of sandy tuff and pulverized volcanic rock. Sample RM39–133 from Red Mountain district south of the Uncompahgre mining district.

Table 5. Chemical analyses of volcanic rocks from the San Juan Formation near the Uncompahgre mining district, southwestern Colorado.

[Analyses by U.S. Geological Survey. Major-oxide data, in weight percent, are from rapid-rock methods by P.D.L. Elmore, S. Botts, G. Chloe, L. Artis, J. Glenn, H. Smith, and J. Kelsey. Trace-element data, in parts per million, are from semiquantitative spectrographic methods by H.C. Worthing, J.C. Hamilton, and J.L. Harris. N, not detected, at limit of detection; L, detected, but below limit of determination; --, no data]

	Lava flow				Tuff breccia									
Sample no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Field no.	**58I51**	**60I45**	**67W1**	**70W2**	**63T4**	**66W25**	**66W22**	**66C2**	**59SJ5**	**63SJ123**	**63SJ124**	**66SJ8**	**66SJ2**	**63SJ125**
Lab no.	**W157572**	**W157673**	**W169359**	**W175091**	**W174233**	**W175608**	**W175607**	**W175592**	**W157570**	**W174219**	**W174220**	**W175594**	**W175593**	**W174221**
SiO_2	52.80	52.80	61.90	61.00	59.20	61.40	57.30	55.50	59.60	61.90	59.00	60.40	59.90	62.00
Al_2O_3	16.10	15.70	16.40	17.10	17.40	17.40	17.60	16.70	16.60	16.50	17.30	17.70	16.40	17.00
Fe_2O_3	5.60	4.30	3.30	3.00	5.20	3.30	7.00	5.60	5.30	3.40	5.30	4.40	4.30	5.80
FeO	4.20	6.10	1.70	1.90	2.00	2.10	0.76	1.60	0.62	1.50	0.96	1.60	2.50	0.60
MgO	4.10	3.60	0.73	1.80	0.90	1.80	1.50	3.80	1.70	1.70	1.90	0.93	2.70	0.92
CaO	8.20	8.60	4.90	5.10	3.20	4.60	5.70	5.00	5.10	4.60	5.90	0.35	5.80	4.50
Na_2O	2.50	2.30	3.70	3.60	4.00	3.80	3.90	3.30	3.10	2.60	3.50	3.80	3.30	3.60
K_2O	1.80	0.97	3.00	3.20	2.20	3.20	2.60	3.10	2.50	3.50	3.00	5.10	1.40	3.10
H_2O	2.20	2.30	1.74	2.21	2.50	1.45	2.30	3.20	3.70	3.19	2.00	1.45	2.53	1.10
TiO_2	1.20	1.10	0.60	0.65	1.00	0.61	0.83	0.74	0.65	0.56	0.73	0.68	0.85	0.79
P_2O_5	0.39	0.39	0.24	0.32	0.39	0.27	0.37	0.40	0.32	0.26	0.33	0.26	0.20	0.33
MnO	0.16	0.16	0.07	0.08	0.05	0.08	0.13	0.13	0.08	0.08	0.16	0.08	0.10	0.04
CO_2	0.16	2.10	1.50	0.05	2.00	0.05	0.05	0.20	0.00	0.05	0.05	0.05	0.05	0.05
Total	99	100	100	100	100	100	100	99	99	100	100	100	100	100
Powder density	2.80	--	2.65	2.52	2.76	2.68	2.68	2.68	2.57	2.52	2.60	2.68	2.68	2.64
Bulk density	--	--	2.60	2.53	2.73	2.49	2.48	2.42	--	2.40	2.58	2.02	2.52	2.43
Ba	700	300	1,000	1,500	1,000	1,000	1,000	1,000	150	1,000	1,000	1,000	1,000	1,000
Be	N	N	1	N	2	1	N	N	N	2	2	N	N	2
Ce	N	N	200	200	200	300	100	100	N	300	200	100	100	200
Co	30	30	15	10	10	10	10	15	15	10	15	10	15	15
Cr	30	15	7	30	5	10	10	20	3	10	20	20	20	20
Cu	30	150	30	15	5	15	10	10	15	10	20	10	5	15
Ga	7	7	10	15	15	15	15	15	7	15	15	15	15	15
La	30	N	70	70	70	100	70	70	30	100	70	70	70	70
Mo	N	N	3	5	3	5	N	N	N	3	N	3	3	3
Nb	15	N	5	10	10	10	10	7	N	10	10	10	10	7
Ni	15	30	N	10	N	5	3	20	N	N	N	7	10	L
Pb	15	300	70	7	20	10	5	5	15	10	10	5	7	7
Sc	30	7	7	15	30	10	15	15	7	10	15	10	20	10
Sr	1,500	1,500	700	1,500	1,500	1,500	2,000	2,000	1,500	1,000	1,500	2,000	1,000	1,500
V	300	70	100	100	150	100	100	100	70	50	70	70	150	50
Y	30	7	50	50	30	30	30	30	30	30	30	30	30	30
Yb	3	N	5	5	3	3	3	N	3	3	3	N	N	3
Zr	150	30	200	150	150	150	150	150	150	300	150	150	150	200

Sample descriptions and (or) locations:

1. Near Bimetallist mine on southeast slope of Potosi Peak, Ouray County; 37°58’48” N., 107°44’10” W.
2. Bench at north end of Hayden Mountain, altitude 11,637 feet (ft), Ouray County; 37°59’16” N., 107°40’26” W.
3. Altered rock; near head of upper basin of Wildhorse Creek, Ouray County; 38°01’16” N., 107°35’06” W.
4. Valley bottom of West Fork of Cimarron River, Hinsdale County; 38°04’52” N., 107°32’43” W.
5. Altered rock; lower east side of Bridal Veil basin, San Miguel County; 37°54’43” N., 107°46’09” W.
6. Saddle in ridge between Middle and East Forks of Cimarron River, Hinsdale County; 38°04’55” N. 107°30’20” W.
7. Altered rock; ridgetop south of Courthouse Mountain, Hinsdale County; 38°06’51” N., 107°33’42” W.
8. East slope of Cimarron Ridge south of Courthouse Mountain, altitude 11,200 ft, Hinsdale County; 38°08’00” N., 107°34’05” W.
9. Altered rock; east side of Chimney Rock, altitude 11,000 ft, Hinsdale County; 38°08’49” N., 107°34’02” W.
10. Near top of Owl Creek Pass, west side of Cimarron Ridge, Ouray County; 38°09’48” N., 107°34’01” W.
11. Altered rock; West Fork of Cimarron River, Gunnison County; 38°11’22” N., 107°31’36” W.
12. Altered rock; East side of northern Dike Ridge, Gunnison County; 38°12’14” N., 107°31’36” W.
13. West side of northern Dike Ridge, Gunnison County; 38°12’20” N., 107°32’42” W.
14. Altered rock; East Fork of Cimarron River, Gunnison County; 38°13’24” N., 107°30’52” W.

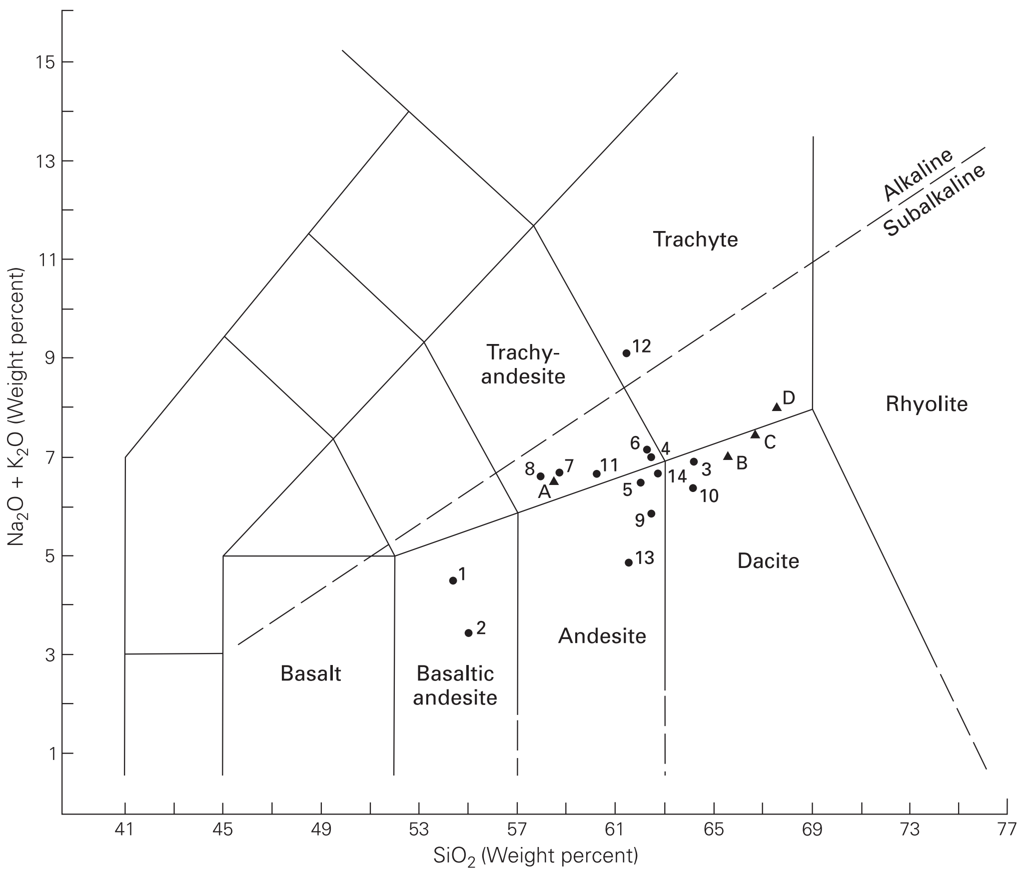

Figure 10. Total alkali-silica variation diagram, with the International Union of Geological Sciences (IUGS) classification grid (Le Bas and others, 1986), showing the composition of rock samples from the San Juan Formation (table 5) and of the Tertiary dikes (table 10). Alkaline-subalkaline division is that of Irvine and Baragar (1971). Major-element oxides were recalculated 100 percent volatile free. •, San Juan Formation; ▲, Tertiary dikes.

the district (although to a lesser degree in the northeastern part), it also was sericitized in the southern part.

The profound erosional unconformity at the base of the San Juan Formation represents a lengthy time interval as suggested by the extreme variation in the exposed thicknesses throughout the area, particularly where it overlies the buried laccolithic hills. These relations contribute important evidence as to the age and time involving emplacement of the granodioritic intrusions. At two localities, one near Twin Peaks northwest of Ouray and the other high on the south side of Dexter Creek valley, finely comminuted debris of the formation are seen draped over and into joint cracks in the spheroidally weathered granodiorite that has as much as a 1.5-in.-thick weathered rind.

A few veins and associated rock alteration of mid- to late Tertiary age occur within the San Juan Formation within the district, such as at the Portland mine located in The Amphitheater. The majority of important ore deposits of this age are located to the south, southeast, and southwest of the district.

Quaternary Deposits

The Uncompahgre district has extensive and varied deposits of Pleistocene and Holocene ages that consist of several types of material and several modes of origin. Most of the deposits consist of unsorted and unconsolidated fragmental material derived from the Uncompahgre River drainage area within a radius of about 6 mi south of the Ouray 7.5-min quadrangle (fig. 4).

The Pleistocene Series is represented by landslide deposits, glacial drift, and lakebed deposits. Landslide deposits consist of locally derived bedrock materials, and have typical hummocky and broken surfaces and flowage features. All gradations exist between small earthflows and larger slumps and block slides. The majority of landslides probably occurred during Pleistocene time, but slumping and sliding on a minor scale have continued to the present.

The isolated masses of glacial drift are considered to be of Wisconsin age, and are not further differentiated according to the stages of Atwood and Mather (1932) or Richmond (1954) because of inconclusive correlation and insufficient data. Most masses of the drift are till, composed of unconsolidated to semiconsolidated, unsorted material ranging in size from clay to boulders; however, some masses locally may include outwash gravels.

The morphology and development of The Amphitheater east of Ouray (fig. 11), which resembles a glacial cirque, and of the large surficial mass considered to be glacial drift occupying the bottom of the basin, is interpreted to be the result of the confluence of two major trunk glaciers where the town is now located. One flowed northeastward down the valley of Canyon Creek, and the other north down the upper Uncompahgre River valley. The angle of impact and the pressure, owing to the massive weight from change in altitude, exerted by the glacier from the southwest pushing into the other glacier may have caused a gradual sapping, or plucking, of bedrock on the opposite side of the juncture to create the bowl shape. The mass of debris within the bowl, subsequent to the retreat of the glaciers, was later subjected to considerable surface slumping and sliding; also, some debris from the oversteepened slopes slumped into the basin. A landslide origin is believed improbable for formation of the basin and its contained mass of debris.

Remnants of former lakebeds were found on the lower part of the valley walls near the mouth of Dexter Creek. They consist of semiconsolidated silt and fine sand that were deposited in a lake formed by the damming of Dexter Creek valley by the lateral moraine of the glacier occupying the Uncompahgre River valley.

Talus deposits composed of angular rock fragments of varying size form cones, aprons, and a general slope cover commonly at or near the base of many cliffs. With the increase of silt and sand, the talus grades into unsorted and unconsolidated colluvial deposits on flatter surfaces, and at the mouths of many gulches and tributary stream valleys into lobate-shaped alluvial fan and cone deposits. Alluvial deposits, found in most stream valleys, are extensive in the Uncompahgre River valley.

Several travertine deposits are associated with active hot springs within the city limits of Ouray. The principal deposit is near Box Canyon and known as the Ouray or Pavillion Hot Spring (see figure 21, no. 33); it contains considerable amounts of metals, especially iron and manganese (table 6). A semiquantitative spectrographic analysis of this manganese oxide-rich material indicates that it contains more than 50 percent manganese and more than 1 percent each of lead and tungsten (Hewett and Fleischer, 1960, p. 41). Bastin (1923, p. 68) cited four water analyses from a hot spring near the old zinc concentrator in Ouray that had water temperatures ranging from 132°F to 152°F and a neutral pH; the waters, with similar solute compositions consisting dominantly of sodium and calcium sulfates and minimal iron and manganese, were being deposited as porous masses of gypsum. He concluded that those analyses failed to indicate conclusively the origin of the spring waters.

Intrusive Rocks

Intrusive activity occurred within and close to a mile or two beyond the Uncompahgre mining district (fig. 12) during three and probably more distinct periods, ranging in age from possibly Proterozoic through late Tertiary. These mostly igneous intrusive rocks have a great range in texture and composition, and their mode of emplacement forms both concordant and discordant bodies that cut rocks in all parts of the stratigraphic section. The intrusive rocks of the Late Cretaceous to early Tertiary Laramide orogeny are the most important within the mining district relative to the emplacement of mineral deposits. Unusual intrusive clastic dikes are closely related to the igneous rocks of the Laramide orogeny.

Diabase

A Proterozoic(?) diabase dike, which intrudes only the Uncompahgre Formation of Proterozoic age, ranges in width from 39 to 150 ft and averages 50 ft. It is vertical to steeply

Figure 11. View looking east into the bowl-shaped Amphitheater, east of the town of Ouray, that was formed by glacial processes at the confluence of two major glaciers moving northward (to the left along the Uncompahgre River valley) during the Pleistocene. At left center are exposed Paleozoic and Mesozoic sedimentary rocks; exposed in the back are volcaniclastic rocks of the Oligocene San Juan Formation. The light-colored rocks in the center and right foreground (roadcuts) consist of Mississippian limestone faulted against Proterozoic quartzite and slate. The bottom of The Amphitheater is covered by glacial debris exhibiting slump and slide features.

Table 6. Analyses of travertine deposits and water from the Ouray (Pavillion) Hot Spring within the town's city limits, Uncompahgre mining district, southwestern Colorado.

[Modified from Burbank and Luedke, 1961, 1969. gpm, gallons per minute; --, not looked for. Samples nos. 1–8: semiquantitative spectrographic analyses, in percent; the following elements were below these limits of sensitivity, in percent: Ag, 0.0002; B, 0.001; Cd, 0.005; Ga, 0.0005; Bi, 0.001; Sc, 0.001; Ge, 0.002; In, 0.001; Ta, 0.005; Ni, 0.0005; Co, 0.0005; Sn, 0.001. Analyses by U. Oda and E.F. Cooley, U.S. Geological Survey; samples collected by D.E. White and R.W. Lakin, U.S. Geological Survey. Sample no. 9: chemical analysis, in parts per million. Analysis by H.C. Whitehead, U.S. Geological Survey; sample collected by D.E. White and R.W. Lakin, U.S. Geological Survey]

	Ouray Hot Spring Deposits								Ouray Hot Spring Water	
Sample no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Sample no.**	**9**
Lab no.	**58–1138S**	**58–1139**	**58–1140**	**58–1141**	**58–1142**	**58–1143**	**58–1144**	**58–1145**	**Lab no.**	**850**
Fe	0.1	0.7	0.3	0.7	0.2	0.7	0.5	7	SiO_2	49
Mg	0.07	0.07	0.15	0.1	0.07	0.07	0.03	0.15	Fe	0.42
Mn	50	30	7	3	3	3	2	15	Mn	0.92
Ba	0.7	0.7	0.07	0.03	0.03	0.05	0.03	0.7	Ca	376
Be	0.03	0.03	0.001	0.001	0.0005	0.001	0.001	0.015	Mg	6.1
Cr	0.007	0.007	0.001	0.0005	0.0005	0.0005	0.0005	0.0015	Na	111
Cu	0.05	0.03	0.0007	0.0005	0.001	0.0005	0.0005	0.0015	K	8
La	0.01	0.01	0.005	0.005	0.005	0.005	0.005	0.005	Li	1
Mo	0.003	0.003	0.001	0.001	0.0015	0.001	0.001	0.001	HCO_3	128
Pb	1	0.7	0.015	0.005	0.003	0.005	0.003	0.07	SO_4	1,030
Sb	0.5	0.3	0.02	0.02	0.02	0.02	0.02	0.02	Cl	45
Sr	0.5	0.5	0.2	0.2	0.15	0.1	0.1	0.5	F	3
Ti	0.003	0.002	0.005	0.002	0.002	0.007	0.001	0.03	PO_4	0.06
V	0.015	0.01	0.001	0.002	0.001	0.0015	0.001	0.002	B	0.23
W	1	1	0.07	0.03	0.03	0.03	0.03	0.2	H_2S	--
Y	0.003	0.003	0.001	0.001	0.001	0.002	0.002	0.002	Solids	1,760
Zn	0.3	0.2	0.02	0.02	0.02	0.02	0.02	0.02	pH	6.8
Zr	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.003	Temperature, in °F	143
									Discharge, in gpm	15

southwest dipping, and although somewhat irregular in trend, having many angular bends, strikes northwest (see figs. 4, 12).

The diabase is dark greenish gray to black and weathers brownish gray. It is fine to medium grained and is composed of labradorite and augite in a subophitic to ophitic (diabasic) texture. Interstitial accessory minerals are magnetite and apatite. Both the labradorite and augite are partly altered to calcite; the augite also is partly altered to penninite. Where the rock is highly altered, its composition of labradorite, quartz, carbonate, and secondary biotite partly altered to chlorite, together with a somewhat granular-appearing texture, is suggestive of a lamprophyre similar in composition to a kersantite described by Cross, Howe, Irving, and Emmons (1905) in the Needle Mountains area (fig. 1).

Like the enclosing Uncompahgre Formation, the dike has been sharply truncated by erosion and is overlain by nearly horizontal Paleozoic strata. It therefore was interpreted to be of Proterozoic(?) age. However, other diabase dikes within Proterozoic terrane in and adjacent to the San Juan Mountains are now suggested to be of Cambrian or Ordovician age, as based upon a Rb-Sr whole-rock date of 510±60 Ma obtained from a diabase dike in the Black Canyon of the Gunnison River, more than 30 mi northeast of Ouray (Hansen and Peterman, 1968).

Porphyritic Granodiorite

The most intense intrusive activity within the Uncompahgre mining district was during the Laramide orogeny of Late Cretaceous to early Tertiary time and consisted of the intrusion of concordant and discordant igneous bodies in a zone near Ouray. Most prominent are the laccolithic domes intruded at or near the Dakota Sandstone-Mancos Shale contact. These plutons surround and were connected to a central conduit in The Blowout that now is occupied by a small stock; this approximately 2,000- by 2,000-ft, square-shaped, intrusive-filled channel, with two western prongs, is somewhat eccentrically located with respect to the outcrop area of the laccolithic bodies. A few thin dikes and sills that intruded into the Paleozoic and Mesozoic sedimentary rocks were possible channels for magma supplied to the laccoliths, particularly the laccolith-like mass between Angel Creek and Canyon Creek (fig. 12). The thickness of the larger laccolithic bodies exceeded 1,500 ft, and, at the time of intrusion, it is estimated that they were overlain by about a mile of Upper Cretaceous impervious shales. Early during emplacement of the laccoliths, the shales served as a blanket effectively preventing the escape of magmatic emanations; internal alteration concurrent with crystallization thus was greater within the laccolithic bodies than if they had been intruded into a more permeable environment. Thermal metamorphism of the country rock adjacent to most of the laccoliths was slight. The stock in The Blowout, however, is surrounded by a contact metamorphosed and hydrothermally altered zone varying from several hundred to a couple thousand feet in width.

The intrusive rocks are remarkably uniform in composition and the few chemical analyses (table 7), all from different parts of the individual intrusive bodies, show little variation. The rocks are granodiorite (fig. 13), which is characteristically porphyritic with phenocrysts in a light-gray, fine- to medium-grained groundmass. Petrographic examination of numerous thin sections indicated only minor textural, mineralogical, and alteration differences. Phenocrysts constitute about 45 percent of the rock and consist of plagioclase, hornblende, biotite, and quartz. Both plagioclase and hornblende phenocrysts are as much as a centimeter long and, particularly near contacts, have a linear parallelism. The plagioclase is dominantly andesine (An_{40}); it is commonly twinned and many grains exhibit oscillatory zoning. In one thin section examined, at least ten major oscillations were counted in addition to other minor ones. The groundmass consists of quartz, orthoclase, and minor sodic plagioclase and biotite, with common accessory apatite, sphene, and iron oxides. Typical alteration products within the rock are chlorite, sericite, calcite, quartz, clay minerals, pyrite, and a little epidote.

The laccolithic bodies were emplaced probably by a single injection of magma of remarkably uniform composition, as inferred partly from internal structures within the laccolithic bodies as well as from their relations to the main feeding channel in The Blowout. Additional magma, probably from deeper sources, was emplaced as vertical dikes and small bodies within the limits of the feeder channel.

A detailed petrographic and chemical study by Burbank (l936) of the emplaced laccolithic body connected to and extending northward to northeastward from The Blowout to Dexter Creek determined its composition to be a sodic granodiorite. Chemical analyses (table 7, samples 3 and 4) and calculated mineralogical compositions and modes (table 8), however, show that any change in the chemical character of the granodiorite was not the result of regional sodic enrichment due in part to a widespread, uniform hydrothermal alteration of rocks of the same composition and of contemporaneous origin closely following the intrusive and extrusive period (Cross and others, 1907, p. 10) but instead was almost entirely the consequence of arrested crystallization in different stages of this magmatic history. In conjunction with the course of crystallization, Burbank (1936, p. 237–238) established the fact that the most pronounced changes in composition of the magma took place during the later stages of crystallization. With the exception of the oxides of iron, a comparatively high ratio of sodium to calcium, and an intermediate potassium content, little difference between the other constituents was indicated in the chemical compositions of these three rock samples. From near the chilled margin of the so-called American Nettie sill, which is really the southern tapered edge of the Dexter Creek laccolith, sample 3 (fig. 14) shows that the formation of modal oligoclase in the laccolith was entirely the result of a more complete reaction and attainment of equilibrium between the earlier formed phenocrysts and the residual magmatic liquid. Crystallization in the so-called sill was arrested at an earlier stage than in the thicker and larger part of the laccolithic body with the consequence that this rock (sample 3) contained only about 15 percent by volume of plagioclase phenocrysts as compared to a rather uniform content of 40 percent in the part of the laccolith indicated by sample 4. The plagioclase phenocrysts in sample 3 are zoned from labradorite (An_{55}) to oligoclase (An_{25}), whereas this zoning elsewhere in the laccolithic body was nearly all destroyed. A reaction, within the sill, between the labradorite and oligoclase cores of the crystals and the magmatic liquid presumably formed orthoclase that affected 5 to 10 percent of their volume. Also, within this part, some but not all of the original hornblende and biotite was unaltered, but in the central part of the laccolith the ferromagnesian minerals reacted completely with the magmatic liquid to form sodic plagioclase, magnetite, orthoclase, epidote, apatite, chlorite, rutile, and other minor reaction products. As deduced from the modal calculations (table 8), there was no introduction of sodium after crystallization.

Alteration of the porphyritic granodiorite in the laccolithic bodies is interpreted to be in part the result of magmatic crystallization beneath an impervious shale blanket that nearly surrounded the laccoliths and lessened the escape of residual magmatic fluids, although it is thought that the stock later vented to the surface. The effect of those fluids upon the intratelluric crystals thus was much greater in the earlier stages of crystallization than would have occurred in a body intruded into a more permeable rock environment. The later stages of crystallization consequently correspond more closely to and overlap the early stages of mineralization. This fact, to be discussed later, can be clearly shown by comparing of processes of contact metamorphism and mineralization that took place near the magma conduit (The Blowout) with the later stages of crystallization within the laccolithic bodies.

Few age data are available for the porphyritic granodioritic rocks. Isotopic ages have been determined only for the laccolithic body between Angel and Canyon Creeks and for the intrusive body in The Blowout. Armstrong (1969) and Cunningham and others (1994), respectively, obtained a K-Ar age of 50.6 Ma and apparent fission-track ages on zircon of 40.7±6.9 and 54.1±4.0 Ma for the Canyon Creek granodioritic body. Billings (1980) reported fission-track data on zircon and apatite; the zircon ages ranged from 27±3 to 47.5±3 Ma for the Canyon Creek body and 31±3 to 49±4 Ma for the stock in The Blowout, and the apatite ages were too young and erratic. We consider all of these ages to be too young; possibly they represent a localized occurrence of alteration and mineralization or younger heating events. Several lines of field evidence mentioned earlier (p. 26) prove beyond a doubt that the intrusives are older and were formed during the Laramide orogeny. Other isotopic data, obtained and reported by Taylor (1974) on

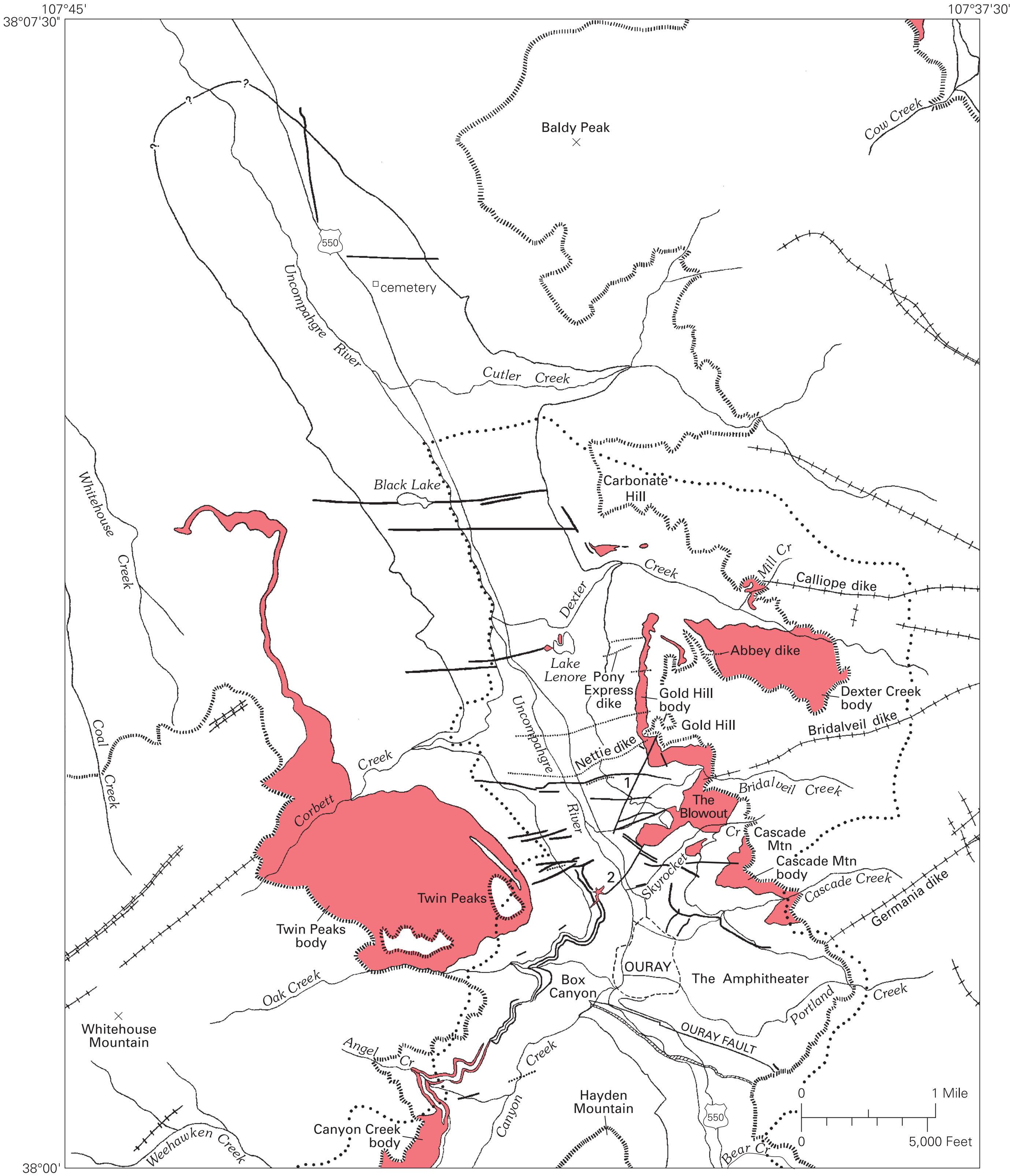

Figure 12. Generalized geologic map showing distribution of intrusive rocks in a stock, dikes, laccoliths, and irregular-shaped masses within the Uncompahgre mining district and the Ouray 7.5-min quadrangle, southwestern Colorado (modified from Luedke and Burbank, 1962, 1981).

EXPLANATION FOR FIGURE 12 (FACING PAGE)

Cretaceous to Tertiary igneous rocks

Other rocks

Limit of volcanic rocks

Tertiary igneous dikes

Cretaceous to Tertiary igneous sills and dikes: 1, Jonathan dike; 2, Speedwell dike

Cretaceous to Tertiary clastic dikes

Proterozoic(?) diabase dike

Contact; queried where uncertain

Boundary of Uncompahgre mining district as shown in Luedke and Burbank (1981)

Table 7. Chemical analyses of porphyritic granodiorite of Late Cretaceous to early Tertiary age in and near the Uncompahgre mining district, southwestern Colorado.

[Analyses by U.S. Geological Survey. Major-oxide data, in weight percent, are from standard and rapid-rock methods by J.G. Fairchild (samples 1, 2, and 4), C. Milton (sample 3), J.J. Fahey (sample 5), and P.L.D. Elmore, I.H. Barlow, S.D. Botts, G. Chloe, L. Artis, J. Glenn, H. Smith, and J. Kelsey (samples 6, 7, 8, and 9). --, no data]

Sample no.	1	2	3	4	5	6	7	8	9
Field no.	O35–55	O–16337	--	O34–20	O–07238	O–57–105	66D1	67W7	67W8
Lab no.	--	--	--	--	--	157568	169345	173362	169362
SiO_2	63.15	67.34	65.38	65.02	65.35	65.20	64.90	57.30	59.10
Al_2O_3	16.78	16.59	15.41	15.83	16.09	16.50	15.90	15.70	16.40
Fe_2O_3	3.39	1.54	1.97	2.13	2.69	2.00	2.80	3.70	3.10
FeO	2.79	1.86	2.19	1.56	1.40	1.50	1.00	2.60	2.80
MgO	1.83	0.75	1.43	1.14	1.33	1.30	0.80	1.90	1.70
CaO	4.27	3.71	2.87	3.32	2.52	3.00	3.70	5.30	4.10
K_2O	2.55	2.96	3.42	3.42	3.34	3.00	2.50	2.60	2.70
H_2O-	0.24	0.11	0.09	0.44	0.14	2.80	0.9	0.81	1.50
H_2O+	1.50	0.95	1.29	1.24	1.26	--	3.10	2.60	1.90
TiO_2	0.56	0.26	0.88	0.40	0.39	0.32	0.33	0.75	0.62
CO_2	0.15	0.20	0.27	0.15	0.19	0.06	0.05	4.30	1.50
P_2O_5	0.06	0.08	0.09	0.12	0.06	0.18	0.17	0.38	0.39
MnO	0.10	0.04	0.23	1.23	0.58	0.10	0.13	0.08	0.18
BaO	0.08	0.08	0.09	0.03	--	--	--	--	--
Cr_2O_3	--	--	--	--	0.03	--	--	--	--
SO_3	--	--	--	--	0.04	--	--	--	--
FeS_2	--	0.62	--	--	--	--	--	--	--
Total	100.39	100.65	99.74	100.06	99.85	99	100	100	99

Sample descriptions and locations:

1. Small crosscutting body on south side of Skyrocket Creek, altitude about 8,750 feet (ft); 38°02’07” N., 107°39’51” W.
2. Stock in lower part of The Blowout, near Horsethief Trail, altitude about 8,500 ft; 38°02’12” N., 107°40’14” W.
3. Laccolith (sill) above the American Nettie mine, altitude about 9,700 ft; 38°02’46” N., 107°40’16” W.
4. Near base of laccolith south side of Dexter Creek 0.75 miles above the Bachelor mine (Khedive adit), altitude about 9,100 ft; 38°03’27” N., 107°38’47” W.
5. Near top of laccolith, south side of Dexter Creek about 5,000 ft northeast of sample no. 3, altitude about 10,125 ft; 38°03’11” N., 307°39’19” W.
6. Laccolith, ridge top on west side of Cow Creek northeast of the mining district, altitude about 9,200 ft; 38°07’29” N., 107°38’03” W.
7. Ramshorn Ridge intrusive mass on east side of Cow Creek northeast of mining district, altitude about 8,100 ft; 39°08’19” N., 108°08’11” W.
8. Dike in Red Creek northeast of the mining district, altitude about 8,400 ft; 38°07’23” N., 107°36’54” W.
9. Dike in Red Creek northeast of the mining district, altitude about 8,600 ft; 38°07’20” N., 107°36’40” W.

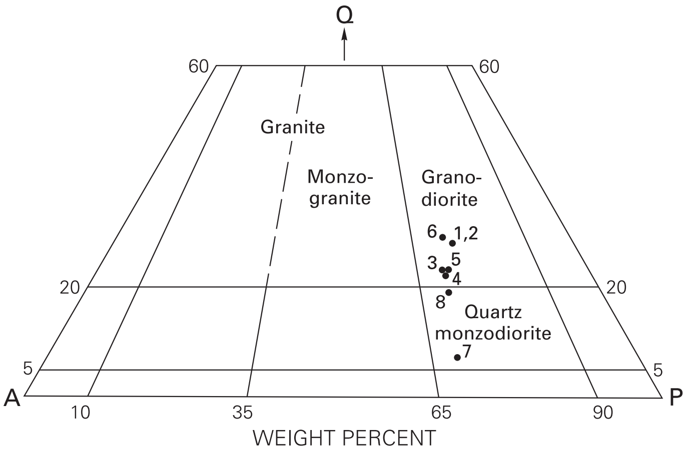

Figure 13. Ternary variation diagram of normative compositions of quartz (Q), alkali feldspars (A), and plagioclase (P), using the diagram of the International Union of Geological Sciences (IUGS) classification and nomenclature (Streckeisen, 1976), of silicic plutonic rocks (table 7) in the Uncompahgre mining district and Ouray 7.5-min quadrangle, southwestern Colorado.

the Canyon Creek intrusive body, were $\delta^{18}O$ of +3.2 and δD of –145; he states that both numbers are low and are indicative of large-scale transport and interaction between circulating ground waters and the igneous intrusions. Taylor (1997) later included the Ouray sample location, based upon values determined on hypogene clay, with the Lake City and Silverton localities as having a $\delta^{18}O$ = –6 to 0 and δD = –150 to –130.

Altered Porphyritic Rocks

The group of altered porphyritic igneous rocks, as classified in the field (see Luedke and Burbank, 1962), consists of several dikes, sills, and irregular-shaped bodies that intrude the Paleozoic and Mesozoic strata along the Uncompahgre River valley mostly in the northern part of the mining district, particularly near the junction with Dexter Creek valley (fig. 12). Most of the dikes average about 6 ft in width and occupy vertical, west-trending fractures. The circular to irregular-shaped bodies at Lake Lenore and north of Dexter Creek, respectively, appear to be upward enlargements or sheet-like offshoots of dikes at depth. The igneous mass west of Lake Lenore, about 195 ft in width, has very irregular contacts and tapers at both the east and west ends into dikes having nearly vertical walls. Also included in this group are a dike in Angel Creek, southwest of Ouray, and a dike on the south side of The Amphitheater.

This nondescript group of rocks is somewhat porphyritic with very small phenocrysts in a dark-gray or green aphanitic groundmass. Feldspar phenocrysts are mostly or completely altered; the mafic phenocrysts are completely altered. The latter, judging from their crystal outlines, were probably amphibole, pyroxene, biotite, and possibly olivine in that order of abundance. The few tabular phenocrysts commonly

Table 8. Calculated mineralogical compositions and modal analyses of porphyritic granodiorite, samples 3 and 4 from table 7.

[After Burbank (1936, p. 238) and used with permission of American Geophysical Union]

Sample no.	3		4	
	Mineralogical compositions			
Quartz		22.98		21.00
Orthoclase		15.11		17.29
Albite		34.58		33.50
Anorthite		12.04		13.53
Biotite[1]		9.17		6.90
Hornblende[1]		1.44		2.92
Magnetite		2.28		1.65
Hematite		0.20		0.90
Apatite		0.62		0.35
Total		98.42		98.04
	Approximate modal analyses			
Phenocrysts		26.00		51.10
Quartz	0.50		2.50	
Orthoclase	0.50		0.60	
Plagioclase	15.00	(An_{55-25})	40.00	(An_{25-30}) [2]
Ferromagnesians[1]	10.00		8.00	
Groundmass		74.00		48.90
Quartz	22.00		19.00	
Orthoclase	14.60		16.50	
Plagioclase	31.00	(An_{20})	7.00	(An_{25})
Accessories[3]	6.40		6.40	
Total		100.00		100.00

[1]Proportions of hornblende and biotite from modal analyses; these minerals largely resorbed to magnetite and chlorite.

[2]Includes some albite.

[3]Accessories include magnetite, hematite, chlorite, epidote, rutile, titanite, apatite, and calcite.

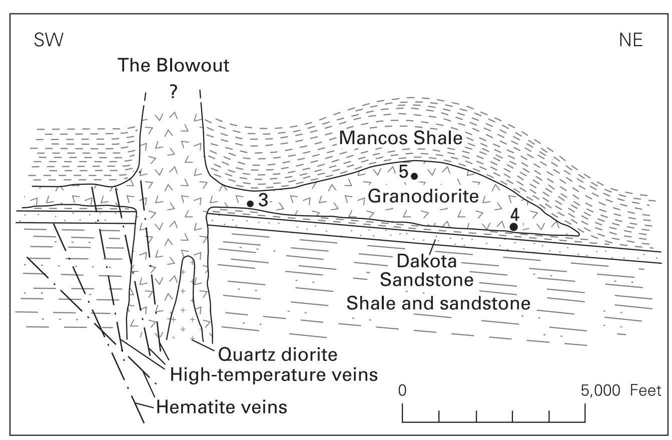

Figure 14. Generalized geologic cross section showing relation of Dexter Creek laccolith to feeding channel of the granodioritic magma in The Blowout, Uncompahgre mining district, southwestern Colorado. Numbers show relative positions of analyzed samples 3, 4, and 5 in table 7 (no. 3 lies 2,500 ft north of plane of section). Veins strike about east. Modified from Burbank (1936, p. 241) and used with permission of American Geophysical Union.

are aligned near the margins of the dikes. The groundmass is a cryptocrystalline to fine-grained aggregate of felsic minerals, or a felted to pilotaxitic aggregate of feldspar laths. Interstitial material is mostly quartz, apatite, and alteration products, the latter consisting mostly of sericite, chlorite, calcite, iron oxides, and clay minerals and smaller amounts of quartz, leucoxene, and sulfides. Most of these rocks are vesicular; the separate body at Lake Lenore contains, in addition, a large number of sedimentary rock inclusions. Chemical analyses (table 9) of these altered bodies suggest a granodioritic to quartz monzodioritic composition (fig. 13), but because these rocks are so intensely altered, any rock name must be stated with reservation.

A particularly unusual feature of the dikes in the north part of the mining district is that they appear to terminate upward in the Morrison Formation of Jurassic age. The dike on the south side of The Amphitheater is cut off at the early Tertiary erosion surface and is overlain by the San Juan Formation. The age of these intrusives is uncertain, but based on rock characteristics, structural relations, and associated ore deposits, they are thought to be Late Cretaceous to early Tertiary rather than late Tertiary.

Clastic Dikes

Closely associated with the granodioritic intrusives are several dikes of intrusive origin, but of clastic or non-igneous composition, occupying east-trending fractures. At least eight of these dikes crop out within the mining district and intrude the stratigraphic section beneath the early Tertiary erosion surface. The best known dikes are those in the Bachelor-Pony Express group of mines and in the American Nettie mine.

The clastic dikes average about 4 ft thick but pinch and swell, ranging from a few inches to 10 ft in width. Contact with the unaltered wall rock is sharp. The dikes are composed of angular to subrounded fragments of pre-Tertiary metamorphic, igneous, and sedimentary rocks, some undoubtedly of deep origin, in a gray to green matrix of similar but pulverized material (fig. 15*A*, *C*). Fragmental quartz, feldspar, biotite, chlorite, and calcite are the common constituents of the matrix. The dikes have textures ranging from that of an angular breccia to that of a rock closely resembling conglomerate. Size and shape of the fragments vary within a single dike as well as between different dikes; the clasts average about an inch in diameter but may be as large as 5 in., and the shape (roundness) depends upon the amount of particle attrition during intrusion.

Fragmentation is thought to have been contemporaneous with the forceful intrusion along a concurrently established fracture system as a result of a sudden escape of vapor from a buried intrusive center. Injection under pressure is indicated not only by the roundness of the fragments and, locally, by a mortar-and-pestle grinding effect from fragmental abrasion, but also by alignment of platy fragments (fig. 15*B*, *D*) parallel to the dike wall and by small-scale piecemeal stoping. Orientation of many of the fragments in the dikes in the Bachelor and Calliope mines indicates there were both vertical and horizontal components of movement; the latter in some cases was equal to or greater than the former. In the upper levels of the Bachelor mine, the clastic dike along strike contains many angular dark shale fragments derived from the Dakota Sandstone and perhaps the Mancos Shale (fig. 15*B*), whereas in the lower levels of the mine dark shale fragments are sparse. The position of the dike with shale fragments in the upper levels of the Bachelor mine suggests that the fragments were injected from east to west (fig. 16); the regional eastward dip indicates the shale beds are deeper to the east than at the west.

The origin of these clastic dikes has been variously interpreted. Ransome (1901), in describing the clastic dike in the upper mine workings of the Bachelor group, recognized that some of the included rocks were from the fissile black shales of Cretaceous age and not shales in older beds stratigraphically lower. Therefore, he postulated the dikes to have been fractures, filled chiefly by rock fragments from above, that were later aligned by fault movement. Downer and DeCou (1901) briefly describe these unusual dikes in their discussion of the Bachelor ore deposits, but only questioned Ransome's interpretation without further speculation upon their

Table 9. Chemical analyses of altered intrusive bodies of Late Cretaceous to early Tertiary age from the Uncompahgre mining district, southwestern Colorado.

[Analyses by U.S. Geological Survey. Major-oxide data in weight percent; analyses are from standard rock methods by J.G. Fairchild]

Sample no.	10	11	12
Field no.	O34–40	O34–35	O–06219
SiO_2	44.02	60.92	64.81
Al_2O_3	16.94	15.84	15.73
Fe_2O_3	4.19	2.20	1.37
FeO	3.54	3.24	1.79
MgO	1.94	1.84	0.94
CaO	9.27	3.55	4.01
Na_2O	2.03	3.65	3.52
K_2O	6.36	3.36	2.54
H_2O^-	0.48	0.32	0.49
H_2O^+	2.90	2.12	1.87
TiO_2	0.81	0.62	0.26
CO_2	7.01	2.32	2.81
P_2O_5	0.31	0.25	0.12
MnO	0.32	0.12	0.14
BaO	0.13	0.05	0.03
Total	100.25	100.4	100.43

Sample descriptions and locations:

10. Extremely altered rock; dike about 4,000 ft north of Dexter Creek; 38°04'12" N., 107°41'04" W.

11. Intrusive plug on north side of Dexter Creek valley northeast of Lake Lenore, altitude about 9,353 ft; 38°04'02" N., 107°40'35" W.

12. Intrusive body on peninsula in Lake Lenore; 38°03'27" N., 107°40'57" W.

origin. Irving (1905) also briefly described the same dikes, and considered them to be a consolidated mass of black shale and other country rock fragments that formed as a friction breccia within the fracture, later reopened, and locally mineralized. In 1923, Spurr described the clastic dikes in the Bachelor and Pony Express mines as sand or breccia dikes formed by the opening of a fracture that was filled by an upwelling mass of mud composed of detritus of the underlying rocks; this mud was then dammed in its ascent by shale beds, but with continued upward pressure, the mud burst the so-called dam to continue its ascent and, in addition, gather fragments of the shales, which were then aligned parallel to the fracture walls.

An important association exists between the clastic intrusions and hydrothermal activity. Mineralizing solutions followed a course similar, in part, to that of the mostly earlier-formed clastic injections, moved along the same fractures, and locally deposited ore in veins and blanket deposits.

Porphyritic Andesite and Quartz Latite

The youngest intrusive rocks are dikes emplaced in mid- to late Tertiary time in the western San Juan Mountains (fig. 12). The Germania dike at the head of The Amphitheater, the Bridalveil dike in the valley of the same name, the Calliope dike in Dexter Creek valley (fig. 17), and several unnamed dikes northeast and east beyond the limits of the mining district, all intrude the Oligocene San Juan Formation. These dikes are related to, and occupy fractures radial to, the mid-Tertiary Cow Creek intrusive center about 5 mi to the east (Luedke, 1972; Steven and Hail, 1989). The central stock in the similar Cimarron intrusive center, another center 7 mi farther northeast, has a zircon fission-track age of 30.2 Ma (Steven and Hail, 1989). Dikes exposed west of the mining district (fig. 12) are related to the mid-Tertiary Mt. Sneffels intrusive center to the west-southwest that has K-Ar and fission-track ages respectively of 32.7±1.0 and 32.5±4.6 Ma (Lipman and others, 1976). Many of these vertical or nearly vertical younger dikes, locally more resistant than the country rock, are extensive and average about 10 ft in thickness.

These dikes vary in composition (fig. 10) and texture, but for descriptive purposes were classified in the field as either andesite or quartz latite. All of these dike rocks are slightly to moderately porphyritic, having phenocrysts 2 or 3 mm in size in a dense aphanitic groundmass.

Dikes cropping out mostly west of the district (fig. 12) and classified as porphyritic andesites (Luedke and Burbank, 1962) have phenocrysts of augite, hypersthene, labradorite, and minor olivine in a felted to pilotaxitic groundmass of plagioclase microlites. Interstitial materials are pyroxene, apatite, quartz, and iron oxides. Locally, the pyroxene phenocrysts occur in clusters that impart a glomeroporphyritic texture to the rock. Alteration products are calcite, chlorite, epidote, clay minerals, iron ores, celadonite, and quartz. The rock is dark greenish gray and weathers brownish gray.

Figure 15 (facing page). Photographs of polished rock slabs of intrusive clastic dikes in the Uncompahgre mining district, southwestern Colorado, showing a variety of compositions and textures. ***A***, Dike exposed at creek level in Canyon Creek valley (fig. 12) contains rock fragments of varying shapes and sizes from the underlying Proterozoic basement of quartzite (qe) and slate (sl), with Paleozoic sedimentary red-bed mudstone (ms) and sandstone (ss) in a matrix of small fragments of altered rhyolite (r) and pulverized materials. Sample O35–92. ***B***, Dike at the breast of drift on the Syracuse tunnel level (east end), north of the Pony Express vein, in the Bachelor mine located east of the Uncompahgre River valley and south of Dexter Creek valley (pl. 4). Platy, mostly black shale (sh) fragments with a somewhat subparallel orientation are interspersed with lighter colored, round to angular, very fine-grained sandstone (ss) and quartz (q) fragments. Included also are rounded fragments of schistose greenstone (gs) derived from the underlying Proterozoic basement. Sample O–06224. ***C***, Short dike exposed high on east side of the Uncompahgre River valley, southeast of the Pony Express dike (fig. 12). Clasts with a variety of shapes and compositions indicate the entire geologic section, exluding that of Tertiary age, was traversed. Granite (gr), gneiss (gn), schist (sch), slate (sl), sedimentary (sed), quartz (q), and clay (c) occur in a matrix of pulverized to finely ground rock fragments. Sample O34–48. ***D***, Oriented specimen of the Bachelor dike from a short drift east from the Syracuse tunnel level in the Bachelor mine, located east of the Uncompahgre River valley and south of Dexter Creek valley (pl. 4). Platy black shale fragments of Mancos Shale (Cretaceous) in a gray pulverized matrix suggest both horizontal and vertical components of movement (from east to west; see fig. 16). Fragments were presumably derived downdip at a shallow depth. Sample O35–38.

Most of the dikes east and northeast of the district (fig. 12) are tan to light-brownish-gray, moderately porphyritic dacite or trachyte (table 10, samples B–D; fig. 10) that contain phenocrysts of hornblende, biotite, quartz, and plagioclase (oligoclase-andesine) in a groundmass of varying textures. In some dikes, the groundmass is cryptocrystalline to fine-grained aggregates of potassic feldspar, sodic plagioclase, and quartz, whereas in others, the groundmass is felted or pilotaxitic orthoclase and sodic plagioclase laths with interstitial quartz, biotite, and apatite. Alteration products consist of calcite, chlorite, chalcedony, and iron oxides.

The Germania dike, a dark greenish-gray, more mafic variety (table 10, sample A), was classified as trachyandesite (fig. 10). It weathers brownish gray. The rock consists of phenocrysts of hornblende, andesine, and sparse augite in a felted to pilotaxitic groundmass of plagioclase microlites. Interstitial materials include apatite, quartz, and iron oxides; alteration products are calcite and chlorite.

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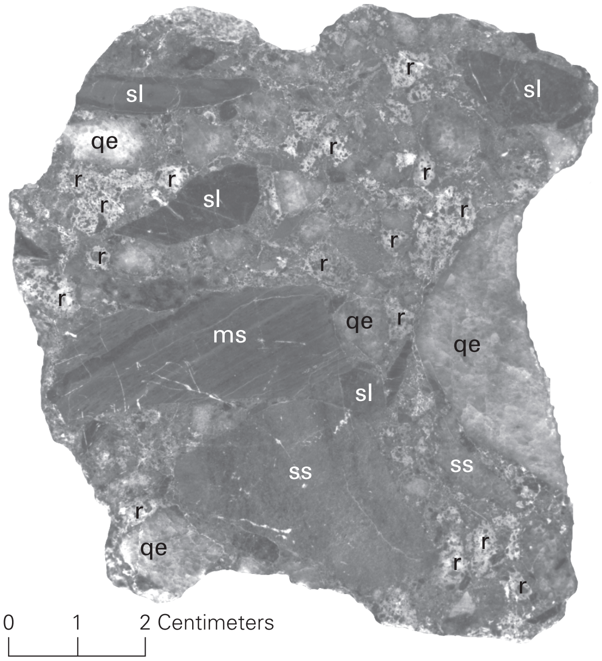
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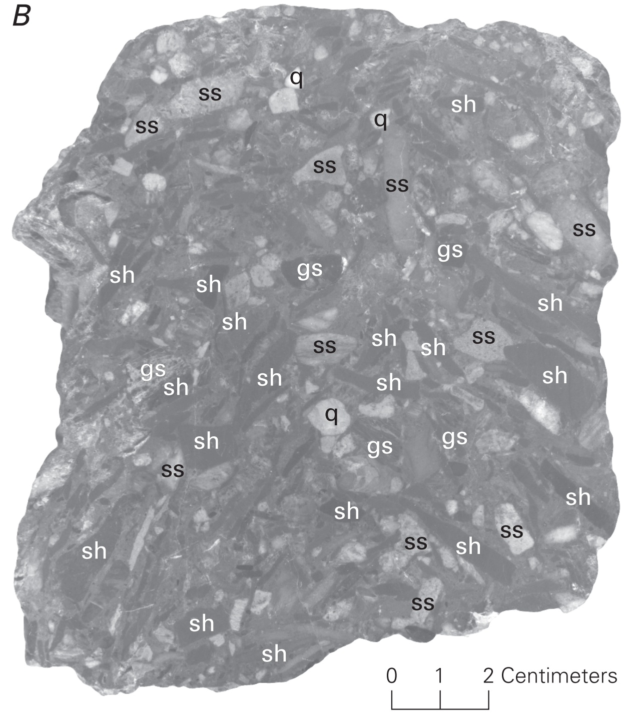
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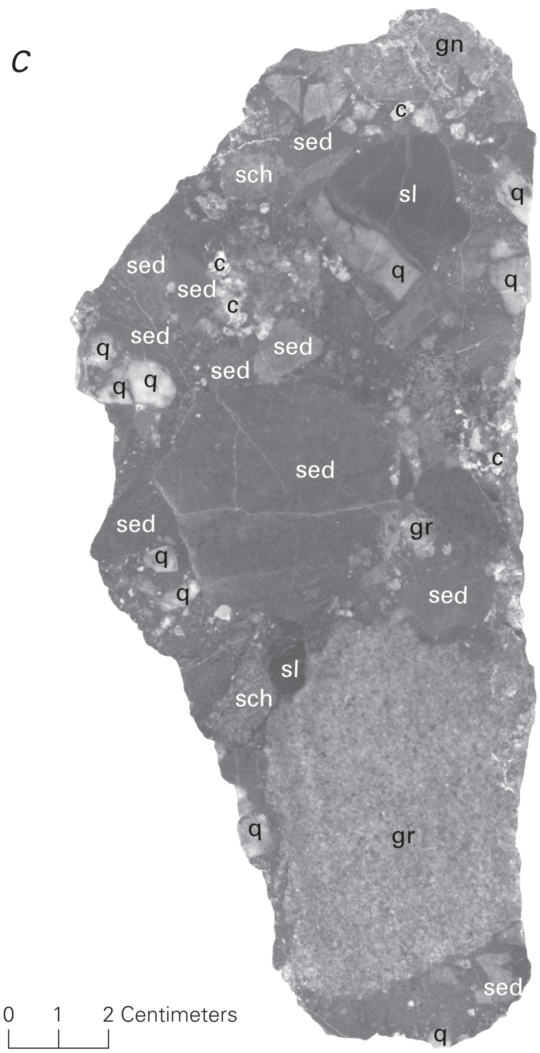
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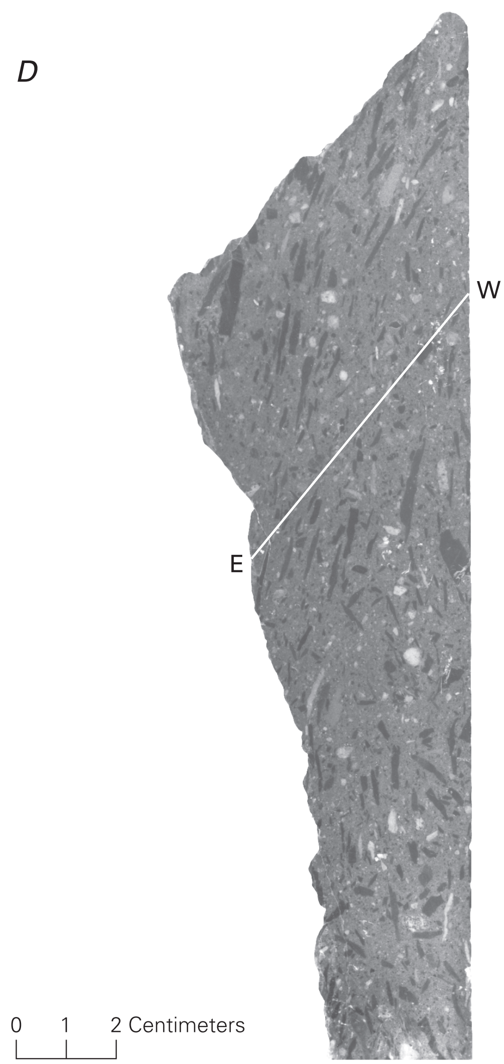
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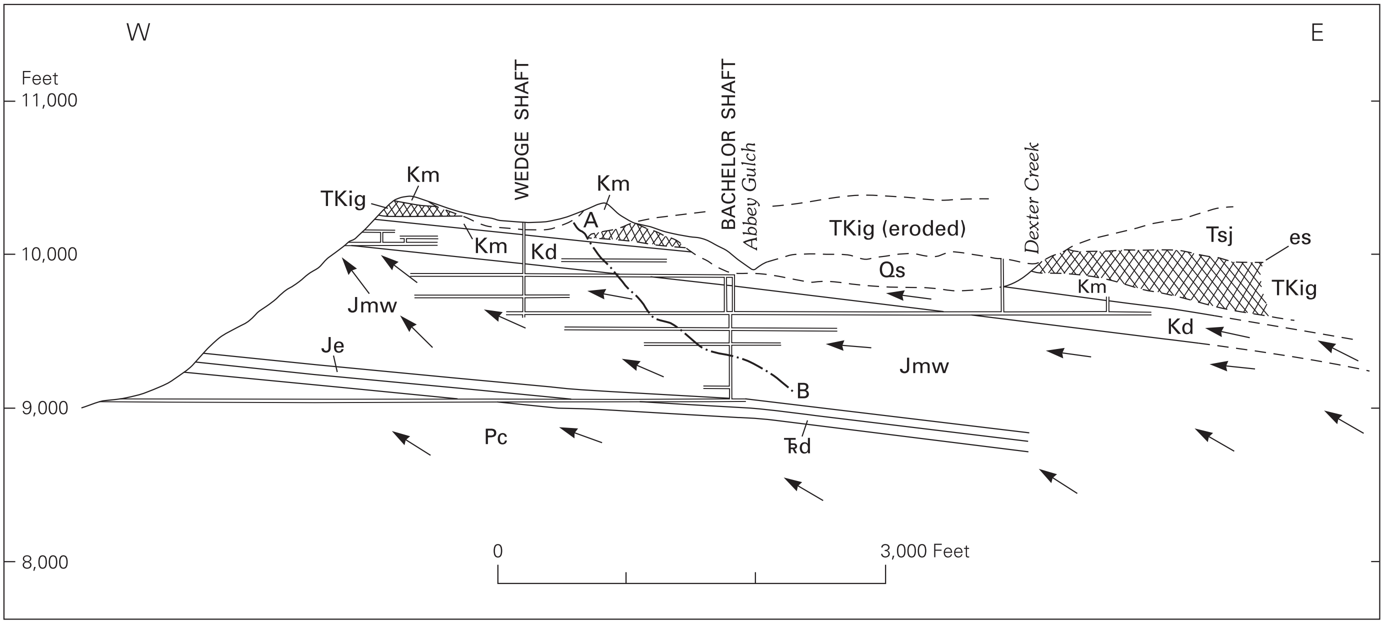

Vertical exaggeration 1.2x

Figure 16. Longitudinal section along the plane of the Bachelor mine workings, vein, and clastic dike indicating the probable course (arrows) of the clastic dike injection. Line A–B is the junction of the Bachelor fracture and the south split or Pony Express fracture. Pc, Cutler Formation; Ꞧd, Dolores Formation; Je, Entrada Sandstone; Jmw, Wanakah and Morrison Formations, undifferentiated; Kd, Dakota Sandstone; Km, Mancos Shale; TKig, intrusive granodiorite; Tsj, San Juan Formation; Qs, landslide debris; es, early Tertiary erosion surface. Modified from Burbank (1930, p. 198).

Structure

Structures within the Uncompahgre mining district, and the Ouray area in general (fig. 18), are typical of the western border region of the San Juan Mountains and are characteristic of deformation closely associated with mountain building. At least three different periods of deformation are visibly marked by major unconformities within the area; the oldest period undoubtedly occurred well within its timeframe, but the middle and younger periods more-or-less represent the closing phases of major divisions of geologic time. Each period differed in certain respects from the others: in general, the intensity of deformation decreased through time, whereas associated igneous activity increased. Rocks of Proterozoic age, only, were faulted and folded by strong compressive deformation; this deformation was accompanied or followed locally by minor intrusive activity. In late Paleozoic time (Rocky Mountain orogeny), domal uplift of the western San Juan Mountains region resulted in folds and faults apparently with little or no accompanying igneous activity. Deformation in late Mesozoic to early Cenozoic time (Laramide orogeny) resulted in a renewal of domal uplift and additional folds and faults that in part paralleled the earlier structural trends. This deformation, however, was accompanied locally by considerable magmatic activity and an early period of mineralization, making the area a part of the southwest extension of the Colorado Mineral Belt (Tweto and Sims, 1963). Each of these three different periods of deformation was followed by extensive and widespread erosion prior to deposition of the overlying strata. Also, numerous crustal disturbances between these major periods of deformation are indicated by erosional unconformities and gaps within the stratigraphic sequence.

Deformation during mid- and late Cenozoic time, representing a fourth major period, occurred south of the area and has minor significance locally. This period was distinguished by widespread volcanic activity that resulted in formation of the San Juan and Silverton calderas and related intrusive centers, and that was accompanied by multiple episodes of alteration and mineralization.

Proterozoic Structure

Rocks of Proterozoic age exposed in the Uncompahgre River canyon south of Ouray (figs. 4, 18) afford only an incomplete picture of the regional structure formed during this timeframe. This limited exposure of rocks is bounded by the west-northwest-trending Ouray fault, of unknown extent, presumably related to ancient and deep crustal structures of east-west trend in the western San Juan Mountains region (Tweto, 1987, p. A46 and pl. 1). However, within the Rocky Mountains of southwestern Colorado, the Ouray area is regionally located along or close to a major northeast-trending shear zone and crustal province boundary (1.65 Ga deformation) established in Proterozoic time (Karlstrom and Humphreys, 1998; CD-ROM Working Group, 2002).

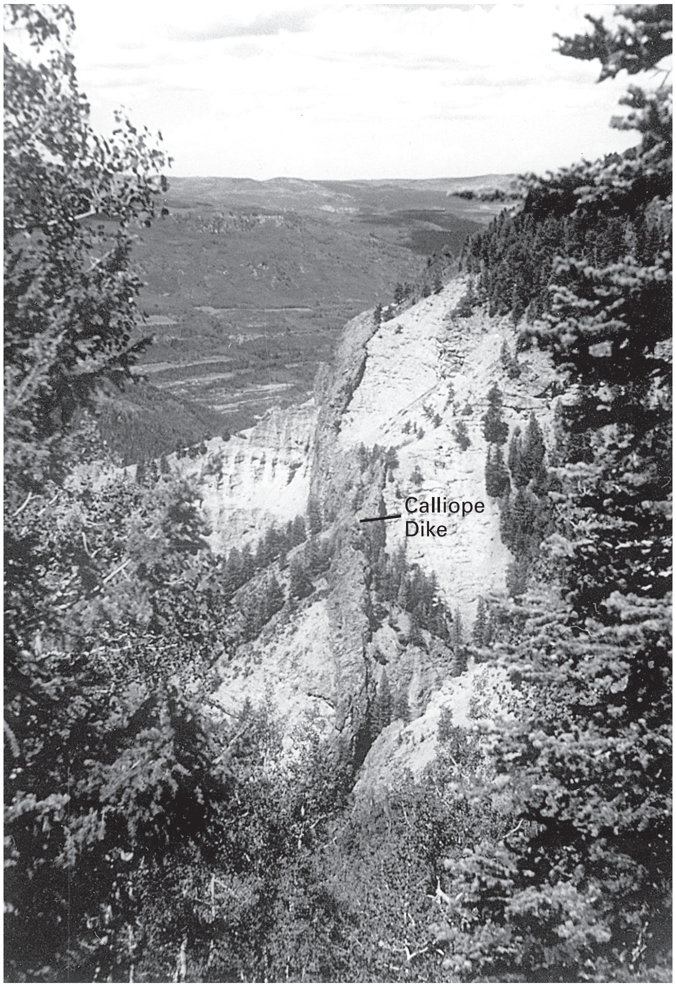

Figure 17. View looking west along the Tertiary (Oligocene) Calliope dike, in the valley of Dexter Creek, toward the Uncompahgre River valley (benches formed on sedimentary beds along the west side) and the Uncompahgre Plateau (skyline) to the northwest. The dike, radiating out from a volcanic center located in the Difficulty Creek-upper Cow Creek area about 3 mi to the east, strikes about N. 80° W. and dips from vertical to 79° S. It is seen here intruded into volcaniclastic rocks of the Oligocene San Juan Formation.

The metamorphic rocks of the Uncompahgre Formation are conveniently divided on the basis of the prevailing strike and dip of beds into two blocks separated by an arbitrary line marked by a zone of crumpled and faulted beds that extends across the canyon a little south of the diabase dike. In the narrower and smaller northern block, the beds strike west-northwest and dip from steeply south through vertical to steeply overturned to the north; in the larger southern block, the beds strike east-northeast and dip 55°–70° north. The rocks in the northern block, in general, are more intensely metamorphosed than those in the southern block. A few thin beds of slate within the quartzite layer in the northern block were metamorphosed locally to a contorted mica schist owing to intrusion of the diabase dike.

Table 10. Chemical and spectrographic analyses of Tertiary porphyritic igneous dikes of mafic to intermediate composition in and adjacent to the Uncompahgre mining district, southwestern Colorado.

[Analyses by U.S. Geological Survey. Major-oxide data, in weight percent, from rapid-rock methods by P.L.D. Elmore, I.H. Barlow, S.D. Botts, and G. Chloe. Trace-element data, in parts per million, from semiquantitative spectrographic methods by K.S. Hazel. N, looked for but not found]

Sample	A	B	C	D
Field no.	O–57–129	O–57–41	O–57–38	O–57–123
Lab no.	154555	154553	154552	154554
SiO_2	56.80	62.00	62.60	65.20
Al_2O_3	16.70	15.80	15.60	15.60
Fe_2O_3	5.40	3.60	1.90	3.50
FeO	2.20	0.53	0.42	0.60
MgO	3.60	1.10	0.58	0.73
CaO	4.80	3.50	5.20	2.50
Na_2O	3.40	3.20	3.60	2.60
K_2O	2.90	3.40	3.60	5.20
H_2O	3.20	3.50	2.80	2.20
TiO_2	0.64	0.44	0.24	0.44
P_2O_5	0.40	0.22	0.13	0.20
MnO	0.17	0.16	0.14	0.08
CO_2	0.06	1.40	2.30	0.62
Total	100	100	99	99
Ag	N	2	3	N
As	100	150	100	100
Ba	700	700	700	700
Be	2	2	3	2
Co	150	15	7	15
Cr	3	3	N	3
Cu	70	150	150	70
Ga	15	7	7	7
La	30	N	30	30
Mo	3	3	7	3
Nb	3	3	3	3
Ni	15	7	7	7
Pb	15	15	30	150
Sc	15	7	7	7
Sn	7	N	N	15
Sr	300	300	300	150
V	150	70	30	70
Y	15	15	15	15
Yb	2	2	2	2
Zr	300	300	300	300

Sample descriptions and locations:

A. Germania dike (trachyte) near head of The Amphitheater; 38°01’57” N., 107°37’56” W.

B. East dike (dacite) on ridge southeast of Mount Baldy; 38°05’27” N., 107°37’51” W.

C. West dike (dacite) on ridge southeast of Mount Baldy; 38°05’26” N., 107°37’53” W.

D. Dike (trachyandesite) in upper Cascade Creek basin; 38°02’10” N., 107°37’39” W.

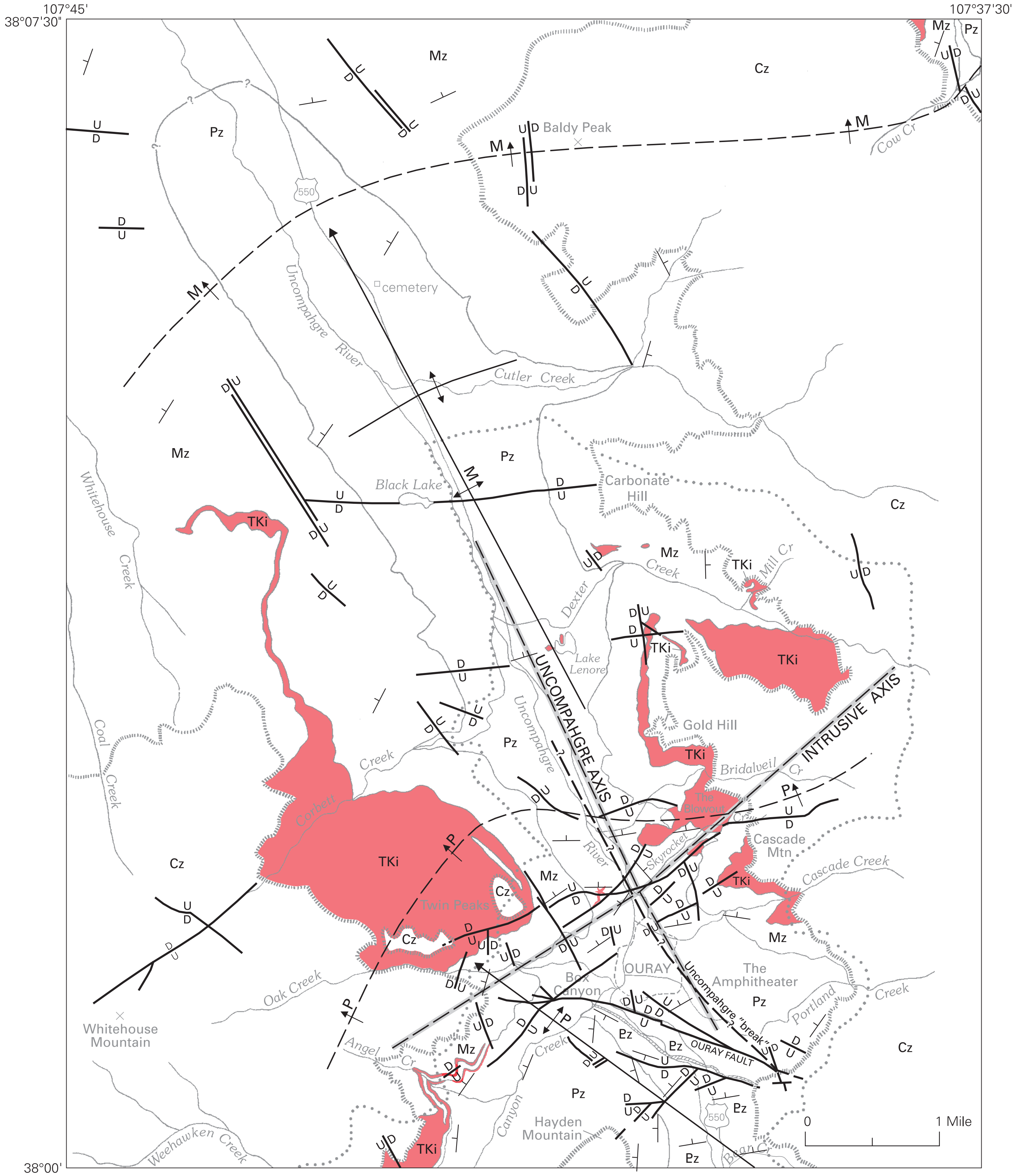

Figure 18. Generalized structure map of the Uncompahgre mining district and the Ouray 7.5-min quadrangle, southwestern Colorado (modified from Burbank, 1940, and Luedke and Burbank, 1962, 1981).

EXPLANATION FOR FIGURE 18 (FACING PAGE)

Symbol	Explanation
Cz	**Tertiary rocks**
Mz	**Mesozoic sedimentary rocks**
Pz	**Paleozoic sedimentary rocks**
Ᵽz	**Proterozoic metamorphic rocks**
TKi	**Cretaceous to Tertiary igneous rocks**
	Limit of volcanic rocks
	Proterozoic(?) diabase dike
	Contact; queried where uncertain
	Boundary of Uncompahgre mining district as shown in Luedke and Burbank (1981)
	Strike and dip of beds
U / D	**Fault**—Dashed where approximately located; queried where uncertain; U, upthrown side; D, downthrown side
M	**Monocline**—Showing approximate trace of fold axis. Arrow barbed on side of steeper dip. M, Mesozoic monoclinal fold; P, Paleozoic monoclinal fold
M	**Anticline**—Showing approximate crest line, and direction of plunge. M, Mesozoic radial axis; P, Paleozoic radial axis

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A fault zone, exposed in the inner gorge east of the Uncompahgre River, strikes about N. 80° W. and dips steeply to the north. Striations on the fault surface plunge 70° W. but probably indicate only the direction of the last movement on the fault. The drag and apparent displacement of the quartzite beds near the fault suggest a relative upward movement of the northern hanging-wall block, but the evidence is not conclusive. On the other hand, faulting within the overlying Paleozoic strata along the west side of the valley, on the extension of this fault zone, suggests that renewed activity resulted in downward movement of the hanging wall. This later movement tended to offset the earlier displacement so that the net result negates the reverse displacement. Whatever the relative displacement, this fault separates Proterozoic blocks of sharply discordant attitudes, and provides evidence for faulting in Proterozoic time.

Along the fault line, the layers of quartzite and slate have been tightly compressed into a west-plunging syncline, the axis of which approximately coincides with the major fault zone east of the river, but turns westward through the fault-bounded slate block (fig. 19*A*) west of the river. Cleavage and drag folds in the slate west of the river suggest the syncline plunges about 40° W. This section (fig. 19*A*) was drawn to include the Ouray fault, which bounds the northern outcrop of the Proterozoic rocks; extensions of the layers and faults in depth are shown chiefly to illustrate the general relations between the different faults and the synclinal axis, and are not considered to be quantitatively accurate. However, field evidence favors the interpretation that the break along the axis of the synclinal fold originated in Proterozoic time.

The diabase dike is presumed to have been intruded into the Proterozoic rocks subsequent to deformation and metamorphism during Proterozoic time; it lacks any effects of the dynamic metamorphism typical of the enclosing beds of the Uncompahgre Formation. The dike occupies a jagged tension fracture, thus suggesting that strong tensional stresses acted upon the Proterozoic rocks prior to Paleozoic time. The dike cuts across bedding in the northern block, which implies, but does not offer conclusive evidence of, later reactivation of inherited Proterozoic breaks. The dike, with the vertical beds of the Uncompahgre Formation, was truncated by erosion. Rocks of Devonian age deposited unconformably upon that erosion surface provide no conclusive evidence for the dike's age being either Neoproterozoic or early Paleozoic (see discussion p. 28).

Paleozoic Structure

The Paleozoic strata in the western San Juan Mountains are exposed in a belt peripheral to the west side of the mountain front. In the Ouray 7.5-min quadrangle, near the northern extremity of this belt, these strata with structures indicative of uplift are exposed for a distance of about 8 mi (figs. 4, 18). Deformation of late Paleozoic age within the Uncompahgre district resulted in relatively simple structures that include monoclinal and anticlinal folds and faults (fig. 18). This period of deformation is readily recognized by means of the local, but profound, unconformity between the Paleozoic and Mesozoic strata, which establishes the age as neither older than Early Permian nor younger than Late Triassic.

The lower part of the Paleozoic section (Devonian and Mississippian) is exposed mainly south of Ouray along the west side of the Uncompahgre River canyon. The upper part of the Paleozoic section (Pennsylvanian and Permian) crops out in the vicinity of Ouray, northward along the Uncompahgre River valley for about 6 mi, and southwestward along Canyon Creek for about 2 mi. For a short distance along the valley at and north of Ouray, the Paleozoic strata dip moderately north to northwest; the strata there are more or less horizontal to where they dip beneath the level of the river valley in a sharp monoclinal fold of late Mesozoic age. About 8 mi to the southwest of Ouray, upper Paleozoic strata reappear in the canyon of the San Miguel River at Telluride (Burbank and Luedke, 1966). Also, about 7 mi northeast of Ouray, a very limited exposure of lower and upper Paleozoic rocks crops out in the valley of Cow Creek (Luedke and Burbank, 1962; Luedke, 1972).

In the general description of the stratigraphy, all Paleozoic units in the Uncompahgre district were noted to be more or less conformable, so that structural features assignable to late Paleozoic deformation collectively apply to all of the units. With Ouray as a focus, the Paleozoic strata dip to the west, northwest, and north (fig. 18; pl. 1). Ouray thus is

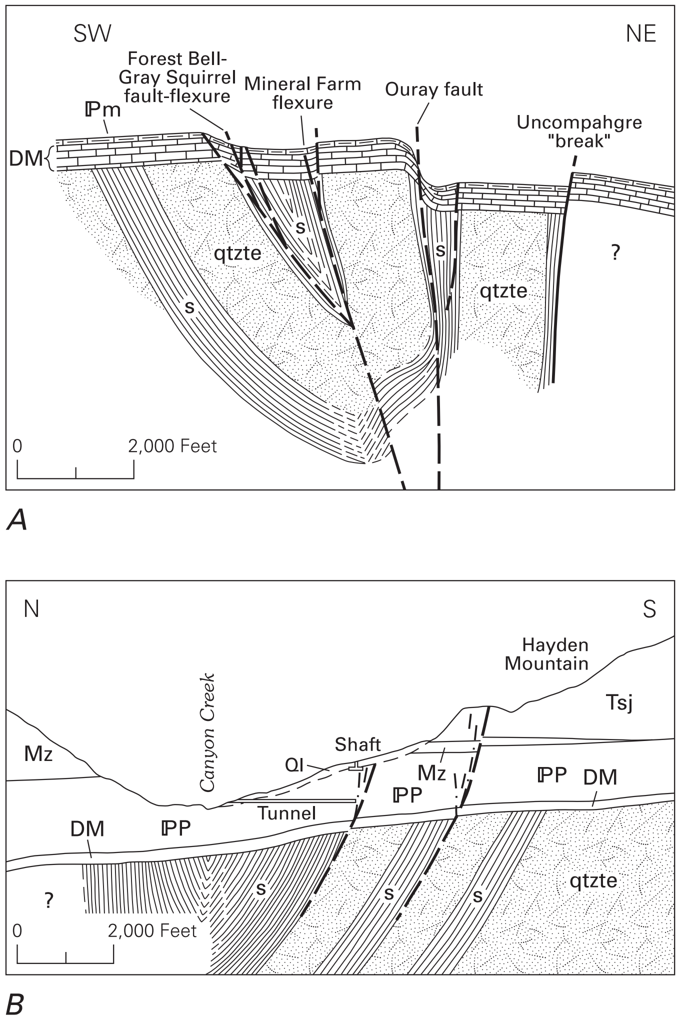


Figure 19. Structural control in the area south of Ouray, Uncompahgre mining district, southwestern Colorado (modified from Burbank, 1940). ***A***, Idealized section, of which the eroded parts of the lower Paleozoic limestones were restored, showing relation of faults and folds in the Proterozoic metamorphic rocks to faults and flexures in the immediately overlying Paleozoic beds. ℙm, Molas Formation; DM, Devonian and Mississippian rocks, undifferentiated; s (slate) and qtzte (quartzite), Uncompahgre Formation. ***B***, Section approximately through the New Mineral Farm mine on the northwest slope of Hayden Mountain showing the approximate position of the concealed syncline in the Proterozoic metamorphic basement rocks; tunnel on the north-striking vein is nearly parallel to plane of section. Ql, landslide mass; Tsj, San Juan Formation; Mz, Mesozoic rocks, undifferentiated; ℙP, Pennsylvanian and Permian rocks, undifferentiated; DM, Devonian and Mississippian rocks, undifferentiated; s (slate) and qtzte (quartzite), Uncompahgre Formation.

located on a nose formed during the Paleozoic uplift of the ancestral San Juan Mountains, perhaps representing some swing or sharp turn along the western flank of the ancient landmass. The surrounding cover of Mesozoic and Cenozoic rocks, however, effectively hides the nature of this feature. On the cross sections (pl. 1), the base of the Triassic Dolores Formation, where not actually transected, has been projected onto the plane of the section in order to help differentiate the effects of the Paleozoic deformation from those of later periods. This erosion surface was presumably a horizontal, featureless plain prior to Mesozoic sedimentation; it is used primarily as a datum to estimate the amount of tilting of the Paleozoic strata. From this datum, the Paleozoic strata on the flanks of the San Juan Mountains uplift declined between 1,000 and 1,200 ft/mi. Using Ouray as the focal point, the beds north of town flattened to almost horizontal within a distance of less than 2 mi, and to the southwest toward Telluride, the beds likewise flattened within about 3 mi. The original extent of these outer flat structural shelves that border the Paleozoic uplift at Ouray is unknown, because Paleozoic strata are not exposed beyond the limits described.

The tilted strata on this northwestern flank of the San Juan uplift do not dip away uniformly but in a series of relatively steep flexures between which the beds have less than average dip. Weimer (1980) referred to these flexures as "paleodrape" folds. These local flexures and the Ouray fault, a major fault which strikes N. 70° W. across the canyon of the Uncompahgre River just south of town, are certainly the more important late Paleozoic structures within the district. Paleozoic strata adjacent to the fault are locally and sharply flexed, whereas the fault has only slightly affected the overlying Mesozoic strata along strike to the northwest. The Paleozoic strata decline about 5,400 ft from the southern edge of the map area to their deepest position in the valley north of Ouray. About 4,000 ft of this amount are the result of tilting, monoclinal folding, and faulting during late Paleozoic time. Most of the Paleozoic displacement occurred within 3 to 5 mi of the faulted margin of the Proterozoic basement rocks. This fact is of significance in interpreting the geologic history of the San Juan Mountains.

Details concerning Paleozoic structures within the Uncompahgre district are conveniently divided between two blocks that are separated by the Ouray fault and the intervening prong-like outcrop of Proterozoic rocks (figs. 4, 18).

Southern Block

Devonian and Mississippian rocks on the bench along the west side of the Uncompahgre River canyon, south of Ouray, are poorly exposed because of a mantle of talus and a covering of soil and timber. Where exposed in gulches and prospect tunnels, the limestone beds exhibit local variations in attitude because of small faults and disordered crumpling where they rest on slate in the underlying Uncompahgre Formation. Most of these minor irregularities are related to faults of Tertiary age, which also cut the overlying Telluride Conglomerate and San Juan Formation. Disregarding these minor variations, the average strike of the strata for about a mile along the high bench is nearly north, with dips of 10°–15° W. (figs. 4, 18). Although the outcrop width on the bench is not great, a westward dip of about 12° suffices to carry the basal Paleozoic units to the top of the quartzite outcrops on the cliff face on the east side of the canyon several thousand feet distant (pl. 1, section *B–B′*). North of the southwest-trending fault that is located west of the river and that cuts the overlying sedimentary beds, there is a moderate steepening of the westward dip of the beds; near Canyon Creek, 4,000 ft to the northwest, the dips are as much as 20°.

Above the bench on the east slope of Hayden Mountain the Hermosa Formation is exposed just beneath the Telluride Conglomerate, but on the west slope it is almost completely covered by landslide deposits. In a few adits and shafts the Hermosa beds dip 12°–13° W. as far as the bed of Canyon Creek. At Angel Creek, a tributary of Canyon Creek, the dips have flattened to between 4° and 10° W. These dips are only a few degrees greater than those of the overlying Triassic beds (pl. 1, section *B–B′*), which dip in the same direction and hence probably are a result in part of a late Mesozoic component of tilting. The Hermosa Formation dips beneath the level of Canyon Creek a short distance to the southwest in the Ironton 7.5-min quadrangle (Burbank and Luedke, 1964). Southwestward from that location, the canyon bottom is underlain by the Cutler Formation, which dips 15°–18° SW., apparently in a series of flexures. At the southwest termination of the Paleozoic outcrops in Canyon Creek, the Cutler dips only 2°–3°.

Sections *A–A′* and *D–D′* (pl. 1), parallel to and across Canyon Creek valley, respectively, illustrate the important structural features of a broad anticlinal nose plunging northwest in the southern block. In this valley southwest of section *A–A′* (pl. 1), the thickness of the Cutler Formation beneath the Triassic unconformity is not known because of inadequate exposures to permit correlation with the type Cutler section; the lithology of the beds in the Cutler indicates that they belong to the lower third of the formation. The southwest part of section *A–A′* thus was based mainly upon structural readings, but the errors in the section are considered minimal. It should be noted that our interpretation of the structure and designation of the Paleozoic strata differ from that of early maps (Cross, Howe, and Ransome, 1905; Cross and others, 1907), in which the valley of Canyon Creek is shown to be underlain by the Hermosa Formation. Our interpretation estimates the depth to the Paleozoic limestone units to be roughly 2,500 to 3,000 ft beneath the base of the Triassic. These limestone units consequently are too deep to be of much immediate interest for mineral exploration.

Northern Block

The Ouray fault, which separates the blocks, was traced over a distance of about 2 mi from the base of the cliffs on the south side of The Amphitheater northwestward to the slopes above Box Canyon (fig. 18). The fault is essentially vertical. An accurate amount of displacement along the fault is difficult to determine, but Paleozoic strata crop out on both sides at each end of the fault and thus permit estimation of the net vertical displacement. At its eastern end, a small wedge of the Elbert Formation and basal part of the overlying Ouray Limestone are exposed in the south wall of the fault; the north wall consists of the Leadville Limestone and Hermosa Formation. Estimation of the exact displacement here is complicated by sharp changes in the dips near the fault and by minor cross-faulting, but the total vertical component of movement on the fault was not less than 400 ft and may have exceeded this amount by 100 ft or more. At the western end of the fault near Box Canyon, the Molas and Hermosa Formations are in contact with Proterozoic rocks, indicating displacement there was not less than 400 ft and possibly was as much as 600 ft. Considering drag and any flexing of beds along the fault, the net displacement between the blocks on the Ouray fault probably was 600 to 700 ft. There is little evidence for any horizontal component of movement along the fault; striations on the fault surfaces are vertical.

In the slopes west of Box Canyon, which are covered partly by glacial drift and talus, continuation of the main Ouray fault is difficult to trace to the northwest. Cross and others (1907, p. 13) thought the fault was Tertiary in age and displaced Mesozoic strata. Traverses of level lines about 1,500 ft long were made along the exposures of the Dolores Formation and the Entrada Sandstone on the mountain slope west of Box Canyon, but the bases of these two formations were found to have been displaced less than 50 ft by either faulting or flexing. The minimal, but consistent displacement, within the Paleozoic units was at least 400 ft along the entire fault length. This establishes that the principal movement on the fault was pre-Dolores.

West of Box Canyon the thickness of the Permian Cutler Formation exposed beneath the angular unconformity provides additional evidence concerning the age of faulting. Its thickness on the north side of the fault is much greater than on the south side. Also, the strike of beds in the Hermosa and Cutler Formations is about N. 65°–80° E. on the north side compared to N. 30° E. on the south side. This consistent relation of strike direction to the projection of the fault and the absence of any appreciable change of bedding attitudes in the overlying Mesozoic strata strongly suggest pre-Mesozoic deformation.

A deceptive but unreal appearance of displacement of several hundreds of feet can be seen along the Ouray fault because of the granodiorite sills within the Cutler Formation farther upslope west of Box Canyon. The sills rise in the stratigraphic section to cut across beds along vertical breaks or splits in the westward trace of the fault, so that the upper sill is between the Entrada Sandstone and Wanakah Formation, a change in position clearly due to some diversion during intrusion, not to faulting of the sill. A similar diversion of exposed sills can be seen along the northwest-trending fault about 1,500 ft southwest of the Ouray fault. Undoubtedly pre-intrusion structures were responsible in part for minor changes in altitude and stratigraphic position of the sills on this fault, but the two sills on the north side are not more than 50 ft thick, thus diversion of a sill in stratigraphic position across the unconformity at the base of the Mesozoic section does not appreciably affect computation of the displacement. Furthermore, both sills thicken immediately south of this fault, giving the appearance, in effect, of more offset than the actual downthrow of 50 ft or less north of the fault. Thus the earlier conclusion that the fault was Tertiary in age is not supported by detailed mapping.

What appears to have been renewed movement at the east end of the Ouray fault on the south side of The Amphitheater was the result of minor downthrow of a narrow wedge of San Juan Formation on the south side of the fault. This movement was opposite to the principal Paleozoic displacement along the main fault and suggests that only minor movement occurred as the result of readjustments during Tertiary time. Renewal of fault activity in Tertiary time, likewise, does not affect the conclusions reached as to the time of the principal displacement on the Ouray fault.

The attitude of the Leadville Limestone changes near the Ouray fault; the Leadville forms the north wall of the fault along much of its exposure in the central part of the canyon, so that where flexed the bedding more or less parallels the fault in strike and dips steeply to moderately north. This relation exists within a narrow wedge from zero to 700 ft wide and about 4,000 ft long (fig. 18). North of this wedge, the beds resume their strike of N. 50°–70° E. As shown on the geologic map (Luedke and Burbank, 1981), the wedge is separated from the main body of northwest-dipping rocks by a fault or zone of flexing that diverges northward from the main trend of the Ouray fault. As this disturbed zone diverges farther from the main fault, the intensity of deformation within the Leadville gradually decreases; this deformation dies out westward, or at least decreases markedly in intensity, at about the presumed location where the Ouray fault crosses a buried contact between slate and quartzite. The relative competency of the underlying rocks traversed by the fault possibly affected the type of structures formed in the overlying beds. This may account for the minor monoclinal flexing in the upper Paleozoic strata along the Ouray fault west of Canyon Creek (pl. 1, section *C–C′*) as compared with the lower Paleozoic strata along the fault on the south side of The Amphitheater (pl. 1, section *F–F′*). This, in turn, possibly may have some bearing on arguments as to the age of the Ouray fault. Absence of a broad zone of monoclinal flexing in the walls of the fault at and west of Canyon Creek is no reason to infer an abrupt decrease in its magnitude. Furthermore, the lack of displacement of the basal Mesozoic strata and the lack of monoclinal flexing of the Cutler Formation west of Canyon Creek is not necessarily a result of the fault dying out in a westward direction. Other supporting evidence is needed.

Rocks in the block north of the Ouray fault (pl. 1, section *A–A′*) appear to have been uplifted with respect to the steeply flexed band of rocks directly in contact with the fault. This uplift requires either some reversal of movement along parts of the Ouray fault and some auxiliary faults, or some mechanism in which graben-like blocks of steeply dipping beds formed during the Paleozoic activity of the fault. No independent evidence exists to determine relative ages of the different Paleozoic faults and flexures involved in these Paleozoic structures. However, there is evidence provided by the Mesozoic structures that show the entire block of Paleozoic and Mesozoic strata east of the Uncompahgre River valley was tilted eastward, probably prior to or coincident with the intrusions of granodiorite. It is thought that this tilting reactivated certain faults and flexures in the north wall of the Ouray fault and thus accounted, in part, for these particular structures. This later deformation does not appear to have appreciably affected beds adjacent to the wall of the Ouray fault west of the Uncompahgre River valley.

Structures more clearly of Paleozoic age are readily apparent in cross section *F–F′* (pl. 1). A sharp monocline in the Leadville Limestone along the south wall of The Amphitheater strikes about N. 45° E. and dips 30°–40° NW. At the head of The Amphitheater in the workings of the Portland mine, the Leadville Limestone strikes N. 60° E. and dips 10°–12° NW., which conforms with the attitude of beds in the Hermosa Formation exposed in the cliffs along the north side of The Amphitheater. Thus, it is assumed that the sharp monocline along the south wall flattens abruptly under the surficial cover and the beds conform to the attitude of those exposed at the entrance of The Amphitheater and in the Portland mine.

About a mile north of Ouray a sharp monocline (fig. 20) in the Cutler Formation is well exposed in the cliffs south of Corbett Creek. Its axis trends west-northwest, nearly parallel to the Ouray fault to the south; the dip on the steep north limb is greater than 40°. A monocline can be seen on the opposite side of the Uncompahgre River valley near Skyrocket Creek, but the dip of the beds there is slightly steeper, and possibly they were rotated by faulting and tilting related to intrusion of granodiorite. However, the local steep dips are not due primarily to the igneous intrusions, which occurred during the Laramide orogeny, because the basal Mesozoic strata on either side of the valley are unconformable on the upturned Paleozoic strata. Projecting the fold axes across the valley indicates that the steepest parts of the flexures are not in line. This may have been caused in part by rotation of the fault blocks on the east side of the valley during later intrusive activity, but possibly the late Paleozoic flexures may have formed an overlapping en echelon pattern of folds, such as the flexures that form the north wall of the Ouray fault. These flexures could have resulted from movement on faults in rocks beneath and within the Uncompahgre Formation; the stress was transmitted upward into the overlying Paleozoic strata, resulting in irregular or en echelon folds because of differences in the competency of the underlying interbedded quartzite and slate. This is best illustrated by flexures related to the Ouray fault, which were most prominent where limestone beds overlay incompetent slate beds (fig. 19*A*).

Inasmuch as the Hermosa Formation dips beneath the valley floor in the area of the intrusive bodies, the Paleozoic structures north of the point where Bridalveil Creek joins the Uncompahgre River were more difficult to determine. Tracing gently dipping key horizons in the Cutler Formation, a broad, very gentle east- to northeast-trending anticline is indicated near Cutler Creek (fig. 18). This flexure is truncated by the overlying Mesozoic strata.

The base of the Paleozoic section is estimated to be about 2,600 ft beneath the floor of the Uncompahgre River valley at the north edge of the mining district compared to about 3,000 ft near Lake Lenore (pl. 1, section *F–F′*). Most of the difference in depth between these points is due to the rise in the valley floor being steeper on the average than the rise in attitude of the rocks. These estimates, however, do not consider possible changes in thickness of the Hermosa and Cutler Formations toward the northwest.

Mesozoic Structure

Mesozoic structures of the Uncompahgre mining district include features related to uplift of the San Juan Mountains region and the locally intruded suite of igneous plutons with related ore deposits in late Mesozoic to early Cenozoic (Laramide orogeny) time. The district is included as part of the southwest extension of the Colorado Mineral Belt (Tweto and Sims, 1963). Late Mesozoic uplift of the western San Juan Mountains region renewed deformation that originated in late Paleozoic time. This uplift, which began late in the Cretaceous Period, continued almost certainly into the Eocene Epoch. Here, as elsewhere in Colorado, the deformation very likely occurred in a number of stages that extended over a considerable amount of geologic time. Granodioritic magma intruded and locally arched the Upper Cretaceous beds, beneath which the magma spread out in sills and laccoliths. Tilting of the larger crustal blocks was accompanied by renewed movement on some of the older faults and by additional fracturing. Some small blocks close to the intrusive center were upthrown and tilted, but not all structural features can be directly correlated with this major period of deformation. This deformation was in turn followed by a period of very extensive erosion prior to deposition of the Telluride Conglomerate of early Tertiary age.

The pre-Telluride erosion surface allows the recognition and assignment of some of the more important structural features to Late Cretaceous to early Tertiary time. The most important features, dated by means of this unconformity, are the igneous intrusions, the regional uplift, and the folding and faulting of the Mesozoic and older strata. Many veins and faults were terminated at the Telluride erosion surface; however, some did not penetrate entirely through the Mesozoic strata to the unconformity.

The Telluride erosion surface is a pediment sloping north and west at less than 50 ft/mi to as much as 400 ft/mi. Within the Ouray area, several prominent residual hills or monadnocks above the general level of this surface are the laccoliths from which the upbowed upper Mesozoic strata were mostly removed by erosion. The most pronounced doming, resulting from the intrusions, can only be inferred by reconstruction of the eroded beds. All of the laccoliths intruded at or near the base of the Upper Cretaceous shales, except one large body emplaced near the base of Jurassic strata.

In the canyon walls of the Uncompahgre River and its tributaries, the laccoliths now exposed lie for the most part beneath the level of maximum local uplift and constitute the roots of a laccolithic mountain group. In this respect, the

Figure 20. View looking northwest at the west wall of the Uncompahgre River valley between Oak and Corbett Creeks showing a monocline involving upper Paleozoic strata. The Paleozoic rocks are unconformably overlain (dashed white line) by nearly flat to gently north-dipping Mesozoic strata. Source is photographs nos. 239 and 240 by E. Howe, from U.S. Geological Survey Geologic Atlas, Folio 153 (Cross and others, 1907).

structure within the district is similar to that of many other laccolithic mountain groups of the western San Juan Mountains and nearby Colorado Plateau, which for the most part reveal only the superstructure of the domed areas. In the root zone of the local group, however, it is difficult to distinguish whether uplift resulted only or mainly from regional deformation or from a deeper unexposed spreading of magma. North of the Uncompahgre district, a gentle monocline in the Mesozoic rocks may possibly represent the margin of basement uplift of the San Juan Mountains. Southward through the district toward the center of the mountain mass, the Mesozoic strata rise gradually in altitude, but what part of this elevation is due to local igneous intrusion and what part to the regional deformation cannot be accurately determined. For this reason, details of the Mesozoic structure are discussed below under three headings: (1) folding and tilting, (2) faulting and fracturing, and (3) structure of intrusive bodies, particularly the superstructure and roots of the laccolithic group.

Folding and Tilting

The regional structure of the northwest flank of the San Juan Mountains has been described by Whitman Cross and his associates (Cross and Purington, 1899; Cross and Spencer, 1900; Cross and others, 1907; Larsen and Cross, 1956). The Mesozoic strata in the Ouray region and the adjacent region to the west and south dip gently north to northwest with a gradient ranging from about 250 ft/mi to 400 ft/mi. Tilting preserved on the flanks of the Mesozoic uplift is somewhat less than that which developed on the flanks of the Paleozoic (ancestral Rockies) uplift. In general, the width of the deformation zone during the Mesozoic (about 9–12 mi) appears to have been considerably greater than that during the Paleozoic (about 3–5 mi). This moderate tilt away from the center of the western San Juan Mountains is broken here and there, just as it is in the Paleozoic rocks, by abrupt monoclines.

Two major Mesozoic monoclines can be seen in the Uncompahgre River valley. One, shown in figure 18, is about 2 mi north of the mining district, and is a comparatively gentle fold that takes the Paleozoic strata beneath the valley floor. The other fold is about 5 mi north of the mining district and also is a comparatively gentle fold; however, within the short distance of about 3 mi it has taken all the Mesozoic strata, with the exception of the Mancos Shale, beneath the valley floor. The declination of the formations to the north-northwest as a result of these monoclines is somewhat in excess of 2,500 ft, and is nearly the same as that of the several monoclines of late Paleozoic age within the Uncompahgre district. These two monoclines apparently merge into a single fold elsewhere in the western San Juan Mountains region; they can be traced laterally along the mountain front from the Uncompahgre River valley, with short distances covered by younger Tertiary volcanic rocks, about 5 mi northeast to the Cow Creek drainage and about 10 mi southwest to the San Miguel River drainage near Telluride (fig. 1), south to Ophir, thence to other valleys south and southeast. The concealed trend of the fold axis west of the Uncompahgre River valley swings to about S. 40° W. around the northwest nose of the San Juan uplift. At Telluride, downwarping of the strata appears to be less, about 1,300 ft, but near Ophir it is again in excess of 2,500 ft. The length of this fold and its conformity to the general concave-east outline of the mountain mass clearly indicates that it is a product of regional deformation, perhaps of a deeper plutonic origin, not the result of igneous intrusion at any particular center. The total declination of Mesozoic strata in the Uncompahgre sector of uplift, about 4,500 ft from the south to north, is the combined result of this monocline and local tilting. This is about the same order of magnitude as that estimated for the combined folding, faulting, and tilting credited to late Paleozoic deformation. The Mesozoic decline did exceed that of the Paleozoic by about 500 ft, a difference caused, perhaps in part, by later tilting of Tertiary age.

Within the Uncompahgre district the Mesozoic strata are gently tilted, and nowhere except near an intrusive body do the beds dip 10° or more. The strata east of the Uncompahgre River valley tilt north to northeast, in contrast to west of the valley and in the valley of Canyon Creek, where the strata tilt 3°–4° north to northwest. This difference in attitudes of strata on the two sides of the valley indicates that the so-defined east and west blocks probably are separated by a zone of faulting or flexing, or both, coincident with a radial axis of uplift; this anticlinal axis (Uncompahgre axis) trends north-northwest approximately parallel to the river valley (fig. 18). Dislocation of the east and west blocks described above is of more than academic interest as it may account, in part, for the distribution and origin of mineral deposits in the sedimentary rocks, particularly on the east side of the valley.

Faulting and Fracturing

It has been shown above that there is a considerable discordance in the direction and amount of tilt of blocks on the east and west sides of the Uncompahgre River valley as far north as Dexter Creek. The more competent beds have been distorted and fractured along the boundary zone now marked by the river valley; also locally, faulting dislocated some of the beds. The north-south and east-west components of tilt in the block east of the valley differ from those in the block west of the valley, suggesting the blocks were the result of torsional stresses rather than of compression.

The greatest distortion was in a zone extending from Ouray northward (downvalley) for about 2 mi (fig. 18). The valley walls diverge to the north and the strata on either side become less tilted; any discordance, therefore, cannot have been the result of comparatively gentle bending of the beds. South of town, the interpretation of and differentiation between structures of Paleozoic and Mesozoic age are more difficult. Between the Ouray fault and Portland Creek, minor diverging faults, fractures, and reversals in the dip of beds in the Leadville Limestone may be in part younger than the Ouray fault. In this area, the limestone is traversed by numerous minor north- to north-northwest-striking veinlets and fractures along which the beds were recrystallized and minor amounts of vein quartz and sulfides deposited. This minor fracturing was of late Mesozoic age, as was the mineralization. In addition, other faults illustrated in section *A–A′* (pl. 1) may have been reactivated by any local movement along the Ouray fault in late Mesozoic time.

Evidence that a concealed fault (Uncompahgre “break”), or possibly a flexure of beds, beneath the town of Ouray (fig. 19*A*; pl. 1, section *A–A′*) is furnished by an outcrop of the Leadville Limestone exposed at the eastern edge of town. Extensive deposits of travertine at this locality indicate a long-continued issuance of modern hot-spring waters, and the altitude of the exposed limestone suggests the existence of the fault shown hypothetically in sections *A–A′* and *C–C′* (pl. 1).

At one locality, almost due south of town, the Ouray fault has been broken by a minor north-striking fault, which disappears in the narrow slate layer south of the limestone and fault; adjacent quartzite on strike with this minor fault is not broken. Other minor cross faults cut the Ouray fault where it crosses the Uncompahgre canyon as well as at its extreme southeastern exposure.

Rocks cropping out in the Uncompahgre River valley walls within 2 to 3 mi north of the Ouray fault afford evidence for sharp flexing or minor dislocation formed in conjunction with the northeastward tilt of the block bordering the valley on the east. Southward, this flexing appears to fan out into minor breaks and to die out for the most part at the slate layer in the south wall of the Ouray fault. Toward the north, this deformational feature is assumed to pass into a gentle anticline or very gentle monocline. The position of this deformation zone and the apparent connection between abnormal tilting east of the valley and crosscutting intrusive bodies suggest the resultant forces are of local origin, and probably, in part, are the direct result of intrusive activity. This zone probably constituted a vent or “leak” that extended upward through the Mesozoic strata, and thus tended to concentrate the lateral migration of gases and mineralizing solutions in the surrounding beds.

A series of north-northwest-striking veins, fractures, and minor faults parallels the concealed zone of flexing in the Uncompahgre River valley. These features are present on both sides of the valley (fig. 18), especially on the east as far north as Gold Hill, about 1.5 mi north of Ouray; beyond that point they are more widely spaced or inconspicuous. One of the largest faults of this trend is found on the west side of the valley just north of Oak Creek. This fault strikes N. 30° W. and has a displacement of about 50 ft, with the east or upthrown side having movement the same as supposed for the main valley break. Another fault, probably of this same system, can be seen crossing the western spur of Cascade Mountain, just north of Cascade Creek, on the east side of the valley. Its east side was upthrown for only a few feet. Several fractures and minor faults on the slopes of Cascade Mountain parallel this fault. The distribution and strike of these fractures suggest they are the result of stresses associated with the local tilting of the strata. In some mines, this fracture system is complemented by other, less conspicuously developed systems, in particular the competent quartzitic sandstone beds. The course of the Uncompahgre River valley might have been influenced by this structural weakening of the rocks along this trend.

The strongest group of fractures in the mining district includes a few dikes and is most prominent just north of the town of Ouray. Both the fractures and dikes are closely spaced, and swing in trend from N. 55° E. at the southwestern edge of the zone to N. 80° E., or nearly due east, at the northeastern edge. Farther north, individual breaks are more widely separated and consist of a few east-trending dikes and veins. At some places, the dikes and veins appear to constitute two systems, one striking northeast and the other more nearly due east; however, this division does not appear to be significant. One of the most prominent faults strikes about N. 55° E. across the Uncompahgre River valley, trending up the spur of Cascade Mountain (fig. 18); to the west, it is well exposed where it crosses the mouth of Oak Creek canyon and the Ouray fault to parallel the valley of Canyon Creek. The fault is downthrown to the north. Displacement on this fault at Oak Creek is about 150 ft and at Cascade Mountain about 100 ft; the displacement appears to decrease both to the southwest and to the northeast. About 2,000 ft to the north, a nearly parallel fault, with similar displacement, terminates to the east in the intrusive bodies of The Blowout area. This fracture system is conjectured to be connected to the deeper crustal deformation that permitted invasion of the granodioritic magma, but there is no indication that the local structure is related to possible structures in the underlying Precambrian basement. The average trend of the fracture system, however, is similar to that of the local northeast-trending margin of the San Juan Mountains uplift.

A number of minor, but locally important, fractures and faults possibly of late Mesozoic age cut the Proterozoic and Paleozoic rocks south of the Ouray fault. One fault striking about S. 45° W. displaced the overlying Paleozoic beds, and perhaps the Tertiary volcanic rocks on the spur of Hayden Mountain. It is uncertain whether this fault was first reactivated in late Mesozoic time, because the unconformity between the Paleozoic or Mesozoic and Cenozoic strata is not preserved here. On the benches south of Ouray and west of the Uncompahgre River, a series of northeast- and northwest-striking minor faults were important in localizing the mineral deposits; they are considered to be of Late Cretaceous to early Tertiary age rather than late Tertiary. The zone of faulting follows the east-northeasterly trend of the quartzite-slate contact in the underlying Proterozoic rocks, and probably reflects minor differential movements between the slate and quartzite beds. Although evidence is lacking, the pronounced tilting of the Mesozoic strata east of the Uncompahgre River valley probably reactivated most pre-existing fault lines. The resulting displacement, however, was very small.

Some displacement occurred on faults subsidiary to the Ouray fault in the Mesozoic strata north of Canyon Creek, but the absence here of beds of Tertiary age prevents distinguishing how much movement occurred during the Laramide orogeny and how much during later Tertiary time. At the southeast end of the Ouray fault, there was definite movement in late Tertiary time because the faults extend into the overlying San Juan Formation. The evidence suggests the Ouray and associated faults were reactivated during all major periods of deformation.

Structure of Intrusive Bodies

Intrusive rocks are an important part of the structural history in the Uncompahgre mining district, and provide data as to the age of certain structural features. Structure of the intrusive bodies is considered on the basis of (1) their root zone and (2) their internal structure and relation to their sedimentary superstructure.

Dikes and Sills

Intrusive bodies in the root zone include dikes, sills, and other crosscutting bodies that occur, with few exceptions, within the east-northeast-trending to northeast-trending zone of fracturing (intrusive axis) just north of the town of Ouray. This zone, having a width of about 1.5 mi where it crosses the Uncompahgre River valley, has at least 15 dikes exposed in the steep walls over a vertical range of more than 2,000 ft; less than half that number crop out north of this zone. The dikes in this zone tend to converge toward the large crosscutting body in The Blowout (fig. 12). The individual dikes, with a few important exceptions, trend from N. 55° E. to due east, and are vertical or dip very steeply southeast. Most of the dikes cut the Paleozoic and Mesozoic strata beneath the horizon of the Mancos Shale, but a few penetrated the laccolithic bodies, and one cuts entirely through the laccolith into the overlying shale. Many of the dikes in this root zone merge with concordant intrusions or pass upward into sheets or sills.

Some of the dikes appear to be feeders formed from the earliest magma injected into the sedimentary rocks. One of the larger of these northeast-trending feeder dikes, known locally as the Speedwell dike (fig. 12), crops out on the west side of the canyon just northwest of Ouray (Luedke and Burbank, 1981). The dike is locally 50 ft or more in width, and is irregular in shape, in part, because it was injected along intersecting fractures and, in part, because of the tendency of the sedimentary beds to split along stratification planes. This dike extends northeastward to merge with the large crosscutting body of granodiorite in The Blowout. Directly southwest along the vein-fault extension of this dike, about 3,000 ft and 5,000 ft from the river, two short dike segments crop out within the Mesozoic strata higher on the north wall of Oak Creek canyon (fig. 12). These dike segments suggest that the main break probably extends southwestward for some distance beneath the less competent mudstones in the upper part of the Morrison Formation. Each dike segment abuts against a fracture trending N. 30° W.

This N. 30° W.-trending fracture system east of the Uncompahgre River valley is thought to be local and the result of northeastward tilting of the strata. Only a few dikes occupy this fracture system; they are short or discontinuous but were seen within mines on Gold Hill and Cascade Mountain. Here also, east of the valley, some dikes of the dominantly east-northeast-trending system terminate against this northwest-trending system of faults and fractures. The northwest-trending system probably formed before the younger rocks were invaded by magma; it very likely was of comparatively shallow origin, owing to the fact that tensional stresses produced by stretching above axes of bending or of doming increase toward the surface. The northwest-trending fractures were sufficiently open only in the shallower and more competent strata that did not yield by stretching, whereas the east-northeast-trending fractures were thought to be of very deep-seated origin and undoubtedly the main feeding channels of magma from depth. These conclusions bear directly upon the influence that the two fracture systems had upon localizing mineralization. The east-northeast-trending system contains the most persistent veins in the district that are mineralized to the greatest depth, whereas the northwest-trending system, serving as local channels for ore solutions only in the competent strata, rarely contains veins of much economic importance.

The few east-trending dikes cropping out farther to the north within the district, in the vicinity of Dexter Creek (fig. 12), differ as described (p. 32) from the granodioritic dikes to the south. These east-trending dikes, including several crosscutting plugs of altered intrusive rock near the mouth of Dexter Creek canyon, from Lake Lenore north (Luedke and Burbank, 1981) are not found in any mines or much east of their mapped surface terminations. Their trend and associated breccia and (or) clastic injections, however, clearly suggest that they formed during the same period of igneous activity. Hence, the more northerly fractures of the east-trending system seem to contain only a minor amount of igneous material that perhaps was fed steeply upward from a source beneath the east side of the valley; contained linear rock fragments, plunging 10°–65° E. in these dikes, support this interpretation.

A few dikes, including the prominent one known locally as the “Jonathan dike” that trends N. 30° E., have cut into or through the larger, overlying laccoliths on Cascade Mountain and on Gold Hill (fig. 12). These younger intruding and apparently less common dikes do not, however, differ appreciably in texture and mineralogical composition from those constituting the main granodioritic dike swarm.

Most clastic dikes (fig. 12) occupy fractures of the east-trending system and most, if not all, postdate the igneous dikes. Some clastic dikes are exposed only locally; others, such as the Nettie clastic dike on Gold Hill, or the Bachelor-Pony Express clastic dikes south of Dexter Creek, have been traced for 1 to 2 mi in both surface and mostly underground exposures. Linear and platy rock fragments in the clastic dikes cropping out east of the Uncompahgre River valley indicate the dikes were injected upward from the east (fig. 16) at angles ranging between about 10° and 55° above the horizontal. Where the dikes were restricted or confined by overlying barriers of impenetrable or poorly fractured rock, the linear features nearly always parallel the dip of the local bedding planes. A few dikes contain east-plunging linear elements even where apparently not confined by immediately overlying obstructions. The Abbey clastic dike (fig. 12), cropping out about 1,750 ft south of Dexter Creek, terminates in the Mancos Shale, but most of the other clastic dikes failed to rise that high in the stratigraphic section. The Bachelor clastic dike, traced underground, clearly terminated at several places within the upper part of the Dakota Sandstone, or at the base of the Mancos Shale in a zone of churned soft shales. On the basis of these features and the eastward extension of the clastic dikes in mine workings, it was concluded their energy source originated farther east of the Uncompahgre River valley at a different and probably somewhat shallower depth than that for the altered porphyritic dikes in the vicinity of Dexter Creek. The projected intersection of their contained linear features with those of the east-northeast-trending dike swarm may perhaps indicate their ultimate sources.

No internal linear features were seen in the few clastic dikes on the west side of the Uncompahgre River valley. They are thought to have terminated not far to the west, and probably were injected vertically, although their origin may have been deep to the east.

An exception to the general distribution of dikes, as outlined, is the presence of an altered porphyritic dike and a clastic dike exposed in the valley of Angel Creek and Canyon Creek, respectively, about 1.5 and 1.25 mi southwest of Ouray (fig. 12). Outcrops of these dikes are mostly concealed by glacial debris; however, both dikes were seen almost side by side in an adit near the stream level of Canyon Creek. The dikes trend N. 70° E. and are vertical. The clastic dike contains a considerable amount of altered rhyolite (fig. 15*A*) in addition to fragments of Proterozoic metamorphic and Paleozoic sedimentary rocks. Structures within the clastic dike suggest that it was injected almost vertically. The linear alignment of hornblende crystals in the igneous dike at Angel Creek indicates that it plunges vertically to steeply northeast. The dikes suggest the main intrusive zone's southwest continuation at depth across the Ouray fault, at least as far as Angel Creek, but the exposed expression has greatly diminished in that direction. These two dikes, otherwise, are the only evidence favoring any possibility of an additional magmatic source beneath the laccolith exposed in Canyon Creek.

Sills associated with the east-northeast-trending dikes are few. The larger sills, without exception, occur in the southern part of the dike swarm. This distribution is probably related to structure and to the cover of Paleozoic strata, which thins southward toward the mountain uplift. The decreased lithostatic load would allow a greater penetration of magma into the sedimentary rocks. Sills penetrating northward along a given bedding plane within the Paleozoic strata would have had to lift a much greater thickness of overlying beds.

A few sills of limited extent on the east side of the Uncompahgre River valley penetrated the steeply inclined beds of the Hermosa Formation near Skyrocket Creek. One thin sill extends south of the main intrusive zone for nearly a mile along the north side of The Amphitheater to terminate at the base of the Entrada Sandstone. The largest sills are in the Cutler Formation on the west side of the valley (pl. 1, sections *C–C′*, *D–D′*), and they extend almost unbroken toward the southwest, where they join the Canyon Creek laccolith. Similar to the sill in The Amphitheater east of the valley, some of the larger sills rise stratigraphically from their presumed sources by cutting across bedding. Where interrupted by older, northwest-trending faults and fractures, they tend to be diverted along these breaks to a higher position; this structural feature is well shown where the sills cross the older Ouray and associated faults (Luedke and Burbank, 1981; fig. 12). The sills diverge from the Speedwell dike at an altitude of about 8,500 ft and gradually thicken southwestward, reaching a thickness of 75 ft before joining the Canyon Creek laccolith at an altitude of about 9,000 ft. Their increase in altitude suggests the magma moved to the southwest; however, their thickening to the southwest suggests also that their source may have been either a concealed extension of the main dike swarm or one of the larger dikes. Unlike the other laccolithic mountain centers of the western San Juan Mountains region, the Rico and La Plata Mountains centers contain many moderately thick sills; fewer sills occur in the Ouray center and are presumed to be of little significance to uplift in the root zone.

Stocks and Plugs

About a mile north of Ouray, a roughly square-shaped intrusive body, or stock, occupies an area of extremely altered rocks between Bridalveil and Skyrocket Creeks, and is known and labeled as The Blowout in figure 12. Near the head of Skyrocket Creek, the eastern and southern contacts of this body are exposed vertically more than 1,000 ft beneath the Tertiary unconformity through the Mesozoic section and some underlying Paleozoic beds. Its northwestern contact is exposed through a lesser vertical range of sedimentary rocks, partly because of the tapered connection to the laccolith to the north. Two west-projecting prongs of the intrusive body taper westward into dikes. The larger prong is thought not to be entirely crosscutting but, as shown in section *F–F′* (pl. 1), is probably a semi-concordant body whose roof was lifted or tilted by magma injection. The main body, or stock, probably does not extend far eastward; however, its extent, particularly to the northeast beneath the overlying Tertiary San Juan Formation, is indeterminable. The basal part of the San Juan Formation there contains many fragments of both altered porphyritic granodiorite and sedimentary rocks. The sedimentary rocks surrounding the stock have been intensely metamorphosed, altered, and mineralized. Several large blocks of sedimentary rocks are enclosed within the larger eastern part of the stock (Luedke and Burbank, 1981), but their exact position and attitude are unknown. As previously stated, the stock is thought to represent the magmatic plug within a former volcanic vent.

The localized structure attributed in part to intrusion of the stock is the convex fault that forms the south boundary of The Blowout area (fig. 18). This fault can be traced eastward from near the mouth of Skyrocket Creek (Luedke and Burbank, 1981), where it strikes about N. 70° E. and is occupied by a dike (fig. 12) for more than 500 ft to a point where it is then concealed for about 2,000 ft by talus and slide debris. East of this cover the fault strikes about N. 55° E. through a small intrusive body to where it connects to the east contact of the stock (fig. 18). North of the fault, near the mouth of Skyrocket Creek, beds in the Hermosa Formation dip 50°–65° N. and have been injected by minor sills and dikes. Farther east and north of the fault, the sedimentary rocks appear to have been thrust upward because fossiliferous limestone beds in the Hermosa are exposed along Skyrocket Creek to an altitude of 8,700 ft. As shown in section *F–F′* (pl. 1), the local position and attitude of the Hermosa beds suggest the block was thrust up 400 to 500 ft. The direction of dip or tilt of the beds north of the fault varies from 12° NE. to 20° NW., but was not entirely due to rotation of the block as a result of igneous intrusion; this also is the position where the north-dipping Paleozoic monoclinal fold crosses the valley. Other small blocks west and north of the stock indicate minor thrusting.

The rock in the stock differs somewhat from that in the nearby laccoliths; it is less porphyritic and contains more quartz and orthoclase than the rocks of the laccoliths. Rock alteration and erosion in The Blowout area mostly obliterated any evidence of renewed magma emplacement. The relative distribution, mineralogy, and degree of alteration of the different facies of intrusive rock, although vague, support such an interpretation. The most siliceous igneous facies occupies the central part of the stock and is generally less altered than the granodiorite of the stock margins or the laccoliths. Microscopically, the protoclastic structure suggests the rock crystallized under dynamic conditions. This facies is also thought to have been intruded late, but whether it or an earlier intrusion resulted in the upthrust along the south edge cannot be determined.

The small intrusive body of non-porphyritic granodiorite, which appears to be cut by the fault forming the south boundary of The Blowout area, is possibly the youngest in this area; this intrusive body invaded the Cutler Formation along the south side of Skyrocket Creek, is mostly unaltered, and has extremely irregular, gradational-appearing contacts. Its small size, the minimal structural disturbance, the intense recrystallization of the surrounding sedimentary rocks, and the fault apparently engulfed by it suggest comparatively static and quiet conditions and the possibility that it formed partly by extreme metasomatism. This is the only intrusive body here in which hematite crystallized contemporaneously during its emplacement. Nearby intrusive bodies also are veined by hematite and epidote.

Several small intrusive bodies or plugs of altered porphyry, located near the mouth of Dexter Creek canyon and at Lake Lenore (fig. 12), are related to east-trending dikes and (or) fractures in the northern part of the mining district where fractures are fewer and farther apart. These fractures formed early, and largely controlled the first invasion of magma. The intrusive bodies are structurally less important, but illustrate how the small necks or plugs were emplaced. Rocks in these small plugs are similar in chemical composition to the granodiorite of the stock in The Blowout, but are finer grained, have trachytic textures, and are commonly altered. Flow foliation and lineation are particularly characteristic of the rocks in both the larger of two bodies on the north side of lower Dexter Creek valley and in two small intrusive bodies near Lake Lenore. North of Dexter Creek, the eastern and smaller of the two plugs is composed chiefly of coarse intrusive breccia consisting of sedimentary and igneous rock fragments. A small amount of intrusive breccia occurs with the western and larger plug as well as with the associated dikes. The two intrusive bodies near Lake Lenore contain an unusually large amount of sedimentary rock inclusions in the dacitic matrix.

The bodies north of Dexter Creek are clearly related to dikes of the east-trending system. A dike forms the northeast prong or extension of the larger body and is exposed underground in a tunnel about 200 ft below ground surface; in this tunnel, there is an additional parallel dike that does not crop out on the surface. These two dikes are about 65 ft apart, strike N. 75°–80° E., and are vertical. Also underground, a breccia or clastic dike occurs adjacent to the northern dike. Linear structures on the walls of the larger southern dike plunge about 50° E.; the south wall of this dike flares outward and upward. The plunge of the linear structures indicates roughly the direction of the magma movement. Linear structures in the dike-like prong at the northeast end rake 15°–20° E. Just east of this dike-like prong, there is a short dike composed of breccia containing igneous and sedimentary rock fragments, some of which are quartzite and shale of local origin.

The larger igneous body north of Dexter Creek was possibly localized, in addition, by the intersection of fractures of the east-trending system with those of the northwest-trending system; the west contact of this body is parallel to fractures of the latter system. At its northwest corner, the igneous body is cut by small breccia dikes having northwestward and eastward trends that parallel its internal flow structure. The flow structure dips steeply and generally is parallel to the contacts, except in the sill-like apophyses where it is more nearly horizontal. The north and west contacts are steep; the south contact near the east end is in part horizontal where the magma spread into shale beds near the top of the Pony Express Limestone Member of the Wanakah Formation. Emplacement of the body probably was accomplished in part by pushing aside the shale and sandstone beds at intersecting fractures and in part by fragmentation of the rocks, the fragments of which were carried along in the viscous melt.

Most of the breccia dikes and masses closely followed the injection of magma, but in a few instances may have preceded or accompanied injection. Any earlier-formed breccias must have been pushed upward or incorporated into the magma. Evidence that local explosive action did precede or accompany formation of an igneous body can be seen in the smaller ovate plug about 1,000 ft east of the larger body (Luedke and Burbank, 1981). It is composed chiefly of fragments of rock similar to that of the larger body but, in addition, contains blocks of crossbedded sandstone 3 to 4 ft across, resembling Pennsylvanian or Permian rocks, as well as abundant smaller fragments of quartzite and shale. Whether this breccia forms the top of a filled vent or constitutes the bottom of an upward-flaring funnel could not be determined, as all exposed contacts are nearly vertical. Analogous with the other large clastic dikes of the mining district, which commonly contain fragments of Proterozoic rocks that have been carried many thousands of feet upward, this breccia body is interpreted to extend to a considerable depth. The abundance of fragments in some of the intrusive bodies in the northern part of the district, such as those near Lake Lenore, suggests that some fragmentation, whether or not of explosive origin, preceded and accompanied injection of the magma.

Laccoliths

The laccoliths are at a stratigraphically higher position than the intrusions previously described. Erosion cut deeply into the superstructure of the laccolithic center in early Tertiary time, before it was buried by local erosional debris and the younger volcanic rocks, so that the relation between individual laccoliths or between them and their respective feeder channels is preserved only in fragmentary form. Remnants of the laccoliths related to the center at The Blowout extend about 5 mi to the southwest and northwest, about 2 mi to the northeast, and about 1.5 mi to the southeast. With the exception of the Canyon Creek body, which was intruded near the base of the Morrison Formation of Jurassic age, all the other laccoliths were intruded near the base of the Mancos Shale or into the upper part of the Dakota Sandstone, both of Cretaceous age (Luedke and Burbank, 1962). Except for the exposed central vent (stock) and dike swarm in the Uncompahgre River canyon, no other feeding channels for these bodies are recognized; the magma moved radially outward along the channels, forming tongue-like masses. These conclusions are based chiefly upon (1) the composition and stratigraphic positions of the laccoliths and the tendency for the bases of the laccolithic bodies to rise stratigraphically away from the Uncompahgre center, (2) the internal flow structures in some of the bodies, and (3) the apparent asymmetric distribution of the bodies and the structures beneath the level of concordant injection.

Three main laccolithic bodies exposed on the east side of the Uncompahgre canyon (fig. 12) are (1) the Gold Hill body prominently exposed high in the cliffs facing the Uncompahgre River valley and north of The Blowout, (2) the Dexter Creek body along the south side of that valley, and (3) the Cascade Mountain body. The Gold Hill and Dexter Creek bodies are separated by a screen of Mancos Shale, with their presumed connection covered by the shale and by volcaniclastic rocks of the San Juan Formation (Luedke and Burbank, 1981). Chemical analyses of the porphyritic granodiorite from these two bodies are similar in composition (table 7). The base of the Dexter Creek body is exposed only for a short distance along the bed of the creek; further evidence is needed to prove positively that most of this body is a laccolith and not a northeastward extension of the crosscutting intrusive body in The Blowout. However, the limited exposure of its floor at the northern margin, the absence of the siliceous protoclastic intrusive facies present in The Blowout, and the lack of intense alteration so prominently displayed in The Blowout area strongly suggest that the body is a laccolith. Flow structures are indeterminate within the Dexter Creek body where the granodiorite is massive or where the hornblende crystals are indistinct because of resorption. However, lineation near the margins of the body in its eastern part consistently plunge zero to 20° in an eastward direction; also, near the top and bottom, flow structure exhibited by feldspar and other tabular crystals roughly parallels the contacts of the body. At the easternmost exposures of the granodiorite along Dexter Creek valley this foliation dips between 10° and 25° N., somewhat steeper than the supposed dip of the concealed underlying sedimentary rocks. At the extreme west end of the body where it thins to a wedge, the horizontal lineation strikes north. Between altitudes of 10,000 and 10,300 ft on a ridge above and south of the large landslide mass along Dexter Creek canyon, the lineation strikes northeast, almost directly away from the northeastern edge of the stock in The Blowout. The internal structures, therefore, strongly suggest that the Dexter Creek body was fed from the Uncompahgre center. They further suggest the magma flowed north to northeast from the center as far as the exposed margins of the body in Dexter Creek valley. The eastern part of this body is quite thick at the point where it is covered by volcanic rocks; because there is little change in attitude of the flow structures here, the body may extend 1,000 to 2,000 ft to the east beyond the exposure.

In addition to the flow structures, several prominent joint sets developed in all parts of the Dexter Creek body. The most prominent of the joint sets strike roughly north and east, and commonly are vertical or dip steeply in either direction. Foliation, lineation, and jointing in the highest outcrops of the body, at an altitude of about 10,500 ft, suggest the former intrusive margin (top) of the laccolith was near the surface now exposed. Exhumed outcrops of granodiorite, in the eastern part of the body, have a blocky weathered surface that is plastered with tuff breccia and has joints filled with tuff of the San Juan Formation.

A few lineation measurements in the southern part of the Gold Hill body trend west to northwest. The small, narrow intrusive mass between the Gold Hill and Dexter Creek bodies has a north-south horizontal lineation indicating this exposed part had penetrated northward, strongly suggesting it connects with the two large bodies. The small body above the Calliope mine, at Mill Creek north of Dexter Creek (fig. 12), is an erosional outlier of the main Dexter Creek body. Other than the northernmost tip of the Gold Hill body, the exposures of the northern margin of the Dexter Creek body are within the Mancos Shale from 25 ft to several hundred feet above its base. The intrusive bodies near The Blowout are mostly at the top of the quartzite in the Dakota Sandstone, with less than a few inches to a few feet of shale parting. The Cascade Mountain body, now separated by erosion from the intrusive center, was undoubtedly fed from this center.

There are two laccoliths west of the Uncompahgre River valley in the mining district (fig. 12): the Twin Peaks body, exposed mostly west and northwest of the district (Luedke and Burbank, 1962), and the Canyon Creek body, exposed mostly southwest of the map area (Burbank, 1930, pl. 1). The Canyon Creek laccolith is about 1,000 ft thick and more than 1.5 mi long on the northwest wall of Canyon Creek valley southwest of Angel Creek. Of these two laccoliths, only the Canyon Creek body was examined closely for structural data. Evidence has been presented to show that sills joining the laccolith were fed southwestward from the dike swarm in the Uncompahgre River valley; it was shown also that the base of the sills rise stratigraphically away from the intrusive center. The base of the laccolith varies little in position at the base of the Morrison Formation from its rise of several hundred feet above the Dolores Formation at the northeast edge. Flow lineation (aligned hornblende crystals) is conspicuous along the base of the body. Random lineation measurements are consistent within the central part of the laccolith. The average trend of 15 measurements in the laccolith from the base to several hundred feet above the base is N. 40° E., and is in almost direct alignment with the dike swarm to the northeast. The lineation trend in the upper sill connecting to the laccolith, where the sill crosses Oak Creek (fig. 12), is about N. 50° E. Thus, the flow structures support the suggestion that both the sills and the laccolith were fed from the dike swarm and that magma in the concordant injections flowed radially outward from the center of intrusive activity. Little evidence exists to suggest the presence of another crosscutting body of appreciable size beneath the Canyon Creek laccolith. Therefore, a concealed center of intrusion and mineralization near this locality is unlikely. The lack of strong alteration in or around the laccolith further suggests the absence of another intrusive center here.

The part of the laccolith below the Twin Peaks is within the Dakota Sandstone. The total extent and original thickness of the laccolith cannot be determined because of cover by the San Juan Formation and landslide deposits (Luedke and Burbank, 1962). Outcrops along the north side of Oak Creek valley west of Twin Peaks, as previously mentioned, have joints filled with volcanic debris; spheroidally weathered joint blocks have up to 1.5-in.-thick weathered rinds and have been plastered by volcanic debris, indicating a former erosion surface. Large blocks of granodiorite are contained in the capping outlier of tuff breccia forming Twin Peaks. The laccolith extends more than a mile west of Twin Peaks, forming the ridge between the upper parts of Oak and Corbett Creeks, and reaches an altitude of about 11,200 ft (Luedke and Burbank, 1962). Near the head of Corbett Creek valley west of the district, the outcrops also are at an altitude of 11,000 ft; this altitude may represent the probable former height attained by the laccolithic body. However, at this place the base of the body is thought to have penetrated the bedding several hundred feet above the base of the Mancos Shale, a feature apparently typical of the laccolithic bodies, which is to migrate upward as they spread away from the Uncompahgre intrusive center. The original total thickness of this laccolith was probably about 1,500 ft, a figure that was apparently a limiting thickness for all of the larger bodies associated with the intrusive center in the district. In no case, however, is it possible to determine how much rock was eroded from the current high parts of the laccolithic bodies.

Ore Deposits

Distribution and General Relations

The principal metallogenic epoch of primary ore deposition in the Uncompahgre mining district is the most important locally, and is closely related to the intrusive activity that accompanied regional domal uplift in Late Cretaceous to early Tertiary (Laramide orogeny) time. The intrusive activity resulted in dikes, sills, and laccoliths that crystallized under about a mile of Upper Cretaceous sedimentary rocks (Burbank, 1930, fig. 1). This sedimentary cover is thought to have been penetrated by a conduit in The Blowout area, now occupied by a small stock. Venting is indicated by volcanic rocks within an Upper Cretaceous formation that is exposed in the Cimarron Ridge area to the north-northeast (Dickinson and others, 1968; Steven and Hail, 1989). Extensive early Tertiary erosion removed most of the sedimentary cover in the area, resulting in a surface of low relief surmounted only by hills composed of the more resistant granodioritic laccoliths. Undoubtedly during this long period of erosion, some mineral deposits were partly exposed and subjected to weathering, and others were destroyed. The Eocene Telluride Conglomerate, particularly that part locally derived and deposited upon this erosion surface north of the mining district, has a very minor concentration of placer gold that proved to be of no economic value. During the Oligocene and Miocene, eruptions from volcanic centers south and east of the district formed an extensive volcanic field that covered the western San Juan Mountains region. This later igneous activity was accompanied by multiple episodes of major mineralization and alteration, most of which is of minor importance in the Uncompahgre district.

A few local ore deposits, whose age cannot be proved directly but which have the same structural character and mineral composition as those of proved (Late Cretaceous to early Tertiary) Laramide mineralization, are found entirely within pre-Tertiary rocks and are not related to a single important fracture or dike traceable into overlying Tertiary rocks. However, a few Laramide fractures that were reopened and extended into the overlying Tertiary rocks are barren or contain only minor gangue minerals; these veins cut the basal unaltered Tertiary volcanic rocks directly overlying the intensely altered and fractured rocks in and near The Blowout.

Ore deposits definitely correlating with the Laramide mineralization surround the Uncompahgre center of eruptive activity (The Blowout). The most productive ore deposits were within an area (fig. 21) extending from near Ouray northward to Cutler Creek, a distance of 4 to 5 mi, and from the Uncompahgre River valley eastward, a distance of about 2 mi. A narrow fringe of deposits occurs along the west side of the valley, but the intensity of mineralization there decreases abruptly westward. The few deposits on both sides of the valley that extends about 2 mi south from the intrusive center were less productive than those north of the center.

Geologic conditions that favored laccolithic intrusions during the Laramide orogeny also favored the formation of "blanket" replacement ore deposits. Fractures surrounding the stock penetrated upward into the overlying sedimentary beds only short distances, but some of the more permeable beds served as channels for the lateral diversion of the ore-bearing fluids and, particularly, where overlain by impermeable shale beds, were especially favorable to the diversion of the fluids laterally, sometimes for great distances. Ore deposits of the "blanket" type were formed in several different permeable beds in the sedimentary section. Some gradation exists between the vein and blanket deposits; a single deposit may include both types. Contact-metamorphic deposits were formed near the stock in The Blowout where higher temperatures prevailed.

The ores, containing gold, silver, lead, zinc, and minor amounts of copper, may be divided on the basis of their metal content into four groups: (1) magnetite-pyrite ores containing a little copper and gold; (2) pyritic ores containing copper and gold; (3) pyritic base-metal ores containing native gold plus gold and silver tellurides; and (4) siliceous and baritic ores containing silver, lead, zinc, commonly some copper, and a little gold. The productivity of the different groups increases in about the order stated, but group 3, because of its relatively rich deposits, returned the most value on small investments.

Deposits of the first two groups, on both sides of the Uncompahgre River valley, are clustered chiefly north and south (fig. 21) within a mile's distance of the intrusive center (The Blowout). Deposits of the third group, richest in gold, are east of the valley and north within about half a mile of the intrusive center. These three groups constitute the so-called gold belt. Deposits of the fourth group, valuable chiefly for silver and lead ores and composing the so-called silver belt, lie outside the zones of highly pyritic ores both north and south of the intrusive center; the deposits in the northern area near Dexter Creek were by far the most productive. As stated, the gold content is low in the siliceous and baritic ores, and conversely, the lead content is low in the pyritic ores; zinc, common in both ore types, is more abundant in the outlying deposits. Silver-bearing minerals of the gray copper group, present in both the silver-lead ores and pyritic base-metal ores, are the most widely distributed valuable minerals.

Ore deposits of late Tertiary age within the Uncompahgre mining district are related, with few exceptions, to centers of igneous intrusion and mineralization that are several miles outside the district, mainly to the south and east (Burbank, 1941; Kelley, 1946; Vanderwilt and others, 1947, p. 419–443). The few veins of this age found around the margins of the Uncompahgre district, containing gold, silver, lead, zinc, and copper ores similar to those deposited earlier, are divided into three groups: (1) base-metal ores containing manganiferous carbonates and small to moderate amounts of gold and silver; (2) baritic silver-lead ores having a low to moderately high silver content; and (3) siliceous low-grade gold-silver ores consisting of native gold in quartz. The first two groups, which in places are filled compound veins containing both types of ore, are found along the southern margin of the Uncompahgre district as extensions of mineralized zones into the area from the south. In addition to these groups, there are fluorite-bearing veins in the Hayden Mountain area southwest of Ouray (fig. 21). The only Tertiary deposits that do not appear to be related to the centers of mineralization south of the district are associated with the Cow Creek center about 5 mi to the east. These are siliceous gold-silver veins in volcanic rocks of the San Juan Formation in upper Dexter Creek valley to the northeast of Ouray, and a few similar veins east of Ouray.

Placer deposits of Holocene age along the Uncompahgre River valley northward from Ouray have proved to be of little economic consequence.

It is neither possible nor our intent within the limits of this report to describe the many individual deposits in the Uncompahgre mining district in great detail. Typical of mining districts, many deposits were not accessible at the time of our investigations (W.S. Burbank, late 1920s to mid-1930s; R.G. Luedke, late 1950s). Published descriptions have dealt with the general and detailed character of many of the ore deposits. Our intent, herein, is to point out certain relations of the ore deposits to the local structure during mineralization, with emphasis principally related to the Laramide orogeny, and to detail the evidence upon which the existence of the ore deposits was determined.

Late Cretaceous to Early Tertiary Ore Deposits

The principal ore deposits of the Uncompahgre mining district were formed after emplacement of the intrusive rocks of Late Cretaceous to early Tertiary time (Laramide) and are genetically related to them. It is inferred from the local structure and stratigraphy of the sedimentary rocks that the somewhat shallower deposits formed at a depth of a mile or less differed from those formed at slightly greater depths. This premise is based upon the presence of clastic dikes and the emplacement of orebodies that filled caves in the sedimentary rocks.

The clastic dikes provide evidence of the close tie between igneous and mineralizing processes. The clastic dike associated with the Bachelor silver vein is typical of this kind of eruptive activity. Its composition, characteristics, and relation to the ores suggest that the dike is a true injection of clastic material torn from the walls of the fracture at depth and propelled upward (diagonally or laterally in places) by expanding gases genetically related to the igneous and mineralizing activity. A number of examples found in the district suggest that some clastic dikes were closely associated with the intrusion of igneous rocks, whereas others were locally independent of them. Some dikes clearly formed between the early and late stages of vein deposition and thus were closely associated with formation of the ore deposits. These dikes are thought to have been formed by the

LIST OF MINES, PROSPECTS, MILLS, AND HOT SPRING

NORTHERN SECTOR

1. Señorita
2. Black Girl
3. Army-Navy
4. Newsboy
5. Little Eva
6. Native Silver
7. Iowa Chief
8. Calliope
9. El Mahdi
10. Old Maid
11. Bachelor
12. Wedge
13. Neodesha
14. Syracuse
15. Pony Express
16. Banner American mill
17. American Nettie group
18. Jonathan
19. Wanakah group
20. Memphis
21. Great Western

WESTERN SECTOR

22. Gem
23. Sequin
24. Ben Hur
25. American Nettie mill
26. Sampler
27. Grand View
28. Rock of Ages
29. Morning Star
30. Speedwell
31. Stenographer

SOUTHERN SECTOR

32. Trout and Fisherman
33. Ouray hot spring
34. Columbine
35. Mineral Farm
36. Legal Tender
37. New Mineral Farm

EASTERN SECTOR

38. Skyrocket group
39. Samoa
40. Lone Widow
41. Chief Ouray, Valley View
42. Portland

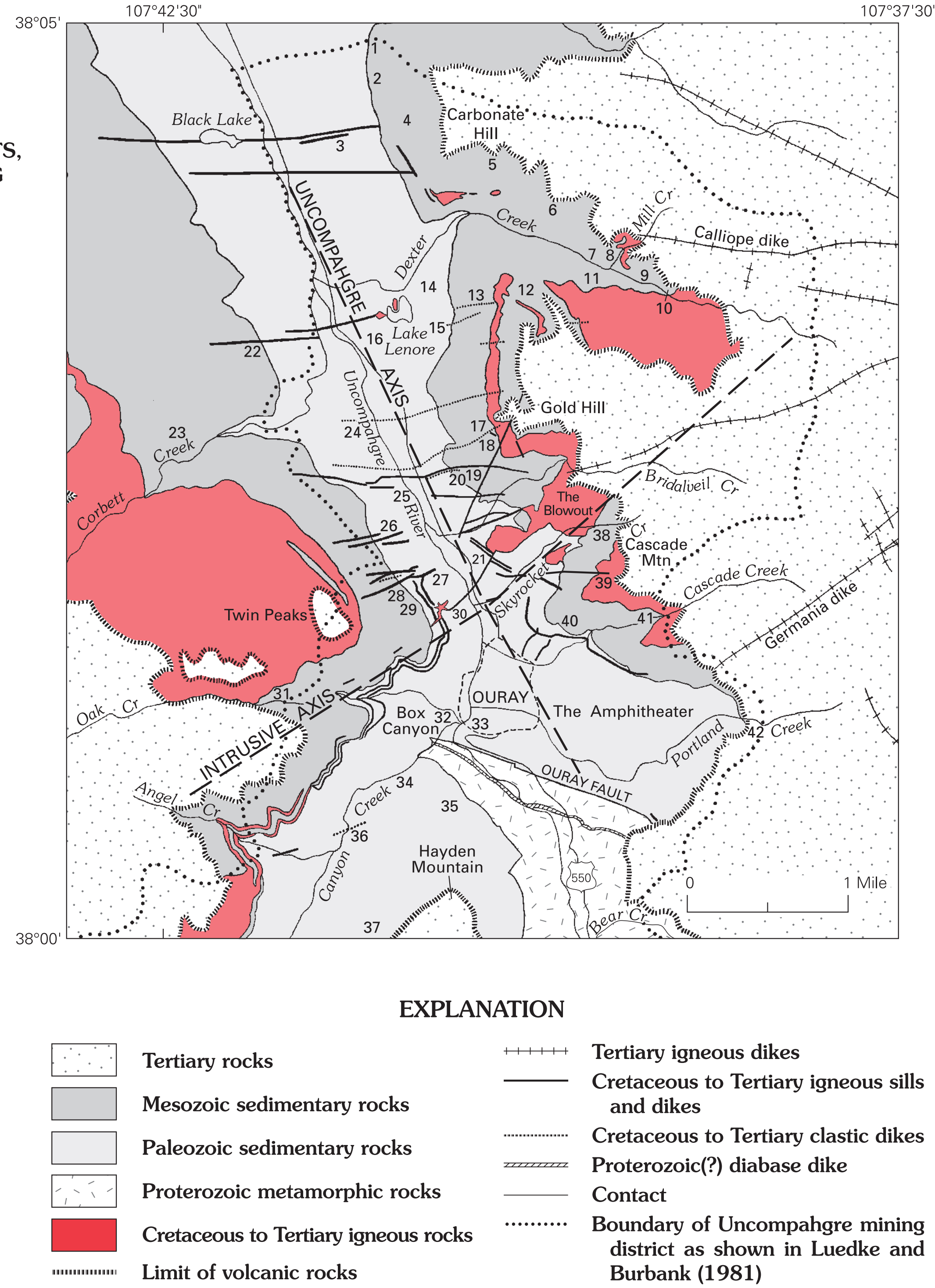


Figure 21. Generalized geologic map of the Uncompahgre mining district and vicinity within the Ouray 7.5-min quadrangle showing the approximate location (numbered positions) of the principal mines or groups of mines, prospects, mills, and hot spring (see list). Modified from Burbank (1930, 1940) and from Luedke and Burbank (1962, 1981).

sudden expansion of mineralizing solutions during reopening of the veins. A typical mineralized fracture, therefore, was filled by an igneous dike, then by major amounts of premineral injected clastic material, and finally by vein material and minor amounts of intramineral clastic material. This is the normal sequence throughout the district, but it was not complete in all veins.

In the central part of the mining district near intrusive contacts, the mineralization sequence began locally with the development of contact-metamorphic silicates, minor amounts of magnetite, and pyrite. However, in most parts of the district the silicate stage was lacking and mineralization began with the formation of sericite, ankerite, siderite, chlorite, calcite, and pyrite through metasomatic replacement of the wall rocks. Both of these processes were interrupted by local reopening of the fractures and the deposition of specularite, by local intramineral clastic injections, and by an interval during which cavities were formed in the rocks by hydrothermal leaching. Deposition of the principal sulfide and gangue minerals followed (table 11).

Large cavities formed locally by hydrothermal leaching along the bedding planes in both sandstone and limestone served as receptacles for ore and gangue minerals. Some cavities, however, were never completely filled and now contain only thin crusts of mineral crystals; others were partly or completely filled with higher grade ores while the adjacent wall rocks apparently were partly replaced by lower grade ores. Two noteworthy examples are the bedding-channel deposits in the Dakota Sandstone in the American Nettie mine (fig. 21, no. 17) and the bedded or channel deposits in the Leadville Limestone and Molas Formation at the Mineral Farm mine (fig. 21, no. 35). Irving (1905, 1911a) recognized that some of the orebodies in the American Nettie mine were formed by cavity filling, although he considered replacement to have been the dominant process. If the entire body of altered rock and the lower grade pyritic bodies in the American Nettie ore channel are considered, the total volume of replaced rock greatly exceeded the open space that was filled with ore. Regardless of the processes involved, the original fluids were sufficiently undersaturated with rock constituents to effect a considerable solution of the channel walls, and were responsible for the leaching activity. The fact that silica was carried away in considerable volume suggests the presence of a condensed medium of some proportion. Saturation probably was rapidly attained, as a certain proportion of the silica dissolved from the sandstone was precipitated in pores of the rock short distances from the main channels of mineralization. The enclosing walls of these channels became converted to hard, massive quartzite, which was very much less permeable than the original sandstone. From experience, the miners considered the hardness or toughness of the quartzite a good indicator of the grade of ore likely to be encountered, as well as a good indicator of the nearness to an ore channel. Induration of the sandstones, or their conversion to quartzite, and silicification of limestones preceded the main period of sulfide formation.

Table 11. Principal primary ore and gangue minerals and some more-prominent secondary minerals, classified according to the principal groups, for Late Cretaceous to early Tertiary deposits in the Uncompahgre mining district, southwestern Colorado.

[Modified from Burbank, 1940]

Contact-metamorphic deposits (magnetite-pyrite)	Pyritic deposits (copper-gold and base-metal, with gold and silver tellurides)	Siliceous and baritic deposits (silver-lead-zinc)
Primary (hypogene) metallic minerals		
Magnetite	Pyrite	Galena
Pyrite	Chalcopyrite	Sphalerite
Chalcopyrite	Sphalerite	Pyrite
Specularite	Galena	Chalcopyrite
	Tetrahedrite	Tetrahedrite
	Tetradymite	Pearceite
	Hessite	Polybasite
	Benjaminite	Pyrargyrite
	Gold	Proustite(?)
Primary (hypogene) gangue minerals		
Andradite	Sericite	Quartz
Hornblende	Quartz	Chalcedony
Actinolite	Chlorite	Chert
Epidote	Calcite	Jasper
Quartz	Siderite	Barite
Calcite	Barite	Rhodochrosite
Thuringite		Ankerite
Stilpnomelane		Calcite
Chlorite		
Apatite		
Rutile		
Siderite		
Secondary (supergene) minerals		
Limonite	Limonite	Limonite
Clay minerals	Goethite	Azurite
Goethite	Jarosite	Malachite
Jarosite	Copiapite(?)	Chrysocolla
Chalcocite	Clay minerals	Native silver
Covellite	Chalcocite	Argentite
Malachite	Malachite	Chalcocite
Azurite	Azurite	Covellite
	Cerussite	Sulfur
	Gold(?)	Calcite or aragonite
	Hydrous sulfates of iron, copper, and other metals	
	Gypsum	
	Sulfur	
	Native copper	

In the gold belt, quartz, ankerite or siderite, and sericite were the principal gangues deposited with the early sulfides. The general order of mineral deposition was pyrite, chalcopyrite, sphalerite, tetrahedrite (with additional chalcopyrite), tetradymite, benjaminite, galena, hessite, and native gold. Although hessite was the principal telluride, small amounts of petzite and possibly calaverite(?) were deposited during the telluride stage of mineralization. Barite, sparingly present except in the cave deposits, formed later than the cupriferous minerals of the gold belt and was most closely associated with galena-bearing ores, or was deposited in relatively late barren veins with quartz. Late scalenohedral calcite also was deposited in the cavities.

In the silver belt, jasperoid and early quartz formed in the first mineral stage, which was preceded or accompanied by hydrothermal leaching of limestones or other easily attacked beds; shale and sandstone beds were not as strongly altered as those in the gold belt, but locally they were leached. Ankerite or ferruginous rhodochrosite, sericite, and pyrite formed by replacement in the second mineral stage. Barite deposition preceded the bulk of the base-metal sulfides that were deposited in order as pyrite, sphalerite, chalcopyrite and tetrahedrite, pearceite and galena, and locally pyrargyrite. Some rhodochrosite or manganiferous calcite accompanied the late base-metal sulfides. In a comparison of this sulfide sequence with that of the cupriferous or pyritic ores of the gold belt, notable differences are the lack of a prominent chalcopyrite stage between the deposition of pyrite and sphalerite, and the usual position of barite early in the sulfide sequence. In the silver belt, quartz, a little barite, and scalenohedral calcite formed as late barren gangues.

Zoning within the orebodies or shoots in many deposits conforms to the general sequence of mineralization: pyritic copper and zinc ores are nearest the sources, high-grade tetrahedrite-bearing silver ores are in an intermediate position, and baritic ores of low sulfide content are farthest from the possible sources of mineralization. Overlapping of the different sequences, beginning with the igneous dikes and extending through the clastic injections to the mineral stages, suggests that mineralization began in the inner pyritic or gold belt and that sulfide ores of the outer or silver zone were formed later. Thus, the ultimate sources of the ore-forming fluids may have migrated with time from their earliest position at the apex of the intrusive bodies near the crossing of the structural axes to positions very much deeper in the crust along extensions to the northeast or southwest of the intrusive axis. This possibility bears directly upon the question of whether zoning at depth corresponds with the lateral or areal zoning of the deposits. We think that the areal and depth zones do not correspond exactly; therefore, it is unlikely the most distant deposits will change in depth to those now found in the inner zone surrounding the shallower intrusive bodies.

The most favorable host rocks for the ore deposits in the Uncompahgre district are those possessing physical or chemical properties that in combination with the structural features tended to yield a maximum of available open space. Formation of open spaces, however, was not dependent solely upon fracturing of the rocks, but also upon the chemical aggressiveness of the mineralizing fluids. All conditions being equal, the more permeable host rocks appear to have been most susceptible to leaching; however, the rocks most susceptible to leaching appear to have been the most susceptible to replacement. Replacement appears to have been less selective near the eruptive center, but the grade of the ore was low. The minerals that replaced rocks most extensively included all the pre-ore alteration products such as carbonates, sericite, quartz, and chlorite minerals. Of the sulfides, pyrite and sphalerite most commonly accompanied those alteration products, but the later sulfides had a distinct preference for open-space filling or for the replacement of the earlier-formed sulfides. Where the earlier-formed sulfides, particularly pyrite, replaced the host rocks so as to form massive sulfide bodies, these bodies in turn acted as hosts to later fluids. Some of the highly pyritic, low-grade sulfide replacement bodies in limy beds near the center of mineralization were later enriched locally by gold-bearing fluids that followed zones of fracturing.

In the Uncompahgre district, the less permeable beds that capped and underlay the sedimentary rocks tended to localize mineral deposition by restricting the circulation of ore-forming fluids to channels nearly conformable with bedding. The term “channel” or “ore channel” as used here applies to the main conduits along which ore shoots are found. Ore shoots in the favorable sedimentary rocks, where form and distribution were controlled by bedding or permeability of the rocks, are referred to as bedded deposits; most but not all of these conform to the bedding. In many ore channels, vein and bedded deposits occur together and have a small vertical range. As there are gradations between and variations in the number of vein to bedded deposits within the same mine, many ore deposits cannot be classified readily according to form. If the controlling break is a crosscutting fracture and the rock has clean fractures and a minimum of gouge, vein deposits are formed; if the controlling structure is a simple flexure, competent massive sandstone beds become jointed and fracture channels are formed. Descriptions of the favorable rocks indicate that in many places the rocks immediately above or below an unconformity had properties favorable for the formation of bedded deposits. The thicker formations in the district, in general, contained fewer favorable beds.

Structural Classification and Control

The classification of ore deposits presented here is based on the major and minor structural features, the outstanding structural feature being the crossing of the northeast-trending intrusive axis and the north-northwest-trending Uncompahgre axis of uplift (Burbank, 1940). This crossing divided the mining district into four parts, each of which is characterized by minor structural features (figs. 18, 21) that largely controlled the distribution, size, and shape of the orebodies. The four major parts, separated by the two axes and although slightly skewed, are designated the northern, southern, eastern, and western sectors.

The major intrusive axis has a trend of about N. 55°–60° E. and is a zone about 2,000 ft wide, perhaps narrowing somewhat southwestward where it crosses the Uncompahgre River valley; this zone contains several dikes and irregular bodies of porphyritic granodiorite and related rocks in Paleozoic and Mesozoic sedimentary rocks. Both to the northeast and southwest the zone is concealed by overlying Tertiary volcanic rocks, but there is little doubt that rupturing of the rocks within and along this zone was of major magnitude and extended deep into the crust. The trend and position of the intrusive zone is perhaps related particularly to the northeast-trending Paleozoic and Mesozoic fronts of the ancestral San Juan Mountains north of Ouray.

The major structural axis trends N. 25°–30° W. along the Uncompahgre River valley, cutting diagonally across the trend of the intrusive zone. This axis marks the trend of several parallel or slightly divergent components dating from both the late Paleozoic and the late Mesozoic uplifts. Two of these components are radial axes of uplift and folding (fig. 18) that are evidently related in their position and trend to a change in direction of the Paleozoic and Mesozoic mountain fronts, and a third, the so-called Uncompahgre “break,” an axis of crustal extension indicated by faults or abrupt changes in the direction and amount of tilting of the sedimentary strata as shown on the geologic section across the valley (pl. 1, section *C–C′*). South of the intrusive zone, this “break” appears to feather out into the north wall of the Ouray fault; north of the intrusive zone it passes into a gentle anticlinal axis in the Mesozoic strata (see pl. 1, section *E–E′*).

The main feeding channel of the laccoliths is on the east side of the “break;” near it and the intersection of the axes, the sedimentary rocks have been intensively altered in The Blowout area by mineralizing fluids. These fluids passed upward toward an ancient land surface along strong fractures or a fracture zone that breached the summit of the domed intrusive area. Elsewhere, the Upper Cretaceous shales and the laccoliths formed a thick blanket that was relatively impermeable to the upward passage of mineralizing fluids. Field studies of the mineral deposits near the axial intersection suggest that mineralizing fluids moved, in general, toward the Uncompahgre axis principally from the east side of the valley. In the northern part of the district, at places more distant from the main axes, many mineralized channels were slightly inclined, about the same as the enclosing strata; zoning within those deposits suggests that fluids moved, in general, from east to west. Associated clastic dikes also were intruded along paths that inclined upward toward the west. Thus it appears that the intrusive zone contained an easterly source for high-pressure mineralizing fluids and that the Uncompahgre axis or “break” was the principal low-pressure zone toward which the fluids moved.

Of the four major sectors, the northern was by far the most productive, having yielded more than 80 percent of the district’s mineral output. The exact production from the other sectors is not known, but the relative differences are not significant. The important feature is that, compared to the northern sector, the productivity of deposits in the eastern and western sectors decreased within comparatively short distances from the intrusive zone. The productivity of the southern sector was intermediate between these extremes. The differences in productivity between the sectors evidently resulted, in part, from the dominant directions of secondary structural control.

There are several systems of fractures and dikes throughout the mining district, most of which appear to be secondary features related to the main structural axes. In both the northern and western sectors the principal system of veins and dikes trends roughly east, and intersects the northeast trend of the intrusive zone at an angle of about 30°. Most of the fractures are vertical or dip steeply toward the intrusive zone, and many contain igneous and clastic dikes as well as vein matter. Possibly the fractures formed by extension resulting from the lateral shifting in the rock masses on either side of the intrusive zone. If the north side moved east relative to the south side, the fractures would be comparable to tension or feather joints. The practical importance of the system is that it appears to have furnished the main long, deep-seated fractures that tapped both the igneous and ore reservoirs.

A prominent fracture system present in all sectors of the mining district trends more or less parallel to the Uncompahgre axis; these individual, steeply dipping fractures strike north to N. 40° W. In contrast to the east-trending system, these fractures are discontinuous, locally are en echelon, and except for those within or near the intrusive zone, do not commonly contain igneous dikes. Some are locally mineralized, but many contain only late barren gangues. South of the intrusive zone a few contain vein matter of late Tertiary age. The presence of this system along the Uncompahgre axis, the discontinuity of individual fractures, and the lack of dikes except near the intrusive zone suggest that it was formed at relatively shallow depths by stretching along the crest of the Uncompahgre arch. In most places the fractures failed to tap the primary sources of mineralizing fluids. Because a few fractures near the intrusive zone do contain dikes, the system must have formed early, but it also was reactivated in late Tertiary time.

In the southern and eastern sectors of the district, the attitudes of the fractures are more diverse than those of the two systems described above. This may have been the result, in part, from interfingering of the Laramide fractures by those of late Tertiary age, the latter becoming more prevalent to the south and east. The effect of structural control of the basement rocks also is increasingly apparent, especially in the southern sector. There, some of the fractures and, in addition, flexures parallel the general easterly trend of the folds in the Proterozoic basement. Other structural features of diverse trend formed possibly by renewed movement on some of the older faults. An increase of inherited structural lines in the southern sector also is in part a result of exposure of the older formations and renewed movement along the hinge line of the Paleozoic uplift.

Flexures and associated complex fractures were important in controlling the form and distribution of some orebodies. In the northern sector, the two most pronounced flexures trend northeast but somewhat more easterly than the intrusive zone, so that if continuous, they would intersect the intrusive zone at a more acute angle than those of the east-trending fracture system. Along these flexures the strata were warped downward toward the intrusive zone, resulting in either a reversal of their normal northward dip or a local flattening of the normal dip (fig. 22). The more competent beds of sandstone, quartzite, or limestone were complexly fractured and thus provided either potential bedding channels for mineralizing fluids or zones of relatively low pressure connecting to the Uncompahgre axis on the west. The most productive orebodies in the northern sector of the district are on these flexures. Flexures in the southern sector of the district were related to old lines of weakness in the Proterozoic basement and affected chiefly the lower Paleozoic strata.

The Uncompahgre and intrusive axes, in conjunction with the main east-trending systems of fracturing and flexing, controlled to a large degree the distribution of the deposits between the district's four sectors. The bulk of the mineralizing fluids originating within the intrusive zone sought the most direct paths from deep sources to the lower-pressure zone along the Uncompahgre axis, traveling westward in the northern sector and eastward in the southern sector along the east-west lines of fracturing and flexing. The eastern and western sectors appear to have been deprived of the main bulk of the fluids, except near the crossing of the axes, where the existing pressures tended to force the fluids to rise steeply within or along the border of the intrusive zone until permeable channels or fractures were encountered that permitted direct escape toward the Uncompahgre "break" or axis. In the eastern sector the mineralizing fluids in part appear to have traveled southward along fractures or dikes paralleling the Uncompahgre axis until they intersected other fractured zones that trended west toward the axis. Because the fractures related to the Uncompahgre axis system are comparatively shallow extensional breaks, the largest deposits in the eastern sector are in the Dakota Sandstone, which forms the uppermost competent unit of the sedimentary sequence. Deposits stratigraphically lower in favorable beds were confined to positions very near the intrusive zone.

Large deposits of silver-lead ores have not, as yet, been found in the eastern and western sectors but are confined to the northern and southern sectors. As noted in discussion of the mineral zoning, fluids that deposited silver-lead ore evidently originated at places distant from the crossing of the two main axes, and hence the bulk of these fluids appear to have traversed east-west channels mainly in the northern and southern sectors. If other avenues of egress existed for these fluids, there is little probability that they will be discovered because they must lie at considerable distances to the northeast or southwest of the intersection of the axes, where the older strata are deeply buried beneath the Tertiary volcanic rocks. Confinement of most of the known silver-lead deposits to the northern rather than to the southern sector suggests some lack of symmetry in the igneous or structural framework. Possibly rocks on the northern side of the intrusive zone were more strongly fractured by the east-west system, or more likely, the intrusive zone was more strongly developed to the northeast than to the southwest.

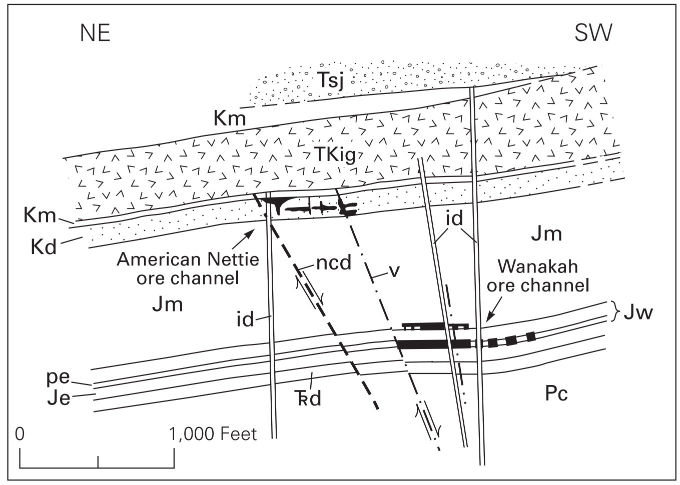


Figure 22. Generalized section through the American Nettie-Wanakah flexure (localized flattening of dip) and ore shoots (solid areas) showing the types of structural control of ore deposition. Modified from Burbank (1940). Tsj, San Juan Formation; TKig, Laramide porphyritic granodiorite laccolith; Km, Mancos Shale; Kd, Dakota Sandstone; Jm, Morrison Formation; Jw, Wanakah Formation, which includes the Pony Express Limestone Member (pe); Je, Entrada Sandstone; Ҭd, Dolores Formation; Pc, Cutler Formation; ncd, Nettie intrusive clastic dike No. 2; v, vein; id, Laramide intrusive granodiorite dike. Arrows, where shown, indicate known relative movement.

Northern Sector

The northern sector contains the largest gold-bearing and silver-bearing deposits. The gold-bearing deposits are in the southern part of this sector, mostly within a mile of the intrusive zone, and include both bedding replacement and vein types. Within or near the intrusive zone, the smaller gold-bearing deposits are veins that contain mainly pyrite and chalcopyrite with lesser amounts of sphalerite and other sulfides; in addition to these sulfides, a few veins also contain magnetite and hematite. However, the larger, pyritic base-metal-type deposits of the gold-bearing group lie mainly within the bedding of favorable sedimentary rocks in both the basal zone of the Upper Jurassic rocks and in the basal zone of the Upper Cretaceous rocks. These deposits not only contain more sulfides, but the richer of them, such as the American Nettie and adjoining properties in the upper of the two ore zones, also contain gold and silver tellurides and silver-bearing tetrahedrite.

Some gold-bearing deposits within and bordering the intrusive zone are of the contact-metamorphic type that occur within favorable beds ranging stratigraphically from the upper part of the Hermosa Formation to the lower part of the Morrison Formation. Owing to location near the central intrusive body, the beds range widely in dip; some are steeply tilted, and have been cut by numerous dikes, fractures, and faults (pl. 1, section *F–F′*). The principal deposits of economic interest, however, occur in the slightly to moderately inclined beds in the basal Jurassic strata. The contact-metamorphic deposits contain the characteristic suite of calc-silicate minerals, magnetite, and hematite plus sulfides that were introduced later and constitute the ore. These deposits, which were enriched by late gold-bearing fluids, were found mainly in highly fractured limestones. The gold in these deposits was not of contact-metamorphic origin, but appears to be more closely related to the pyritic base-metal phase of deposition.

The best examples of contact-metamorphic deposits were those in the Wanakah group of mines (fig. 21, no. 19; pl. 2, section *B–B′*) consisting of slightly inclined orebodies that conformed to the bedding in the Upper Jurassic strata. The two horizons most favorable to replacement were (1) the Pony Express Limestone Member of the Wanakah Formation (so-called “Iron Clad contact”) and (2) the limestone and enclosing shale beds (so-called “Bright Diamond contact”) about 10 to 15 ft above the basal quartzite in the Tidwell Member of the Morrison Formation. Some gold-bearing sulfide masses also occurred in the upper part of the quartzite, but they were not typical of contact-metamorphic deposits. Limy shales, interbedded with and above these two horizons, contain considerable quantities of silicate minerals. The underlying Dolores Formation contains deposits of lodestone and minor amounts of sulfides.

The principal silicate minerals are andradite, hornblende, actinolite, epidote, thuringite, stilpnomelane, and chlorite. Magnetite and hematite are commonly associated with the contact-metamorphic silicates, minor apatite, rutile, and titanite, as well as the dominant sulfide, pyrite. Ore and gangue minerals were deposited in several fairly well defined stages (table 11). The earliest stage began with the formation of andradite, hornblende, and actinolite, and ended with the introduction of iron oxides. Before or early in the sulfide stage, fracturing was renewed with the addition of hematite, epidote, and thuringite. Sulfides were deposited in the normal order of the gold belt, namely pyrite, chalcopyrite, sphalerite, and galena. Finally, native gold was deposited in late-formed fractures.

Outlines of the lower or “gold channel” in the Pony Express beds in the Wanakah mine shown in plate 3*A* extend northeastward diagonally across the sulfide replacement body. The northwest boundary of the channel grades into barren beds, whereas the southeast boundary is an indefinite assay wall within the sulfide replacement mass. The upper channel is about 120 ft above the lower channel, and is essentially parallel to it. Along the south side of the gold channel, particularly at the west, gold ore was closely associated with contact-metamorphic silicates. To the northeast and toward the apparent source of the gold-bearing fluids, the ore channel is bordered by altered rock including the minerals chlorite, thuringite, quartz, sericite, siderite, and calcite rather than the higher-temperature contact-metamorphic silicates. The gold appears to have been concentrated in fractures or minor faults that are parallel or diagonal to the main channel. At the extreme northeast end of the channel, a pocket of high-grade gold ore was found along the southwest side of the northwest-trending fault, locally known as the Iron dike (pl. 3*A*), but exploration northeast of the fault found only weakly mineralized ground, which did not constitute ore grade. Massive pyrite bodies within the channel contained very little gold, commonly no more than 0.05 ounces (oz) to the ton; according to early records, however, gold-enriched pockets of ore from the channel averaged about 0.5 oz of gold to the ton, and the ore pocket along the Iron dike contained from 3 to 5 oz of gold to the ton. A similar pocket of gold ore was found near the Jonathan dike at the northeast end of the American Nettie ore channel in the Dakota Formation (pl. 3*A*). The location of these two pockets of high-grade ore, relative to their location along the dikes, suggests that the gold-bearing fluids had a source to the east or northeast of the dike barriers.

Silver-lead deposits in the northern sector occurred from a mile to more than 3 mi north of the crossing of the Uncompahgre and intrusive axes. Most were veins that had some associated bedded and wall-rock replacement deposits, but the richest ore was in the veins. The main channels of mineralization, closely associated with clastic and igneous dikes, were confined mostly to a lower zone in the basal Upper Jurassic strata and an upper zone in and just below the Dakota Sandstone. Veins along and south of Dexter Creek valley were mineralized in both the upper and lower zones, but the fractures north of the mouth of the valley (fig. 21) were mineralized mainly in the lower zone. Almost all of the silver-bearing veins strike east. Those that contained ore shoots or local pockets of enriched ore occur 0.5 to 2 mi east of the Uncompahgre axis, but farther east, the ores were more depleted in silver and lead and enriched in iron and zinc. The ore-forming fluids apparently originating from sources near the intrusive axis, here about 3 mi east of the Uncompahgre axis, moved upward and westward along paths nearly conformable to the eastward-dipping beds. The principal valuable sulfides in these veins include galena, tetrahedrite, and other silver-bearing minerals such as pearceite and pyrargyrite. The amount of pyrite and sphalerite in these deposits commonly increased eastward, especially in the veins along and south of Dexter Creek.

The position of an individual ore shoot in the east-striking veins was dependent on the character of the enclosing rocks, the strike and dip of the fracture, and certain deflections in the dip of the fracture locally known as “rolls.” Within alternating sandstone and shale beds, the more massive sandstones maintained open fractures, whereas in the interbedded shales, fractures tended to choke or tighten; fractures deflected from the vertical in certain more favorable horizons were diverted 10 to 40 ft or more laterally upon passing from a massive sandstone into shale or limy shale. Along these rolls, the ore spread out in the flatter parts between the diverted more-vertical segments of the vein; some ore in these flats was continuous for long distances along the strike of the vein. Where the beds were locally flexed, the rolls were wide and the permeability of some beds, such as the breccia in the Pony Express Limestone Member of the Wanakah Formation, favored the development of bedded deposits. Deflection of the fracture may be the result of dip change in the course of the fracture so that minor faulting along it may have changed the dip, resulting in the creation of favorable openings. Most fractures are remarkably straight, and most strike changes were not sufficient to appreciably affect the distribution of the ore.

An important structural feature coincident with ore shoots in the group of veins south of Dexter Creek, such as in the Pony Express and Bachelor veins, was the reversal in the normal northward dip of the country rock. This dip reversal was strongest along the line of the Pony Express vein at the extreme west end where beds dip locally 15°–20° S. (fig. 23*A*, *B*). In the easternmost workings on the Bachelor vein, the greatest dip reversal occurred on the north side of the vein and extended north of Dexter Creek into the trend of the Calliope ore shoot about 1,200 ft north of the Bachelor vein. There, the beds locally dip as much as 30° S. or SE., but only for short distances. In most veins north of Dexter Creek, there are no pronounced flexures. Ore shoots lie either to one side or the other of cross breaks that are essentially parallel to the Uncompahgre axis. These cross breaks are interpreted to be gentle extensional fractures that formed along the crest of the arch and did not extend to depths great enough to tap the sources of mineralization. Few of these cross breaks, which extend northward from the intrusive axis to beyond Cutler Creek, contain ore except in the south nearer the intrusive zone, where they also may contain igneous dikes. Fractures of this trend are not continuous for long distances, but appear to be en echelon.

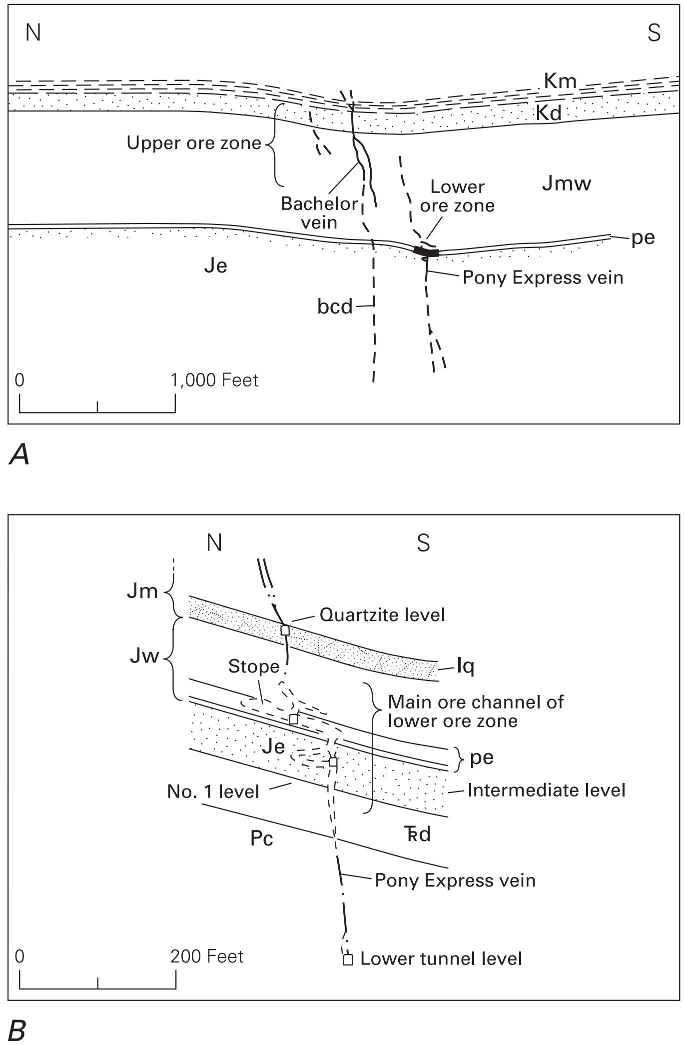


Figure 23. Generalized sections showing types of structural control of ore deposition in veins south of Dexter Creek (modified from Burbank, 1940). ***A***, Bachelor and Pony Express veins and flexure. Km, Mancos Shale; Kd, Dakota Sandstone; Jmw, Morrison and Wanakah Formations, undifferentiated; pe, Pony Express Limestone Member of the Wanakah Formation; Je, Entrada Sandstone; bcd, Bachelor intrusive clastic dike. ***B***, Pony Express vein and bedding channel of lower ore zone (enlargement from section *A* above). Jm, Morrison Formation; lq, "lower quartzite" of miners (Tidwell Member of the Morrison Formation); Jw, Wanakah Formation; pe, Pony Express Limestone Member of the Wanakah Formation; Je, Entrada Sandstone; T̄Rd, Dolores Formation; Pc, Cutler Formation.

Western Sector

The larger deposits of the gold-bearing veins in the western sector are located along the west side of the Uncompahgre River canyon in a narrow zone near, but west of the intrusive and Uncompahgre axial intersection (fig. 21). Most of the veins strike nearly east, but a few follow the more northeasterly trend of the few associated porphyritic granodiorite dikes. All have cut the Cutler Formation and overlying Mesozoic strata. The ore is mostly of the pyritic gold-bearing type that also contains minor amounts of chalcopyrite, sphalerite, galena and other base-metal sulfides; quartz, sericite, and chlorite are the principal gangue minerals, but locally a little calcite and barite are present. Some veins contain specular hematite, partly associated with and partly independent of sulfides. The gold ore here always seems to contain some chalcopyrite, which is not necessarily true in ores in the other sectors. In addition to fracture fillings that contained the better grade ore, the ore locally replaced the more permeable sandstone beds near the fractures.

Where the east-trending veins and dikes intersected favorable beds in the basal Upper Jurassic strata, some bedding-replacement deposits were formed either in breccia in the Pony Express Limestone Member of the Wanakah Formation, such as that in the Rock of Ages mine (fig. 21, no. 28; fig. 24) or in some of the more massive sandstones. The quartzite of the Tidwell Member of the Morrison Formation, which in the western sector contains some bedded deposits, shows evidence of leaching and cavity formation similar to that in the American Nettie mine; the caves, however, are typically small and decrease westward in size and number, suggesting that the mineralizing solutions moved eastward toward the Uncompahgre axis. Accessible mine workings along veins on the west side of the Uncompahgre River canyon are mostly less than 1,000 ft in length; the ore appears to have been slightly impoverished in the westernmost workings. Most of the bedded deposits lie close to the crest of the arch along the Uncompahgre axis and, in general, they were less productive than those in the northern sector east of the axis.

Some of the mines in the western sector were developed on veins in the Cutler Formation. The massive sandstones and arkosic sandstones interbedded with commonly tight shales were more favorable for the formation of small ore shoots, particularly where the alternations of the sandstones and shales caused deflections of the fractures so that changes in strike and dip, as well as in the nature of the rocks, apparently influenced the formation of ore shoots. Most of the veins are narrow and the ore shoots are small.

Although most of the deposits in this sector are near the intrusive axis, some are a mile or two to the west and north (fig. 21). To the west in the Oak Creek area, the deposits consist of gold-bearing veins in the Dakota Sandstone, and to the northwest near Corbett Creek they consist in part of similar gold, silver, and lead vein deposits in the Dakota Sandstone and in part of bedded deposits in the Pony Express Limestone Member. The latter are essentially the western extensions of the silver-lead-zinc channel deposits of the northern sector. Most ore shoots here were of little economic importance. The total production of the outlying deposits in the western sector was comparatively small.

Southern Sector

The southern sector contains chiefly vein and bedded deposits of silver-lead-zinc ores. Except for small pyritic deposits close to the south margin of the intrusive zone, most of the deposits are in Paleozoic limestone beds close to or south of the Ouray fault southwest of the town of Ouray (fig. 21). Rocks of Mesozoic age have been eroded, except for a narrow strip along the south side of the intrusive zone on the north side of Canyon Creek valley. Formations of Pennsylvanian and Permian age, exposed along both sides of Canyon Creek valley, overlie the carbonate rocks of Devonian and Mississippian age near the junction of Canyon Creek and Uncompahgre River valleys. Because the Molas Formation is dominantly shale, most of the silver-lead deposits within the bedding of the Leadville Limestone occur just beneath those impermeable shaly beds. Production from this sector has come mainly from one bedding-channel deposit, the Mineral Farm mine (fig. 21, no. 35), and from several smaller combined bedded and vein deposits. Production of silver-bearing ores of Laramide origin in this sector was probably less than $1 million.

The silver-bearing ores are similar to those of the northern sector, and include baritic or siliceous lead-zinc sulfide ore that contained chalcopyrite, tetrahedrite, pearceite, and ruby silver (pyrargyrite). The ore contained little gold. These deposits differ from the nearby late Tertiary silver-lead veins of Hayden Mountain by the latter's typical association of pearceite and tetrahedrite in an ankeritic carbonate gangue.

For purposes of description, the southern sector is conveniently divided by the Ouray fault. The area south of the fault was the more important commercially. The area north of the fault and south of the town of Ouray contains a few pyritic deposits close to the intrusive zone and some silver-bearing veins in the limestone just north of the fault.

Deposits related to fractures, flexures, and faults of generally easterly trend parallel the strike of the underlying Proterozoic rocks. Differences in competency of the steeply dipping to vertical, alternating thick quartzite and slate layers and the probable presence of very old lines of weakness along their contacts strongly influenced the younger deformation. Because fracturing was parallel to the underlying steeply inclined bedding, the Paleozoic beds lying discordantly above were flexed or slightly faulted, and the fractures in them became feeder channels for the relatively few mineral deposits found in the favorable limestone beds. Weak fractures and flexures commonly died out in the shaly beds at the base of the Pennsylvanian strata. Near Hayden Mountain, where the strata are thin, a few of the stronger fractures extended through and into the overlying volcanic rocks, suggesting that renewed movement along established fault lines continued to late Tertiary time.

South of the Ouray fault, mineralizing fluids evidently originated to the west along the intrusive axis and moved up along the trend of the formations toward the Uncompahgre River valley and the Uncompahgre "break." The main channels for the mineralizing fluids were the fractures in the south wall of the Ouray fault and certain minor flexures associated with the east-trending faults. Ore in the silver-lead veins of the southern sector is somewhat similar mineralogically to that in the northern sector.

At the Mineral Farm mine, which is the principal mineral deposit in the southern sector, leaching appears to have preceded and partly accompanied silicification of the country rocks. Leaching of the Leadville Limestone along fracture channels, just beneath shale in the overlying Molas Formation, formed caves and cave breccias in which most of the ore was deposited. Individual ore shoots were controlled, in part, by fractures of northwest and southwest trends, but the main ore channel appears to parallel a fault in the underlying Proterozoic rocks striking N. 75° W.; this fault is between layers of quartzite and slate but several hundred feet north of the deposit. Numerous small ore deposits in this general area are mainly veins, but locally the ore extended into favorable layers to form bedded deposits in the adjoining sedimentary rocks. Solution channels were leached in the limestone near or along the fractures. High-grade silver ore was found only locally.

The area north of the Ouray fault, extending to the intrusive and Uncompahgre axes, is underlain by Paleozoic formations, and is mostly covered by surficial debris. The most productive deposit in this part of the southern sector was the Trout and Fisherman vein (fig. 21, no. 32), in the Leadville Limestone and Molas Formation near the Ouray fault. Fractures in this area have a northerly trend and are probably extension fractures parallel to the Uncompahgre axis. Sulfides, including pyrargyrite, were deposited mostly in solution channels leached in the limestone near and along the fractures; the

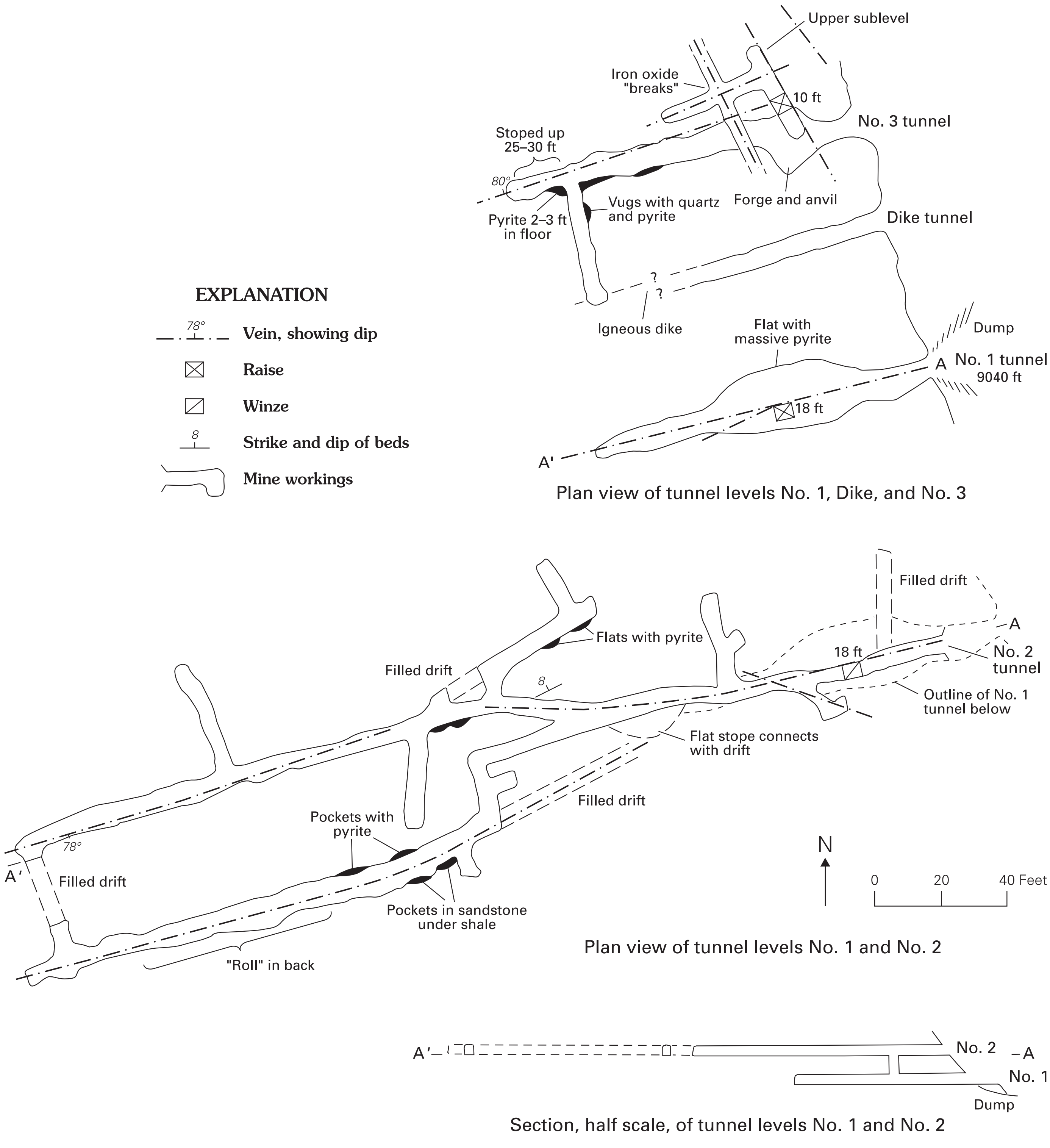


Figure 24. Plan map and partial vertical projection of underground workings, Rock of Ages mine (fig. 21, no. 28). Compiled from descriptions and field sketches of W.S. Burbank.

ore-forming fluids presumably reached the area along fracture channels that dip west along the Ouray fault.

Eastern Sector

The eastern sector contains small contact-metamorphic deposits along the south margin of the intrusive zone and pyritic gold-bearing deposits that extend for about 4,000 ft southeast of the intrusive zone. The northern part of the sector, between the latitude of Ouray and the intrusive zone, is underlain by both Paleozoic and Mesozoic rocks; in the southern part, the Mesozoic and part of the Paleozoic rocks have been eroded. The Amphitheater area east of Ouray is covered by glacial and landslide deposits.

South of the faults that limit the southern margin of the intrusive zone, a few favorable beds contain contact-metamorphic deposits. The deposits of the Skyrocket group of mines (fig. 21, no. 38), in the limestone of the Pony Express Member of the Wanakah Formation, consist of highly pyritic ores that replaced the altered rocks. In this area the beds have been cut by an igneous plug, dikes, and sills, and numerous small fractures, features that guided the mineralizing fluids into the more favorable rocks. The deposits, however, have not been extensively developed because of their low content of gold and silver.

Gold deposits in this sector extend about as far from the intrusive zone as do those in the northern sector, but all of the deposits explored were much smaller and their production was very much less. As in the western sector, no commercial lead-silver deposits were formed during the Laramide mineralization. A few lead-silver veins, however, were emplaced east and southeast of Ouray during the late Tertiary.

Pyritic ores along the south side of the intrusive axis are related to fractures and dikes that trend either east or north to northeast. They resemble deposits in the northern sector in their stratigraphic position and mineral content, and they range from low-grade contact-metamorphic deposits in limestones of the Hermosa Formation and basal Upper Jurassic strata to higher grade gold deposits in the Dakota Sandstone. Sandstones in the Dakota were altered to quartzite, which was irregularly warped and faulted along north- and northwest-trending fractures that acted as feeding channels for mineralizing fluids to enter and deposit ores. The fluids were in part diverted to west-trending fractures along which some deposits were formed by either replacement of beds or filling of solution cavities.

Late Tertiary Ore Deposits

Ore deposits of late Tertiary age, Miocene and perhaps some Pliocene, in and near the Uncompahgre district are related principally to a major center of mineralization, the Silverton caldera area to the south. The principal deposits of late Tertiary age are mainly in volcanic rather than sedimentary rocks and are related to structures of deep-seated volcanic origin. Ores of late Tertiary age are similar to those deposited during the Late Cretaceous to early Tertiary time of mineralization in their content of gold, silver, lead, zinc, and copper, but they differ somewhat in their mineralogic character (tables 11 and 12). The principal gold deposits formed during this younger stage consist of native gold in quartz veins in contrast to the pyritic gold deposits formed during the earlier stage. Silver-bearing veins also appear to differ somewhat in details of their mineralogy.

Near Ouray, the late Tertiary ore deposits are mostly veins and were only of minor interest. They include the veins of The Amphitheater in the San Juan Formation and underlying sedimentary rocks as well as those along the Uncompahgre River canyon in the Proterozoic quartzites and slates. Some veins strike north to northwest; others strike more nearly east. The north-trending system appears to be the northward termination of the fractures and veins in the Bear Creek area adjacent to and just southeast of the Uncompahgre district, where the San Juan Formation has been cut by a strong system of north-striking fractures.

Northeast of Ouray, the east- and north-striking fractures are weak or absent. A conjugate system of northeast- and northwest-striking fractures, some of which contain veins, is present within the San Juan Formation immediately east and north of The Blowout area. Many of these veins are barren quartz and sparse barite, but some contain small amounts of base-metal sulfides and are reported by miners to have been prospected for their gold content. In this same area, however, a few fractures and faults having easterly and northerly trends appear to represent the reopening of Laramide fractures in late Tertiary time; most of these fractures contain either barren quartz and barite or barren carbonates.

Veins in the walls of The Amphitheater east and southeast of Ouray strike north to N. 30° W. and dip steeply east and west. The intensity of late Tertiary fracturing in the San Juan Formation here was undoubtedly controlled by the underlying Proterozoic rocks at the south and the northward-thickening wedge of Paleozoic and Mesozoic rocks between the volcanic and Proterozoic rocks. This feeble system of younger, north-striking fractures was weakly mineralized to the north; the few veins were mostly barren quartz or barite containing small, widely scattered pockets of galena.

On Hayden Mountain south of Ouray, and partly south of the map area (Luedke and Burbank, 1981), the San Juan Formation is cut by two prominent fracture systems, one striking N. 15° W. and the other N. 50°–70° E. These late Tertiary fracture systems were more strongly mineralized than those northeast of Ouray; however, the few veins that were developed have not proved to be of economic value.

A few dikes and veins of late Tertiary age extend into the Uncompahgre district from the upper Cow Creek center several miles to the east (Steven and others, 1977; Steven and Hail, 1989). The southernmost dike, the Germania dike in the east wall of The Amphitheater (fig. 21), reportedly contained pockets of complex base-metal ore; some gold was found along the dike walls. The northernmost east-striking dike, known locally as the Calliope (fig. 17), parallels the Calli-

Table 12. Principal primary ore and gangue minerals and some more-prominent secondary minerals, classified according to the principal groups, for late Tertiary deposits in the Uncompahgre mining district, southwestern Colorado.

[Modified from Burbank, 1940]

Base metal deposits	Baritic lead and silver deposits	Siliceous silver-gold deposits[1]
Primary (hypogene) metallic minerals		
Pyrite	Pyrite	Pyrite
Galena	Sphalerite	Sphalerite
Sphalerite	Galena	Gold
Chalcopyrite	Chalcopyrite	Proustite
Specularite	Tetrahedrite	
	Stephanite	
	Polybasite	
Primary (hypogene) gangue minerals		
Quartz	Quartz	Quartz
Sericite	Barite	Sericite
Calcite	Rhodochrosite	Beidellite(?)
Rhodochrosite	Calcite	
	Sericite	
	Chlorite	
Secondary (supergene) minerals		
Limonite	Limonite	Limonite
Wad	Wad	
	Malachite	
	Azurite	

[1]Dexter Creek area.

ope vein of Laramide origin, but is about 500 ft north of the vein. Walls of the dike were locally fractured but only weakly mineralized. The parallelism of the Calliope dike and the vein is thought to be accidental and controlled here by the tendency for fracturing in the basement rocks in this direction.

Geologic conditions during the late Tertiary stage of mineralization did not normally favor the formation of replacement deposits similar to those of the earlier Laramide mineralization. Mineralizing fluids apparently were confined to the late Tertiary fractures, and accordingly, did not form extensive lateral replacement deposits in sedimentary rocks beneath the San Juan Formation, providing that either those rocks were not removed by early Tertiary erosion or they were too deeply buried at the time of ore deposition. The Portland vein, at the head of The Amphitheater, is a late Tertiary vein in this area. The Portland mine (fig. 21, no. 42) contained complex base-metal and precious-metal ore in veins that cut the San Juan Formation and the immediately underlying Paleozoic rocks. The ore spread laterally short distances near the contact and replaced basal layers of tuff in the San Juan Formation and brecciated limestones in the Paleozoic rocks. At and near the base, the tuff here is locally calcareous and contains some more easily replaced thin lenses or beds of limestone. Most of the production from this mine came from shallow stopes. The ore minerals were pyrite, sphalerite, galena, and chalcopyrite in a gangue of silicified limestone, quartz, barite, and rhodochrosite or manganiferous carbonate; a later generation of comb quartz, pyrite, and kaolin possibly constituted the gold-bearing vein material. The last barren stage of mineralization consisted of abundant drusy quartz and coarse calcite.

Rock Alteration

The most important period of rock alteration within the Uncompahgre district, excluding any changes to the rocks as a result of igneous activity during Proterozoic or Paleozoic times, was related to the Late Cretaceous to early Tertiary Laramide orogeny. At that time, the most pronounced changes were the result of heat and related hydrothermal effects of the contemporaneous igneous activity, which locally indurated and altered many of the adjacent sedimentary units.

As a result of that igneous activity, the more important types of rock alteration occurred in several ways: (1) from the effects of direct heating of the rocks, which varied according to their composition and moisture content, (2) from direct permeation of the rocks by hydrothermal emanations given off by the igneous masses, and (3) from the heating of circulating ground waters on the borders of the local uplift. These processes undoubtedly were integrated and (or) combined. The highly altered rocks near the main intrusive center (The Blowout) were unquestionably the result of direct heating and hydrothermal emanations.

Discussion of rock alteration has been arbitrarily divided between the early effects near the main center of igneous activity, which are correlated with the end-phases of igneous rock crystallization, and the effects produced in the immediate walls of ore deposits within the mining district. Some overlap exists between the different phases of alteration and related mineralization so classified, but this division facilitates the comparison of alteration resulting directly from local igneous activity with alteration in which the genetic relations are less clearly defined.

The earlier discussion of the porphyritic granodioritic rocks pointed out the important mineralogical changes that occurred in the laccoliths during the later stages of crystallization. When the magmas intruded comparatively impermeable strata, the changes resulted entirely from interaction of the pyrogenic minerals and the constituents concentrated in or released from the residual fluids of the magma. Those conclusions are supported by the bulk compositions of the rocks, which show little change other than a progressive oxidation of ferrous to ferric iron. Most of the capping shales were eroded from the larger laccoliths, but a few shale remnants found adjacent to those bodies were only moderately baked and altered by heat or by emanations from the intruding igneous rocks. In sharp contrast to this relatively minor alteration near contacts of the concordant intrusions, a zone of very strong alteration and mineralization occurs near the central vent through which the large volume of magma was intruded. Alteration in The Blowout area not only strongly affected the surrounding sedimentary rocks over a distance of several thousand feet from the center, but also resulted in alteration of the porphyritic igneous rocks that filled the narrow neck at the cessation of intrusive activity.

Rock alteration as a result of widespread volcanism and intrusive igneous activity during Oligocene and Miocene time, while extremely important in much of the western San Juan Mountains region, was minor within the Uncompahgre district except in the walls of a few veins.

Recrystallization of rocks and the deposition of minerals near the conduits of the modern thermal springs in the district are most likely the result of meteoric waters of deep circulation. Alteration effects of ordinary weathering and shallow ground-water circulation were for the most part of relatively minor importance, and are considered only as phases associated with the supergene enrichment of ores.

Alteration of Sedimentary Rocks

Sedimentary beds in The Blowout area include about a 2,000-ft thickness of rocks ranging in stratigraphic position from the upper part of the Hermosa Formation (Pennsylvanian) to the base of the Mancos Shale (Cretaceous). A great variation exists locally in the kind and degree of alteration found in the different rocks, which depended upon composition, relative permeability, proximity to the stock, and the rocks' position with respect to channels that allowed the circulation of fluids. The most intense alteration occurred in the rocks beneath the mudstones of the Morrison Formation, and included many of the calcareous shales and limestones of all the formations, the breccia in the Pony Express Limestone Member of the Wanakah Formation, and the limy beds of the Dolores Formation. The basal beds of the Wanakah Formation constitute the most widely altered and mineralized strata in the mining district. Dense limestones of the Hermosa Formation, of which only a few crop out, were slightly metamorphosed; the coarser sandstones and grits of the Hermosa and Cutler Formations, although strongly bleached, retained their sedimentary textures. Most rock units are easily recognizable except locally or within the central, highly altered zone of The Blowout, where in places it was difficult to distinguish between sedimentary or igneous rocks.

On the south side of The Blowout, ordinarily red calcareous shale and limestone-pebble conglomerate beds of the Dolores Formation were converted into (1) color-banded or mottled green and gray rocks, or (2) dark-gray, dense calc-silicate hornfels. The original color banding of the rocks was partly preserved by color alternations or by alternations of finer and coarser textured metamorphic minerals. Within the hornfels, the coarser grained minerals occur as irregular lenticular patches or nodular segregations. Microscopically, this rock has a felted texture owing to numerous interlacing prismatic crystals of amphibole. This amphibole has a yellow to blue-green pleochroism and an extinction angle of 26°–27° corresponding to the variety pargasite; the crystals are very small, mostly less than 0.1 mm long. Scattered grains of other minerals large enough to identify were quartz, orthoclase, albite, labradorite (An_{65}), emerald-green epidote, brownish-green biotite, titanite, rutile, chlorite, hematite, and magnetite. Local, finer grained crystalline aggregates contain a few embedded larger grains ranging from less than 0.01 to 0.03 mm in size, and consist largely of intergrowths of quartz, orthoclase, and albite. Cordierite, which might be expected in rocks of this type, was not identified, but if present, must occur as extremely minute grains. The great variation in texture from almost submicroscopic to coarser, nodular aggregates suggests that equilibrium between the different metamorphic minerals had not been attained; this suggestion is emphasized by presence in the rock of both albite and anorthite that were definitely identified both in thin section and by oil immersion studies. Minor amounts of alkali feldspars may have resulted from recrystallization of the micaceous constituents of the shales. Epidote, commonly associated with clusters of magnetite and hematite crystals, definitely formed later than the plagioclase (andesine/labradorite) and amphibole. Both epidote and the iron minerals appear to have been introduced into coarser textured, nodular segregations. These rocks probably formed by the incipient recrystallization of the original constituents followed by the introduction of iron-bearing fluids. The original layers of these rocks were not as rich in iron as those that were altered.

A color-banded and mottled green and gray altered mudstone from the Wanakah Formation at the same locality contains highly silicified layers composed of quartz and sodic feldspar; this quartz-rich mosaic, having grains less than 0.1 mm in size, has been peppered with numerous small grains of garnet, epidote, rutile, chlorite, and calcite. Iron oxides are not evident, thus the ferric iron presumably is, in part, in the garnet, which is nearly pure andradite. Coarse layers in the rock contain andradite, epidote, and calcite in grains as large as 1.0 mm. The borders of the nodular aggregates are marked with albite crystals having both Carlsbad and albite twinning. Apatite, rutile, and zircon crystals are scattered in the coarser quartz. Feldspar and garnet apparently formed early because epidote replaces garnet, and quartz-epidote-hematite intergrowths crosscut the other minerals. Chlorite and calcite formed late.

Bleached impure sandstones of the Cutler Formation unconformably underlie the rocks described above. Rock textures were preserved both megascopically and microscopically. The larger grains of quartz and feldspar remain mostly unaltered except for replacement locally by scattered growths of hornblende, epidote, and secondary quartz. Where recrystallization was most advanced, rounded quartz granules and larger quartz mosaics were formed together with crystals of epidote and hornblende. Hornblende veinlets also cut the rock. The fine-grained matrix of the sandstone has been recrystallized to intergrowths of various metamorphic minerals and some calcite. Sericite is present, but is not conspicuous. Paragenetic relations between these minerals are obscure.

The most highly altered sandstone beds are found near the central part of The Blowout area, either in the large block of sedimentary rock enclosed by the intrusive body or in sandstone beds bordering the edges of the stock; recrystallization of both sedimentary and igneous rocks here is far advanced. In a sandstone from the north branch of Skyrocket Creek, quartz was segregated or recrystallized into rounded grains, about 0.5 mm in diameter, which have sutured or scalloped edges, and have been embedded in larger orthoclase crystals or intergrown in a granular mosaic with the orthoclase. The texture, except for the large size of the quartz grains, resembles that developed in the groundmass of the porphyritic granodiorite of the laccoliths where recrystallization was farthest advanced. A few larger crystal outlines may have been originally plagioclase, but the shape suggests they were probably porphyroblasts rather than original detrital constituents. Other minerals of the rock are sericite, stilpnomelane, chlorite, epidote, albite, and pyrite. Orthoclase has replaced and veined the sericite, and chlorite was converted to brown stilpnomelane. These relations suggest a compound metamorphism in which the rocks had earlier been partly sericitized and pyritized. This reversal in the normal crystallization sequence of these minerals, also found in certain high-temperature replacement veins in this same area, suggests either rising temperature during a single stage of metamorphism, or possibly two separate injections of granodioritic magma.

On the north side of The Blowout, alteration in the lower part of the Mesozoic strata, particularly the more permeable beds, was characterized by a conspicuous introduction of iron oxides and by the presence of tabular bodies of sulfides. A bed of sandy calcareous shale in the Dolores Formation was converted into an aggregate of quartz, actinolite, epidote, and calcite. Small grains of quartz were partly recrystallized, but the original texture of the rock was not destroyed. Epidote formed later than actinolite, and calcite replaced both minerals. With further replacement by calcite and chlorite, however, the actinolite-bearing rock was converted to a mottled dark gray and green layered rock containing prominent cleavage plates of calcite more than an inch across. The darker colored layers are chiefly composed of quartz and some apatite, biotite, and orthoclase, or of epidote and a little calcite and chlorite; the latter minerals have a relict fibrous texture presumably inherited from replacement of earlier-formed actinolite or hornblende. Biotite and orthoclase probably were also early-formed minerals. The lighter colored layers are composed of quartz, calcite, and chlorite. Again, both calcite and chlorite have inherited fibrous textures like that of the actinolite, although none of that mineral remains. Replacement by calcite and chlorite occurred later than the formation of epidote in both the dark and light layers. The typical epidote in rocks of The Blowout area has abnormally high refractive indices; however, some common epidote was recognized. Perhaps an additional element, such as titanium, may cause the high refractive indices; megascopically the mineral has neither the reddish-brown or pink pleochroism of manganiferous epidotes nor the black of rare earth-bearing epidotes. From the mineral association, it is suggested that the ferric iron content increased during the intermediate epidote stage, but not in a sufficient amount to form iron oxides. The described sequences of mineral crystallization suggest several pulsations of replacement in which the intensity of each successive pulse was sufficient to partly or completely destroy the effects of earlier ones.

Some layers of dark siliceous rocks in other strata within The Blowout area were locally converted to massive lodestone. These rocks are mottled by epidote and quartz in interlacing veinlets; thuringite, stilpnomelane, and epidote having high refractive indices are common in these rocks. The magnetite masses (lodestone) embedded in quartz are bordered in some places by sheaf-like growths of a highly birefringent chlorite-like mineral having the optical properties of stilpnomelane. The quartz has been charged with small crystals of apatite, rutile or other titanium minerals, epidote, and some zircon. Magnetite apparently was one of the earlier minerals to replace the sandstone, and was accompanied by some apatite, rutile, and zircon. The rock then was fractured; epidote and hematite were formed, accompanied by additional veining and recrystallization of the quartz and, possibly, introduction of more titanium minerals. Calcite is present, and pyrite occurs in minor amounts. In other rocks from the same locality, thuringite rather than stilpnomelane was the predominant mineral deposited following or accompanying the epidote stage. The general order of mineral formation was fibrous hornblende, andradite, magnetite, pyrite, hematite, epidote, thuringite, and finally calcite as well as additional pyrite and other sulfides of the orebodies.

Alteration of Igneous Rocks

The igneous rocks in The Blowout area are generally much less altered than the enclosing sedimentary rocks, but compared with the igneous rocks in the laccoliths, have equally striking mineralogical changes. For this reason, it is thought necessary to attempt to distinguish between true endomorphic alteration and deuteric alteration resulting during the later stages of consolidation of these rocks. Many minerals are common to both types of alteration so that mineralogical changes alone are insufficiently diagnostic, but, as suggested by the mineralogical changes that occurred in the laccoliths, the state of oxidation of the iron and the extent of reaction in the plagioclase crystals are fairly accurate indicators of the degree of alteration. The chemical analysis (table 7, sample 2) of granodiorite from The Blowout and the sample containing magnetite crystals suggest a comparatively minor oxidation of the iron. This rock is similar to that of the rapidly chilled margins of the laccoliths where only minor deuteric alteration occurred. The lack of late magmatic reaction is further indicated within the plagioclase phenocrysts, despite local endomorphic alterations, by the retention of their pronounced zoning. In some instances, although the plagioclase crystals in the igneous rocks of The Blowout are completely replaced by secondary minerals, the magnetite crystals appear to have been little affected by endomorphic processes of alteration.

The igneous rocks subjected to the highest grade of metamorphism, and more or less pyritized, are found within the main crosscutting intrusion in The Blowout. As in the sedimentary rocks, the extremes of alteration are confined to narrow zones of high-temperature mineralization. Granodiorite from the east-central part of this stock, in which the magnetite was not oxidized, retained most of its original texture. Plagioclase phenocrysts are comparatively fresh and the zoning was unaffected, but a few contain a little sericite; some quartz phenocrysts were recrystallized into a granular mosaic. Ferromagnesian minerals, however, were completely altered and their outlines indicated only by a dusting of magnetite crystals or by aggregates of biotite intergrown with quartz, magnetite, rutile, calcite, and chlorite. Biotite, the most prominent secondary mineral, has been scattered throughout the rock in clusters or in small flakes; it differs from ordinary pyrogenic biotite chiefly by its texture and mode of crystallization. Chlorite has replaced part of the biotite, and calcite has partly replaced all minerals in the rock.

In other parts of the stock, alteration similar to that in the surrounding feldspathized sedimentary rocks consisted mostly of calcite and sericite. Within the igneous rocks, the ferromagnesian minerals were altered to aggregates of quartz, chlorite, magnetite, and calcite. Orthoclase phenocrysts were little altered except for some replacement by late calcite. The groundmass of the intrusive rocks has been largely recrystallized and contains coarse patches or lentils of a mosaic of quartz and orthoclase grains. Veinlets of quartz and orthoclase traverse the rocks and formed later than the sericite in the plagioclase. Pyritization probably occurred both before and after the veining by quartz and orthoclase.

The alteration, so far mentioned, was comparatively weak and applies chiefly to the more massive parts of the stock. Where this intrusive body was highly fractured or near contacts with sedimentary rocks, it was more extremely altered, and granular rocks consisting chiefly of aggregates of quartz, orthoclase, and sericite were formed. As stated above, it was not always possible in the zones of extreme alteration to distinguish clearly between originally sedimentary or igneous rocks. Typically, little evidence existed as to which rock type was most subject to alteration, but it is thought that the igneous rocks were somewhat less permeable to altering fluids. The more extreme alteration thus was confined at the contacts or to fractures in the igneous rocks.

The effects of epidotization are inconspicuous or lacking in rocks of the stock. However, epidote is more conspicuous than biotite in the larger, west-extending prong from this igneous body (fig. 12). The principal alteration products are epidote, chlorite, and calcite. All original biotite and hornblende have been altered to aggregates of chlorite, epidote, and commonly magnetite and rutile; plagioclase has been replaced partly by epidote and calcite but otherwise was little altered. Joint surfaces of these igneous rocks are coated with pyrite or with epidote, hematite, and calcite. The chemical analysis of porphyritic granodiorite from this area (table 7, sample 2), differed very little from the other analyses, except for the addition of a minor amount of pyrite and possibly a slight leaching of magnesia. Pyrite is restricted to coatings on joint surfaces, suggesting that, except where fractured, the intrusive rock was less susceptible to the alteration than were the sedimentary rocks.

Wall-Rock Alteration of High-Temperature Veins

Both sedimentary and igneous rocks in The Blowout area were cut by small, so-called high-temperature veins. These veins occur in tight, minor shear zones or along irregular, narrow fractures as a result of replacement rather than open-space filling. In a few places, they were prospected or mined for their gold content. Their mineralogy is intermediate between that of high-temperature feldspathization in the sedimentary and intrusive rocks and that of the contact-metamorphic replacement deposits north of The Blowout. The ore minerals are mainly pyrite, chalcopyrite, and a little sphalerite and galena. These veins are notable because of the recrystallization of orthoclase in the vein walls as well as veinlets or seams of plumose or massive magnetite. Orthoclase forms granular masses, and the grains, intergrown with quartz, are usually not more than a fraction of a millimeter in size. Minor accessory minerals formed in the vein walls include apatite, epidote, hematite, thuringite, and less commonly rutile and zircon.

In the Great Western mine (fig. 21, no. 21), both orthoclase and quartz have replaced and veined the sheared and crushed sandstones in the Hermosa Formation; there were several phases of shearing and fracturing. Early orthoclase and magnetite were veined by pyrite, again by magnetite and hematite, and then followed by quartz, thuringite, chalcopyrite, and sphalerite. Comparatively abundant apatite, in minute crystals, probably was introduced along with magnetite and hematite. Thuringite commonly accompanied chalcopyrite, and in places was intergrown with it. A few small grains of yellow to deep-brown pleochroic epidote, resembling allanite, formed during this stage of mineralization. Calcite was later than all the other minerals.

Somewhat similar veins have cut both sedimentary rocks and porphyritic granodiorite near the central part of the main intrusive body in The Blowout. One vein, cutting the block of altered sedimentary rock enclosed within this body, is composed chiefly of quartz, sericite, and orthoclase and lesser stilpnomelane, pyrite, magnetite, and hematite. Sericite formed early in the altered porphyritic igneous rock surrounding the sedimentary block, and was later veined and replaced by orthoclase and quartz. Veins of magnetite and stilpnomelane cut the early quartz and other minerals. Some pyrite, probably associated with the early sericite, was commonly rimmed by altered iron oxides or a ferric silicate mineral. Late-formed pyrite was disseminated in all rocks in this area; chalcopyrite was not detected. These same mineral relations were noted in the contact-metamorphic ores of the Bright Diamond mine in the Wanakah group of mines (fig. 21, no. 19) on the northwest side of The Blowout.

Similar to but separate and distinct from the so-called high-temperature veins are the so-called hematite veins (Burbank, 1936, p. 241–243). Immediately west of the central intrusive body (figs. 12, 14), numerous small, dominantly hematite-bearing veins have cut all the rocks; hematite also locally coats the joint faces in the porphyritic granodiorite. On the west side of the Uncompahgre River valley, some of the hematite veins are a foot thick. These veins typically followed pre-existing zones of weakness such as the walls of igneous dikes or pyrite veins; in places, however, they independently filled other fractures, and contain only hematite or chiefly hematite and minor amounts of quartz, thuringite, epidote, and calcite. Some sulfide minerals are present wherever there are quartz and other silicate minerals. The paragenetic relation of hematite following pyrite, where hematite veins parallel walls of pyrite veins, suggests that the hematite veins corresponded to the ferric-iron stage evident in all sequences of rock alteration, and were emplaced following widespread, renewed fracturing or reopening of earlier-formed fractures. Hematite veining was less conspicuous in tight shear zones and replacement deposits. The high-ferric-iron hypothermal stage of mineralization, represented by stilpnomelane, epidote, thuringite, and second-generation magnetite, paragenetically corresponds to or immediately followed the hematite vein-forming episode of mineralization. In the orthoclase-bearing veins of the Great Western mine, the hematite episode of mineralization clearly represented a period of fracturing that followed deposition of early magnetite and pyrite and preceded deposition of thuringite, chalcopyrite, and other sulfides.

Wall-Rock Alteration of Other Ore Deposits

This category is differentiated on the basis of the predominant mineralogical composition of alteration products resulting from the processes of sericitization and chloritization, silicification, and carbonatization. The mineral assemblages duplicate, in some instances, those already described in the rocks of the intrusive center. Most or all of the comparatively high-temperature minerals, however, are less conspicuous or are absent in the walls of veins and replacement deposits in areas outside the zone of contact metamorphism. Alteration generally was confined to the immediate walls of veins, or was more or less coextensive with the orebodies in the replacement deposits.

Sericitization and chloritization were the predominant processes of alteration found in the walls of pyritic veins of the mining district. The formation of much pyrite was in almost every instance accompanied by sericite both in vein walls and in quartz gangue. Chlorite commonly was more conspicuous where the vein walls are intrusive rocks; chlorite typical of zones of higher temperature alteration is commonly absent. Alteration of intrusive wall rocks therefore ranged from more highly sericitized and pyritized selvages near fracture walls to weaker propylitic types in which sericite, chlorite, and calcite were the predominant alteration minerals. The largest bodies of more-or-less completely sericitized rock are those in the pyritic replacement deposits in quartzite best seen in the American Nettie and Jonathan mines (fig. 21, nos. 17 and 18). Sericite and recrystallized quartz are the predominant minerals, but minor amounts of chlorite and grains of rutile, anatase, and apatite were found.

Sericitization and chloritization of the rocks in walls of the silver-lead-zinc veins are less conspicuous, but apparently become more so with an increase in pyrite in the veins. Intrusive clastic dikes along some of these veins are generally characterized by a sericitized, chloritized, and carbonatized matrix; some fragments within the dikes may be pyritized. It thus appears that the fluids involved in propelling the clastic material were sufficiently heated to produce recrystallization of the finer grained matrix. Pyritized fragments also suggest some alteration occurred near the initial sources of the dike material prior to its injection. The walls of these dikes are seldom, if at all, altered unless they were reopened and subsequently mineralized. Apparently, the occluded fluids were so cooled and attenuated by expansion during injection of the dikes that their temperature and volume after condensation tended to minimize alteration of the walls.

Silicification is a more conspicuous type of alteration in the outlying deposits of the mining district than it is nearer the center. The lower grade silver-lead-zinc replacement deposits, particularly in the Pony Express breccia beds, are characterized by silicification. The breccia may locally be highly silicified for hundreds of feet along its outcrop and converted into a porous, clinker-like rock. Any accompanying mineralization, however, was weak. The limestone fragments were replaced by light- to dark-colored, fine-grained quartz (fig. 25*A*), and the cavities of the breccia were lined with drusy coatings of small calcite crystals. Nearer the orebodies, fine crystals of barite were found in the cavities of the breccia (fig. 25*B*). The massive limestone and red shaly beds in the Molas Formation were strongly silicified in the Mineral Farm mine (fig. 21, no. 35) in the southern part of the district. There, the shaly beds were especially converted into brown jasper, which formed a casing to the pipe-like ore shoots.

Carbonatization was more or less active in all parts of the district. Carbonate minerals were disseminated in noncarbonate wall rocks, and carbonatization aided the recrystallization of the limestone and breccia in the Pony Express Limestone Member of the Wanakah Formation. These beds, completely recrystallized in some areas into layered carbonate rock,

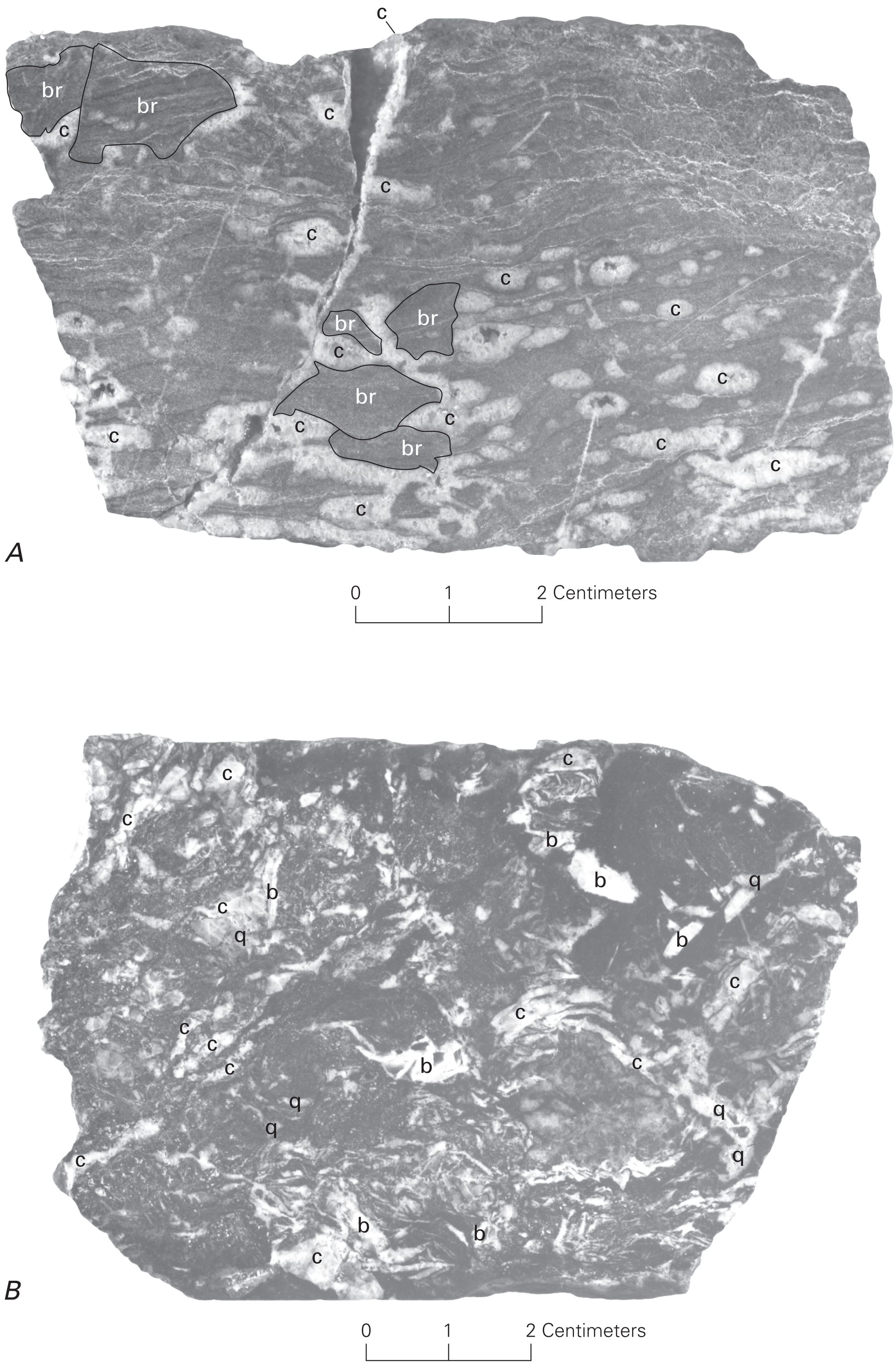


Figure 25. Photographs of polished slabs of typical altered and mineralized wall rock of veins in or near Dexter Creek, north of The Blowout area. ***A***, Matrix of silicified limestone breccia composed of angular, loosely compacted platy fragments (br) in the Pony Express Limestone Member of the Wanakah Formation, showing thin seams of unidentified carbonate material and cavities (some developed by leaching) filled or lined with small calcite (c) crystals; dark centers in two cavities near right center of photograph are voids into which scalenohedral calcite crystals project. From Pony Express mine (fig. 21, no. 15). ***B***, Silicified limestone breccia from the Pony Express Limestone Member of the Wanakah Formation showing vugs lined with crystalline quartz (q), barite (b), and calcite (c). From vein roll in the Señorita mine (fig. 21, no. 1).

have cavities lined with small to large crystals of calcite. An intermediate-temperature type of alteration probably resulted in the development of iron- and manganese-bearing carbonate minerals near orebodies. The most common carbonate minerals are (1) manganiferous ankerite, such as that found in replaced limestone at the Mineral Farm mine, and (2) ferruginous rhodochrosite that was found in many lead-zinc deposits in the northern part of the district.

Source of Altering Fluids

Various aspects of both the foregoing and following discussion were published by Burbank (1936). The views and conclusions expressed in that paper, although dated but based upon valid observations, have been summarized in order to present some of his interpretations concerning the relation of the magma solidification to the altering and mineralizing processes as applied to rock alteration and ore deposition in the Uncompahgre mining district. They, for their historic value, are included here to show the breadth of his understanding of the problems at that time (1930s).

The localization of zones of contact metamorphism, intense alteration, and mineralization of rocks within a few thousand feet of the central intrusive channel in The Blowout area suggests a genetic relation between these processes and the igneous intrusions. Numerous studies of similar occurrences have considered the source of altering and mineralizing fluids to be crystallizing magma. The intensity of the alteration and the extent of recrystallization in the granodiorite of the laccoliths during late stages of crystallization and the so-called hydrothermal conditions existing at that time make it appear unnecessary to require the existence of a large stock immediately beneath the central part of The Blowout area.

Alteration and mineralization in The Blowout area thus are thought to have been the result of superheated residual fluids from the later stages of the granodioritic magma crystallization. The bulk of the fluids' original constituents were acquired from within the magma. There is little or no evidence of a discontinuity in the physical state of the fluids controlling the end phases of magma crystallization or the corresponding hypothermal phases of mineralization and alteration in the surrounding rocks. However, there seem to have been episodic breaks in the continuity of the mineralizing processes, marked by the formation of hematite veins. Structural conditions attending the formation of hematite veins suggest a relation between widespread fracturing and a consequent sudden release of pressure upon the crystallizing igneous bodies.

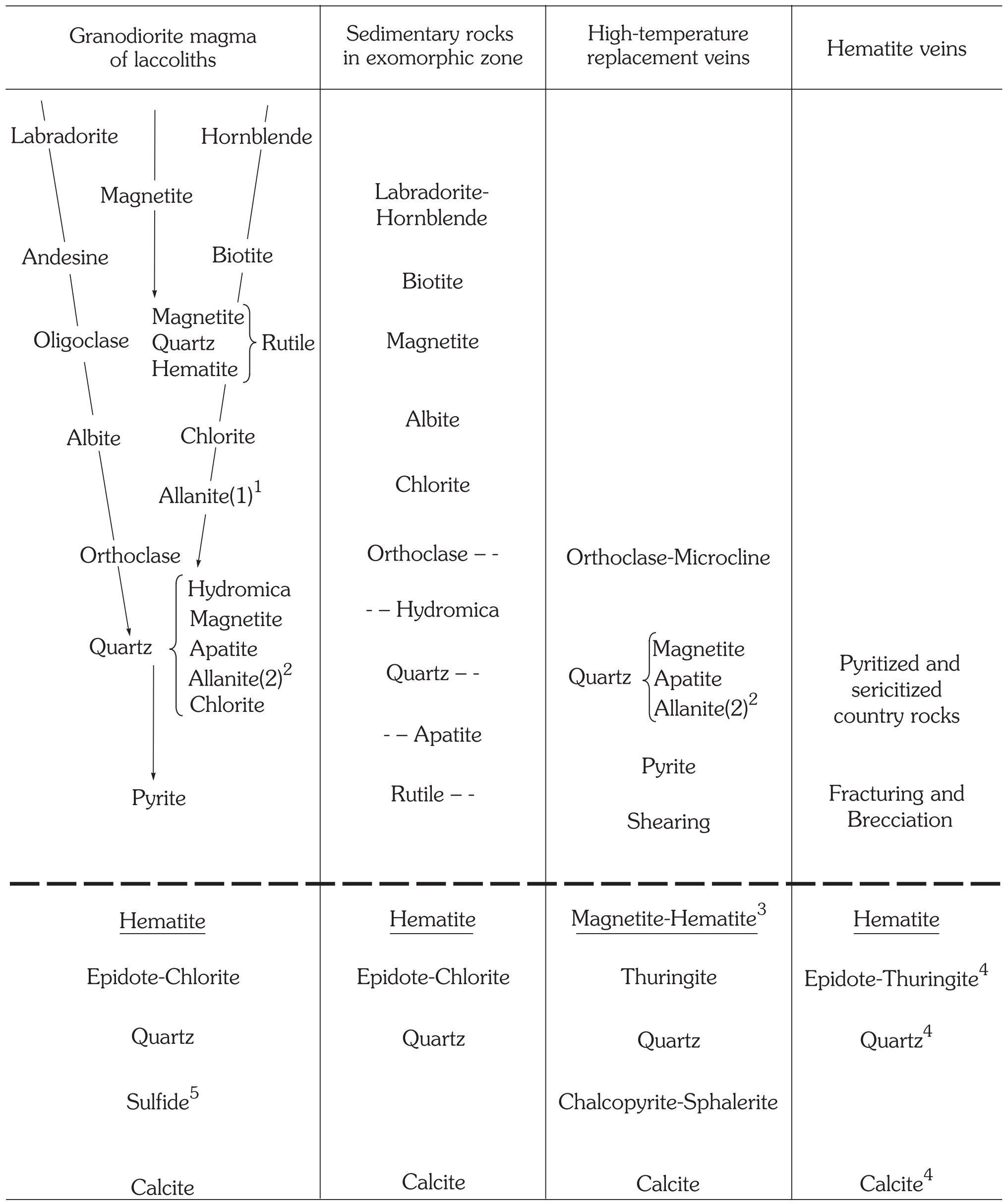
Rock Alteration Compared With Late-Stage Igneous-Rock Crystallization

The described principal stages of rock alteration are compared with those of igneous-rock crystallization in figure 26. Correlation between different columns is indicated by the placement of the minerals (oldest at the top). The only stage for which there is evidence of an approximate time equivalence is indicated by the connecting dashed line across the four columns. All minerals above this dashed line may or may not be correlated correctly with respect to the time of their formation because it is evident that local reactions between the host rocks and mineralizing fluids may have displaced members within a reaction stage. Different minerals, belonging to one or another of the columns in the figure, formed products in a more or less definite order or pseudo reaction-series that have a considerable range of stability whereas other minerals have identified and limited positions in the series; some minerals occupy a definite position herein referred to as a discontinuity.

The crystallization sequence of hematite in all columns, thought to have followed a sudden structural adjustment such as shearing, fracturing, brecciation, or intrusion of some clastic dikes, and followed by the sequence of ferric iron-bearing silicates (epidote, chlorite, and thuringite) and metal sulfides, is probably a true time correlation. This interpretation is supported by observed field relations in both veins and mineralized rocks. The fact that hematite, an oxide, is locally the only or the principal mineral in some veins and that it has entered into a sulfide sequence suggests a break in the physical and chemical conditions of mineralization. The ferric iron-oxide stage of mineralization is thought to represent a discontinuity in the series resulting from an oxidation stage during late crystallization of the parent igneous bodies. The acidic emanations supposedly had large enough volume to dissolve and carry away much material to be deposited elsewhere. Hematite veins are in fact better developed west of the central zone of mineralization. Veins containing orthoclase and other magmatic minerals are more common close to the eruptive vent. Hence, the mineralogy of the highly altered rocks nearer the center of intrusive activity more closely resembles that of the intrusive body.

Conditions of the late recrystallization in the laccolithic bodies must have differed in some respects from those that existed during rock alteration and the emplacement of the high-temperature veins. The laccoliths presumably crystallized under conditions in which most of the residual fluids were retained until very late stages of crystallization, whereas the altered zones and veins in The Blowout area formed under conditions in which the mineralizing fluids were moving and reacting with the rocks they traversed. The physical and chemical conditions in the granodiorite in the laccoliths, not yet completely crystallized, were inferred from their later stages of crystallization history on the basis of the comparatively late episode of ferrous to ferric iron oxidation. This is suggested by chemical analyses (table 7, samples 4 and 5) of the rocks, and is indicated microscopically in the fairly well crystallized groundmass before oxidation of the embedded magnetite crystals took place. The most advanced stages of recrystallization in these rocks appear to correlate with a high ratio of ferric to ferrous oxide. These late stages resulted in complete recrystallization of feldspars, both as phenocrysts and in the groundmass, and in development of abundant secondary minerals such as orthoclase, albite, epidote, hematite, magnetite, calcite, and chlorite. Minor accessory minerals formed or recrystallized during these stages include apatite, rutile, and zircon(?). Sulfides such as pyrrhotite, pyrite, and chalcopyrite in addition to calcite were segregated in the interstices of the crystallizing rocks. These minerals are exactly the same as those formed in the altered and metamorphosed sedimentary rocks and the high-temperature veins.

In contrast to the granodiorite in the stock, the small intrusive body on the south side of Skyrocket Creek, within The Blowout area (fig. 12), was little altered. Its contacts are both gradational and interfingering; adjacent beds of shale, along bedding planes or joints, were recrystallized and contain porphyroblasts of plagioclase. This body intruded the sedimentary beds with no evident disturbance of the bedding and local structure. Composition of this equigranular rock (table 7, sample 1) is slightly less siliceous than the granodiorite, and contains slightly less potash and soda and more iron, magnesia, and alumina. The plagioclase is much less strongly zoned and



[1]Greenish-brown variety in groundmass of granodiorite.
[2]Deep-brown pleochroic variety occurs as accessory mineral in granodiorite and high-temperature veins.
[3]Present in small amounts.
[4]May or may not be present.
[5]Some sulfide doubtlessly belongs here but paragenetic relations are obscure.

Figure 26. Paragenetic relations of minerals in porphyritic granodiorite, in sedimentary rocks in the exomorphic zone, and in veins. Modified from Burbank (1936, p. 242) and used with permission of American Geophysical Union.

has only trace amounts of sericite. The only ferromagnesian mineral, brown biotite, has been altered partly to chlorite and partly to green biotite with a high birefringence; some magnetite and apatite are clustered around the partly altered biotite. Very minute flakes of chlorite are scattered sparsely throughout the rock. Accessory minerals include small grains of epidote, titanite, zircon, and hematite. Quartz was clearly the last mineral to crystallize; it cuts across grains or fills grain boundaries. Magnetite crystals, unlike those in the granodiorite stock in The Blowout, contain intergrowths of hematite similar to that in the moderately recrystallized and altered granodiorites in the laccoliths. The mineral composition and texture (grain size 1–2 mm in diameter) of the rock in this small intrusive body, as well as the lack of strong reaction and alteration compared with the other granodiorites, suggest that it crystallized at a higher temperature; equilibrium was more closely maintained between melt, the volatile constituents, and the already crystallized minerals throughout the crystallization process. The strong recrystallization and feldspathization of the surrounding shales indicates that they have been granitized. Similar relations, but on a much larger scale, have been described by Eckel (1949) in the La Plata Mountains to the southwest. Plagioclase porphyroblasts, formed earlier than the epidote, chlorite, magnetite, and hematite in the surrounding beds, suggest that the rock in this small body was not intruded in a molten state; it perhaps crystallized during the metamorphism of the surrounding rocks.

Oxidation of magnetite to hematite and formation of small amounts of epidote were contemporaneous with and genetically related to the ferric oxide stage of alteration. The lack of more advanced alteration and recrystallization of minerals in the rock, compared with those in the granodiorite of the laccoliths, was then the result of a slightly higher temperature of crystallization and a lower content of volatile constituents in the residual fluids during late stages of crystallization of this small intrusive body.

Rock Alteration Compared With Clastic Dike Formation

The sequence of alteration and mineralization observed near The Blowout is less applicable away from the igneous center. Correlating the timing of events in the central area with those in the outer areas is difficult. There is a suggestion of timing, however, as indicated by the hematite vein formation and clastic dike intrusion. Deposition of hematite, following a renewal of fracturing (fig. 26), is a fairly definite correlation in the mineralogical sequence. This ferric oxide discontinuity has not been recognized beyond about a mile north or about 1.5 mi west of the intrusive center. Clastic dikes, fairly common throughout the Uncompahgre mining district, appear to have preceded deposition of ore, but in the central part of The Blowout area it was difficult, because of the intense alteration, to differentiate between clastic dikes or breccia masses formed by other means. A clastic dike on the northwest side of The Blowout contains fragments of shale and quartzite plus inclusions of highly sericitized and pyritized rock; this dike probably was intruded following the first period of sericitization. This occurrence, in conjunction with evidence found in the Ben Hur property (fig. 21, no. 24) on the west side of the Uncompahgre River valley near Corbett Creek, shows that some small clastic dikes formed more or less contemporaneously with the hematite veins, and that their occurrence with barite, galena, and manganiferous calcite marks a transition to the silver-lead deposits. However, in other parts of the district, clastic dikes and the mineralogical characteristics of the silver-lead ores did not necessarily follow the discontinuity in the central area. Fragments of pyritized or sericitized rock were found locally among breccia fragments, but at most places, the immediate walls were little altered prior to breccia injection. Clastic dikes in intermediate to outer areas of the district also are commonly much larger than any found near The Blowout.

General Conclusions

The mineralogical interrelation of the high-temperature veins, contact deposits, hematite veins, and pyritic copper-bearing veins and the fact that all are closely clustered about the central intrusive vent suggest that the mineralizing fluids carrying copper and iron were derived from a comparatively shallow igneous body beneath the central part of the Uncompahgre mining district along the line of the east-northeasterly dike swarm. The processes occurring in later stages of crystallization of this igneous body were responsible for the segregation of the mineralizing emanations and their metal contents. As stated earlier, igneous rocks in the area of the central vent and surrounding laccoliths probably crystallized under a cover of about a mile of relatively impermeable rocks, mostly shale, of Late Cretaceous age. The environment within the central vent area and its influence on the later stages of crystallization of the rocks thus are thought to be responsible for the relatively greater concentrations of copper and iron in the high-temperature veins and replacement deposits compared to the amounts of those metals in outlying deposits of the district. This zonal arrangement of metallization probably resulted from an increase in depth and change in position of the loci of segregation as crystallization and consolidation of the magma progressed. Solidification of the hydrous magma and related hydrothermal fluids may have a bearing upon conditions favoring disseminated concentrations of copper and iron, with an affinity to a porphyry copper deposit, in the igneous rocks beneath the central eruptive vent area.

Factors controlling metal concentrations may depend to a considerable degree on the manner in which energy contained within the magma was expended during crystallization. This seems to be illustrated by the local intrusive bodies and other mineralized rocks as related to copper and iron concentration. However, a detailed analysis of the magmatic processes was not undertaken concerning the distribution of energy in the system locally represented by the crystallizing igneous body and the surrounding zone of altered and mineralized rocks, because it is thought that metamorphism of the surrounding rocks required an expenditure of energy of which most was derived from the crystallizing body of igneous rock. The loci of energy release would have begun at a shallow depth in the top of the igneous body and retreated downward as the body crystallized.

In the Uncompahgre mining district, no exposed rock in The Blowout area is suggestive of concealed, recrystallized rock forming a porphyry copper deposit, but perhaps disseminated concentrations of copper could be present at moderately greater depths. Concentrations of copper were found in the La Plata Mountains (Eckel, 1949), a laccolithic center in the San Juan Mountains similar to and southwest of the Uncompahgre district (fig. 1).

Copper and iron concentrations were less in deposits in the northern and more outlying parts of the district because the source rocks were at a much greater depth. The lack of copper concentration was probably due, in part, to the structural relations of the crystallizing igneous sources from which the silver-lead-zinc deposits were derived. However, clastic dikes associated with many of the lead-bearing veins would have acted similarly to the hematite veins in releasing pressure, reducing fractionation, and promoting rapid oxidation of the iron and sulfur in the residual solutions. Rocks that crystallized at greater depths would presumably have had less tendency to concentrate iron in the later stages of crystallization. The pyrite and sphalerite content in the lead-zinc ores increases slightly eastward from the Uncompahgre River valley, but massive pyritic ores, in general, are not characteristic of the area. Lead-zinc veins closest to the central part of the district contained greater proportions of pyrite and chalcopyrite. The total iron content also was considerably less where barite is prominent because most iron in the sulfide fraction had been previously eliminated by oxidation.

Paragenesis of Primary Ores

Paragenesis of the high-temperature veins and of the minerals formed in the narrow aureole of metamorphism in The Blowout area was described briefly in connection with the discussions on both crystallization of the granodioritic rocks (p. 28–32) and wall-rock alteration of high-temperature veins (p. 65–66). Burbank (1936) described in considerable detail the close relation between the igneous rocks and the mineralizing processes, and documented the gradual passage from the later stages of crystallization of the porphyritic igneous rocks to the introductory stages of high-temperature mineralization. Here, the discussion is concerned with the minerals constituting the bulk of the ore deposits that form a continuation of the high-temperature veins and contact deposits. The paragenesis of the ores must also take into account three equally abrupt "breaks" or distinguishable discontinuities: (1) clastic injections of both premineral and intramineral age, (2) hematite veins or deposits and their associated mineral assemblages, and (3) processes of leaching and solution of the wall rocks or of previously formed mineral assemblages.

As previously discussed, it was concluded that the clastic injections, constituting the premineral clastic dikes, resulted primarily from the sudden releases of pressure upon the magma chamber(s) of the igneous rocks. The potential gas-forming constituents of the fluids expanded violently in the manner of gaseous volcanic eruptions, resulting in an injection of clastic debris carried along by the expanding medium. The most prominent clastic injections in the Uncompahgre mining district are premineral in age. Later intermineral clastic injections, commonly containing fragments of ore minerals and rocks of definitely local origin, resulted evidently from the local expansions of gases in the vein-forming fluids ranging from those of high temperature to those that deposited the sulfide minerals. Later explosive interruptions of the mineralizing processes definitely are tied to renewed fracturing, or to reopening of veins as the clastic dikes penetrated the walls of the original fractures or along newly formed fractures. The emplacement of the clastic dikes is thus part of the deformational history of the ore deposits.

Hematite mineralization of high-temperature type was associated with renewed fracturing of the rocks near the central intrusive vent. The release of pressure on the crystallizing igneous rocks perhaps resulted in boiling of the residual fluids and consequent production of vapor phases that removed the ferric iron from the igneous rocks and deposited it in the open fractures above. This was merely a milder form of gaseous expansion and, in certain instances, appeared to have been more or less contemporaneous with the more violent bubbling of the fluids that produced the local clastic injections and the hydrothermal leaching.

Hydrothermal leaching represents merely a negative phase of mineral formation. Dissolving of wall rocks or resolution of gangues in some ore deposits in the district tended to enrich the ore grade enough to be of commercial interest. This process, however, is not everywhere sharply distinguished from that of metasomatic replacement. Where hydrothermal leaching resulted in the formation of solution cavities in the rock, the cavities subsequently were more or less filled by minerals precipitated from solution, but the final result of open filling and replacement under some conditions may simulate that of metasomatic replacement. However, the chief concern here is hydrothermal leaching as related to the unfilled or partly filled solution cavities common in and near the ore deposits.

In many bedded deposits, such as those in quartzite at the American Nettie mine and in limestone at the Mineral Farm mine, the orebodies were localized in relatively minor fractures and cavities or along the bedding. In other places, such as within the permeable limestone breccia beds of the Pony Express Limestone Member of the Wanakah Formation where intersected by veins, bedded deposits are more common near veins than elsewhere. A correlation of mineral paragenesis in veins with that in the bedded deposits suggests that certain effects of hydrothermal leaching were concurrent with the reopening of fractures and injections of clastic material, and thus were apparently consequent upon the release of pressure. A similar correlation of hydrothermal leaching involving pressure release upon vein-forming solutions, following an effective distillation of volatile acid constituents, was postulated by Lasky (1936) for veins of the Virginia mining district in New Mexico.

Leaching discontinuities in the mineralization sequence in the Uncompahgre district, like the hematite veins and clastic injections, appear to have been related to pressure changes controlled by structural disturbances. The temporary leaching power of the fluids can be attributed to desaturation and a pH increase in acidity resulting from vaporization or from the so-called distillation column of Lasky (1936). Some hydrothermal leaching in the district also appears to have resulted from wall-rock reactions to hydrothermal fluids, dependent upon existing pressures and temperatures, in the ore channels as discussed by Holland and Malinin (1979, p. 465–471). Fluids passing from tight fractures into highly fractured or open permeable beds would have been affected by a drop in pressure, especially in the more open parts of the channel that were connected by conduits or other fractures to the land surface.

Normal Mineral Sequence

A recognizable mineralization sequence can be seen in many of the deposits despite numerous irregularities and local complexities. This sequence, omitting the silicate minerals in the contact-metamorphic deposits, is as follows:

(1) Fracturing and (or) premineral clastic injection.

(2) Sericitization, pyritization, chloritization, and carbonatization—chiefly or entirely metasomatic processes—followed, or accompanied in places, by the hydrothermal leaching of the wall rock or by renewed fracturing.

(3) Open-space filling, or replacement in part, by pyrite, sphalerite, chalcopyrite, and possibly small amounts of other sulfides. Quartz, the principal gangue of this early mineral aggregate, was deposited in open spaces; fine-grained quartz or jasperoid was fairly common in the wall rock.

(4) Mineralization in this stage was the one of greatest economic significance in all parts of the Uncompahgre mining district. Early mineralization may or may not have been interrupted by fracturing, intermineral clastic injection, or leaching, but it was nearly always followed by a copper-silver or copper-gold mineralization. Characteristic minerals are tetrahedrite and chalcopyrite together with other copper-silver sulfantimonides or sulfarsenides. In certain types of gold ores, such as in the American Nettie mine, tetradymite, copper-lead sulfobismuthides, and tellurides are also present. Varying amounts of the common base-metal sulfides nearly always accompanied these other minerals, and may be either new acquisitions of material from deep sources or mineral matter redissolved and reprecipitated by preceding intermineral leaching processes. The gangue was commonly quartz, but barite may have appeared late in the sequence or may have accompanied minimal galena deposited during this stage. The bulk of the galena, however, was always later than the copper minerals, but minor amounts of chalcopyrite and other copper-silver minerals may have replaced or veined galena locally. Calcite or manganiferous calcite occurred with the later minerals of this stage. Native gold likewise appeared late, either by a breakdown of the previously precipitated tellurides or by some process of local "dumping," such as that which occurred in the American Nettie deposit. The occurrence of very late-formed, large nugget-like masses of native gold in this ore and the localization of ore shoots in the large pre-ore cavities leached in the quartzite, suggest that localized throttling processes (Burbank, 1950, p. 300) were responsible for the precipitation of this ore. In general, these rich, highly complex silver-gold ores probably formed by both open-space filling and metasomatic replacement. Especially during the later stages, metasomatism was almost entirely confined to the sulfide series, suggesting that either the fluids were saturated with all the common wall-rock constituents at this time or their energy was insufficient to cause much of an interchange with the more refractory gangue minerals.

(5) Refracturing and local clastic injection may have initiated the final stage. Galena with lesser amounts of other base-metal sulfides commonly was deposited following the copper-silver or copper-silver-gold mineralization closing the main period of sulfide deposition Galena ores are more characteristic of the silver-bearing deposits than of the gold-bearing deposits. In the higher temperature pyritic veins in the central parts of the district, late galena is sparse or lacking. Both barite and quartz are present as gangue, and barite was commonly deposited after the galena, so that barren baritic or very low-grade galena-barite deposits are found in the silver veins, or more especially, in the veins in the outermost parts of the district. Carbonate minerals such as manganoan calcite accompany galena in places, and rhombohedral and scalenohedral calcite, containing minor amounts of dolomite and ankerite, locally fill vugs in the sulfide ore or in the barite masses. Banded or delicate drusy quartz was commonly deposited on the carbonate minerals, and the carbonate material was then leached to leave a skeleton of quartz. Very locally, particularly in limestone wall rock, the post-ore stage of leaching attained considerable prominence, with the result that the carbonate gangue surrounding the sulfide ore was extensively leached and formed caves in which fragments of sulfide masses and residual clay were deposited.

Hydrothermal Leaching

The most striking examples of hydrothermal leaching are found near the central part of the Uncompahgre mining district, where massive sandstone beds are extensively leached, forming pre-ore caves. The most permeable sandstones, or those that were strongly jointed, were more susceptible to leaching; capping or parting shales localized the horizons of strongest leaching. Pre-ore cavities appear to have been most closely associated with those stages of mineralization that immediately followed or accompanied the early sericitization and carbonatization.

The sandstones are intensely indurated near the ore channels, and conversion of the permeable sandstones to quartzite was widespread throughout the district. This is true particularly of (1) the massive sandstone beds of the Dakota Sandstone known by miners as the "upper quartzite," (2) some sandstone beds in the uppermost Morrison Formation, and (3) the basal sandstone of the Tidwell Member of the Morrison Formation, known by miners as the "lower quartzite." In the central part of the district, in addition, small scattered crystals of pyrite were found in the recrystallized beds for a considerable distance from the principal concentrations of sulfide minerals; closer to the orebodies, minor amounts of sericite accompanied the pyrite. Silicification of the more permeable sandstones definitely correlates with this particular phase of the paragenetic sequence. It is significant that the most indurated beds are also those that were the most leached and pyritized. The "upper quartzite" sandstones contain the largest caves; some caves are referred to as "pear shaped" (Cross and others, 1907, p. 18), are as much as 20 ft wide and 30 ft long, and are commonly aligned on fractures. The "lower quartzite" sandstone contains the next largest caves. The permeability of the beds and the volume of pore space must have been important factors controlling the degree of hydrothermal leaching. Furthermore, the silica that dissolved near the ore channels migrated mostly outward into the permeable beds with the later sulfide solutions that deposited the pyrite. Additional dissolved silica was carried along the main open channels and was deposited as incrustations of crystalline quartz and banded material on the walls of both fractures and cavities.

In the quartzitic beds in the central part of the mining district, the processes of supersaturation and undersaturation of silica apparently were not separated by any recognized event and evidently were closely related in time and space. In the early phases of hydrothermal leaching, solution exceeded deposition, and the cavities gradually were enlarged until a balance was reached. Locally, this balance was not attained until after the beginning of sulfide deposition, but in other places, incrustations of quartz formed before the beginning of sulfide deposition. In the latter case, the sulfides were deposited in lesser amounts, and a saying among miners was "… as soon as one finds crystals in the quartzite there will be no more ore" (Irving, 1905, p. 68). Where this balance was not reached until after the beginning of sulfide deposition, the sulfides were deposited immediately on a smooth wall of impervious quartzite, or they graded outward into a narrow zone of metasomatic replacement or as fillings of small openings. This gradation zone commonly was called "honeycombed quartzite." In zones close to the main feeding channels of the ore fluids, especially along tight fractures, or where the fractures passed from less permeable rocks into quartzite, metasomatic replacement appears to have been the dominant process from the beginning to the end of mineralization, and there is little or no evidence of hydrothermal leaching or the formation of open cavities.

In the bedded deposits in limestone or limestone breccia, the processes of hydrothermal leaching were marked by the formation of cave breccias or of very extensive open brecciated ground in which the ore was only locally deposited. Cave breccia formed by hydrothermal leaching in limestone is best illustrated by the orebody at the Mineral Farm mine. There, the ore channel lies in the topmost part of the Leadville Limestone immediately beneath the capping lower shales of the Molas Formation. In cross section, the channel is a brecciated mass of silicified and otherwise altered shale occupying a linear depression in the underlying limestone. The ore has filled quartz-lined openings or spaces in porous, silicified breccia chiefly in the central parts of the channel, but also occurs in smaller masses formed by replacement in the surrounding altered shale and limestone. Mostly barren, quartz-lined caves also are found in the shale and limestone, but they are not as extensive, beyond the limits of ore deposition, as those in quartzite. Paragenesis of the minerals is complex and evidence of the actual beginnings of the mineralizing processes is obscure. Structural conditions indicate, however, that the caves and cave breccia were of early origin and preceded or formed concurrently with silicification. Conditions preceding and following formation of the caves in the limestone and shale were more complex than in the quartzite because the two kinds of country rock differed widely in chemical reactivity. Open cavities formed mostly in space previously occupied by the limestone, hence the solution of limestone was certainly much more rapid than the solution of shale. As the openings in the limestone enlarged, the shale caved into them. The following or overlapping wave of silicification, on the other hand, advanced much more intensively into the shale than into the underlying limestone. Shales and sandy beds capping the ore channel were silicified through a thickness of 5 to 10 ft, whereas the underlying limestone was chiefly recrystallized and, if silicified, recrystallized only near the ore. Ore in the limestone may have only a fraction of an inch to several inches of a silicified casing. Silicification was followed by veining and replacement of all the rocks, whether previously altered or not, by sericite, pyrite, ankerite, and quartz. The chemical character of the solutions introducing the stage of sulfide mineralization was the same as that which deposited ore in the quartzitic rocks previously described. Compared to the quartzite, the solution of limestone did not attain a balance with deposition until the beginning of the sulfide stage, whereas in the shale, silica was deposited comparatively early in the sequence. The lack of extensive silicification in the limestone presumably indicates that leaching overbalanced deposition and that the solutions were undersaturated with calcium carbonate. Overlying shale beds, because of sagging, slumping, and consequent fracturing, thereby permitted greater penetration and condensation of the solutions and their siliceous material. The solutions appear to have begun their leaching when they were nearly saturated with silica, in contrast to conditions nearer the sources such as those resulting in the quartzitic deposits.

The limestone breccia in the Pony Express Limestone Member of the Wanakah Formation was also hydrothermally leached. This unit, as described, possessed an original permeability and porosity far exceeding that of any other rocks in the mining district. Leaching and solution of the sedimentary nodular gypsum took place considerably prior to mineralization; it was not hydrothermal but the result of ground-water circulation. The breccia thus formed is a collapse type composed of the broken and compacted, relatively insoluble shale and limestone layers of the original shaly limestone-gypsum deposit. Conditions were favorable for leaching where this breccia bed was traversed by fractures that served as conduits for the hydrothermal solutions. Evidence indicative of the hydrothermal leaching process is obscure, but at many places near the ore deposits, the partly mineralized breccia is locally much more porous than the original breccia. This is particularly evident along the immediate borders of the ore channels, where the rock now consists of a porous, clinkery mass of fine-grained dark quartz, in which the original bedded nature of the breccia has been locally preserved. In other places, the original bedding was completely lost and only a jumbled breccia of silicified ribs or fragments remains. The latter condition appears to have been brought about by successive stages of leaching, local slumping and fracturing, and silicification. This is locally illustrated in the Pony Express vein and in several other silver-lead veins that transected this breccia horizon. Stages of leaching and silicification are correlated in part with the stages of deposition of a similar but fine-layered colloform silica on the walls of the feeding veins. This type of silica was commonly deposited upon the walls of veins immediately following a stage of fracturing or reopening of the fractures, in part preceding the deposition of the early sulfides and in part between the stages of sulfide deposition. Intermineral stages of silicification also were tied closely to clastic dike injection. Fragments of silicified material are found within the clastic debris, and the fractured walls of the clastic dikes are locally cemented by similar siliceous material.

Quantitatively important hydrothermal leaching seems to have been confined to permeable sandstones or to limestone. Less pervious rocks also have been leached along fractured zones or near other openings. The fine-grained silty sandstone of the Bilk Creek Sandstone Member of the Wanakah Formation that overlies the Pony Express Limestone Member has been leached at a number of places. In the Seaburg tunnel, beneath the American Nettie mine workings, this sandstone was fractured and local zones of solution breccia were formed. The sandstone was locally silicified, or chloritized and sericitized, evidently prior to leaching. The cavities formed by leaching were lined with clear quartz. Some hematite, chlorite, pyrite, sphalerite, and calcite were deposited in the openings, but for the most part, the cavities were not filled. Along the north side of The Blowout, near the Skyrocket group of mines, this sandstone was locally brecciated, apparently as a result of slumping brought about by leaching of the underlying breccia in the Pony Express Limestone Member. The cavities were filled with either sulfides or hematite, chlorite, calcite, and other minerals. This is the only locality where there is evidence that silicification of the rocks preceded hydrothermal leaching. The breccia fragments contain garnet and outlines of other silicate minerals and associated hematite, all of which appear to have been formed prior to brecciation.

Open-Space Filling

The structural and textural evidence for open-space filling in bedded deposits in both quartzite and limestone is summarized as follows:

1. Open or partly filled cavities were crustified by quartz in the intermediate and outer zones parallel to the trend of the ore channels in quartzite, limestone, or shale.

2. The downward-bulging capping shale, where in direct contact with unoxidized ore of the massive sulfide bodies, can be seen in the host rocks in the downdip and central part of the ore channels. This feature was noted by Lakes (1901) from the quartzite-shale associations exhibited in the Dakota Sandstone in the American Nettie deposit.

3. Breccia clasts, consisting of detached fragments of shale, fell below their normal stratigraphic position to the floors of cavities or filled caves. They now are found only in the outer parts of the ore channel. This feature is especially well preserved in the shale-capped limestone in the Mineral Farm mine. It is seldom found in quartzite.

4. Crystal faces of minerals project into the vugs in the sulfide orebodies, suggesting that solution commonly exceeded deposition in the late stages of ore deposition to an extent incompatible with true metasomatic replacement.

Both large and small open cavities were crustified by comb-quartz crystals and sulfides in layers ranging from one layer deep to essentially a complete filling. This is the most direct evidence for the existence of voids prior to ore deposition, and was noted by Irving (1905, p. 68), who examined the deposits during their early mining development. Regarding formation of the cavities, he stated, “There can be no question that they were produced by solution.” These features can still be seen along the unmined borders of the original orebodies. Remnants of the crustified linings of the caves also can still be seen in the central channel of the orebody, but essentially all the sulfide ore was removed from the caves during mining. In some centrally located caves, surfaces were not crustified but were very smooth and had the type of intersecting, concave-outward surfaces so common in solution-formed limestone caverns. This feature was originally reported by Irving (1905), but it also was found in true replacement deposits (Bastin and others, 1931, p. 602), so that it may not necessarily be evidence of prior cavity formation.

Fragments of shale detached from the walls of the cavities also were seen along the borders of the ore shoot, but crustification was sufficiently well preserved to furnish independent evidence of the opening. The most significant reference to possible caving of the shale from the roofs of some of the larger orebodies was made by Lakes (1901, p. 243) who noted that “…when there is a bulge or roll of the shale down into the quartzite … locally large bodies of ore are likely to be found.” These downward “rolls” of the shale may have been similar to those now seen in the Mineral Farm mine where solution cavities in the Leadville Limestone resulted in slumping or “rolling” of shale from the overlying Molas Formation.

The foregoing discussion concerns many of the ore deposits in the Uncompahgre mining district that provided strong evidence for open-space filling, particularly at a time when the concept of metasomatic replacement (essentially “molecule by molecule” with negligible open space available) was becoming more readily recognized as discussed by Lindgren (1933, p. 91–92, 173–174). Evidence that indicates the effects of metasomatic replacement processes locally in the formation of the ore deposits is as follows:

1. Recrystallization of host rocks in walls of the orebodies and their conversion to sericite, quartz or jasper, and carbonate minerals or mixtures of these minerals with disseminated sulfides, as well as the preservation of the original internal features of the host rock.

2. Massive sulfide bodies, lacking preserved textures but conformable to bedding surfaces or localized by fractures or dike contacts, that exist where continuous open space was precluded by structural conditions. As suggested by the wide extent of orebodies beneath incompetent capping beds, or by the lack of caving or slumping of these

capping beds, these orebodies consist of both contact metamorphic ores and associated pyritic ore masses.

3. Massive ores, examined under a reflecting microscope, showing that a complex series of metasomatic interchanges took place between host rocks and earlier formed gangues, different sulfide minerals, and the later mineral-bearing fluids. This evidence consists of preserved relict mineral textures, formation of pseudomorphs, and other commonly accepted microscopic criteria (Bastin and others, 1931, p. 590–606).

Quartz and calcite were the principal minerals dissolved, but this apparent selectivity is thought to result from mainly structural and physical properties in the sandstone and, perhaps, from chemical properties in the limestone. The clean quartz sandstones were the most permeable rocks other than the limestone breccia in the Pony Express Limestone Member of the Wanakah Formation. These rocks tended to permit clean or open fractures. The permeability of the limestone breccia was probably a factor in promoting low pressure conditions favorable to solution. If the solutions tended toward acidity, resulting from the process of distillation, the susceptibility of limestone to attack is easily accountable. Lasky (1936, p. 163–164) reported that in the Virginia district of New Mexico, calcite, sericite, and chlorite were dissolved. In the Uncompahgre district, it was not possible to establish with equal certainty the solution of other mineral aggregates. Some sericitized and chloritized rocks have abundant small solution cavities lined with quartz crystals; these furnish the most positive evidence of leaching of other minerals. Solution cavities in shales in the Molas Formation, near the Mineral Farm mine orebody, probably were the result of the solution of broken or shattered shale. The volume of other mineral matter dissolved is apparently subordinate to that from sandstone and limestone. Sulfide minerals also appear to have been dissolved locally, leaving casts or ribs of siliceous material.

Hydrothermal leaching of the quartzite was more or less concurrent with early sericitization and carbonatization in deposits such as those at the American Nettie mine. Perhaps the quartzite was first replaced with an aggregate of sericite and calcite that was dissolved afterward, leaving the outlines of the replacement body. However, little evidence favors this interpretation; the quartzite surrounding the cavities in the outer parts of the ore channel supposedly would be expected to contain more of the metasomatic alteration products in the walls of the cavities. During the beginning stages of hydrothermal leaching near the more central parts of the channel, some sericite and calcite may have been dissolved, but evidence is lacking because later deposition of massive sulfides obscures the early stages of the process.

Sulfide Paragenesis

The sulfide minerals have a common paragenetic sequence in most of the ore deposits. Pyrite is the earliest formed mineral in all deposits. Nearest the intrusive body in The Blowout area, pyrite was followed by hematite, and in turn by chalcopyrite, quartz, and thuringite. Sphalerite and galena are not abundant, but where present, were formed later than this introductory sequence.

A moderate distance from the restricted high-temperature zone of The Blowout area, chalcopyrite followed more directly after pyrite, and both pyrite and chalcopyrite were fractured and veined by sphalerite. Pyrite appears to have been selectively and extensively replaced by chalcopyrite. In the massive sulfide and telluride ores of the American Nettie mine in this principal gold-bearing zone, the order of crystallization sequence, as determined by microscopic examination of ore specimens, was pyrite, chalcopyrite, sphalerite, tennantite and minor additional chalcopyrite, tetradymite, benjaminite(?), galena, hessite, and native gold. According to descriptions of the large orebodies from which ore of this type was mined (Endlich, 1889; Lakes, 1901; Irving, 1911a), barite also was contained in the massive sulfide ores. Its position in the sequence, however, is indeterminate as most ore of this type had already been mined; where seen by W.S. Burbank, barite was definitely later than pyritic copper ore but was commonly coated with pyrite. Similar ore types in nearby mines indicate that barite was deposited late with galena. In ore from the Ben Hur vein, copper minerals were followed by barite, manganiferous calcite, and galena.

The complex ores of the American Nettie mine, from which the above mineral sequence was determined, have a roughly, concentrically layered texture, particularly along the margins of sericitized and pyritized gangue fragments. The pyrite was reduced mostly to minute, rounded fragments engulfed in the chalcopyrite, which evidently replaced it. Tetradymite is the only mineral in the crystallization sequence that has well-developed crystal outlines.

In the silver-lead veins farther to the north from the intrusive center, pyrite together with sphalerite formed early. Chalcopyrite commonly followed rather than preceded sphalerite; chalcopyrite, however, is a subordinate mineral in the zinc-lead-silver ores, suggesting that the common sulfides were deposited successively more or less in the order of their abundance. Silver deposition followed the early base-metal sulfides. Chalcopyrite and silver-bearing tetrahedrite were deposited more or less contemporaneously, and they veined or replaced the sphalerite. Small veinlets of chalcopyrite and tetrahedrite in sphalerite and quartz were truncated by galena. In most mines in this zone, the late origin of galena was clearly shown; ore consisting chiefly of pyrite, sphalerite, and a little chalcopyrite, often brecciated, was veined by the galena.

Pearceite or polybasite is closely associated with tetrahedrite or with tetrahedrite and chalcopyrite, and as noted and shown by Bastin (1923, p. 70) there was little doubt that pearceite is primary (fig. 27); its deposition overlaps that of galena. Bastin (1923, p. 71–72) did describe late veinlets of pearceite, chalcopyrite, and calcite veining all of the earlier sulfides, but considered them to be probably of supergene origin. In view of the solution and redeposition of recognizable non-sulfide

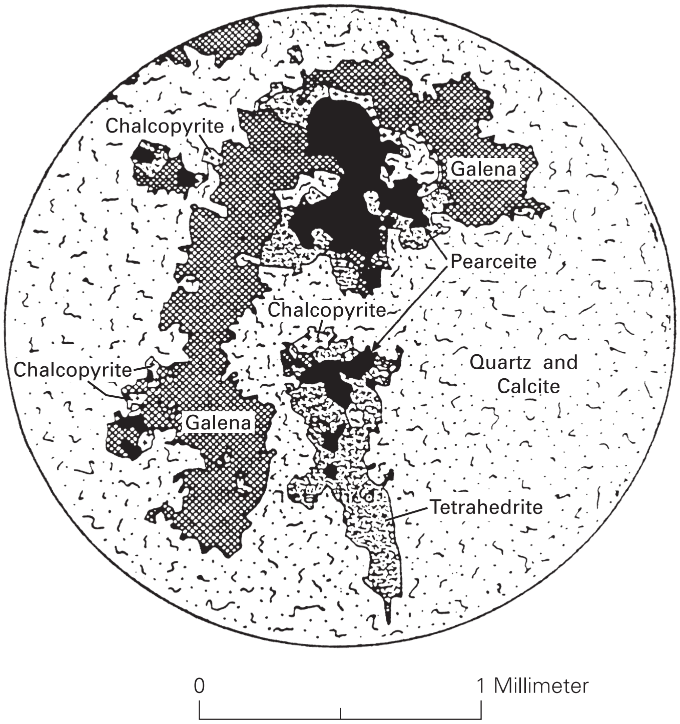


Figure 27. Camera lucida drawing of a polished thin section of an ore specimen showing primary pearceite intergrown with tetrahedrite, chalcopyrite, and galena, Bachelor mine, Uncompahgre mining district, southwestern Colorado (modified from Bastin, 1923).

minerals and of small stringers of late fine-grained pyrite and chlorite noted in some ores, we think that the late veining by certain sulfides such as chalcopyrite, pearceite, and pyrargyrite was a primary or hypogene process rather than a supergene process. Veinlets of this kind seem to be no more common in ores indicative of definite supergene deposition than in ores in which supergene mineralization was greatly restricted.

Repetition of the sulfide crystallization sequence is common in the silver ores. Ore from a prospect on the north slope of Dexter Creek valley consists of a breccia of early pyrite, sphalerite, and galena in a matrix of sandstone fragments and fine-grained material; this breccia was replaced and veined by a second generation of pyrite, sphalerite, chalcopyrite, and galena and some freibergite and pyrargyrite. The second generation of pyrite and sphalerite consists in part of concentric colloform layers deposited on the earlier minerals. In ore from the James V. Dexter vein, deposited near a granodiorite sill, the crystallization succession was early quartz, pyrite, and sphalerite followed by hematite, second-generation pyrite, chalcopyrite, and galena. The early sphalerite, where brecciated, was healed and cemented by a second-generation sphalerite having a slightly lighter color. Second-generation sphalerite is typical in the sphalerite ore; it is thought to have resulted principally from the solution and redeposition of first-generation sphalerite. The second-generation pyrite has an unusual texture in that it has a much finer granular form, and many of the grains are anisotropic. Ore from the Dexter vein, however, contained some gold and is not typical of the high-grade silver-lead ores. This vein locally provides evidence for deposition at a higher temperature, based both on the percentage of base metals present and the recurrence of the hematite discontinuity, which is not commonly recognized in ores several miles from the intrusive center. The hematite discontinuity here was very weakly developed. Because the Dexter vein strikes north-northeast across the silver-bearing vein of the Calliope mine, there is a possibility that the Dexter vein tapped local, but somewhat different, sources to the south where the pyritic gold veins occur. Ore fluids forming the Calliope vein came chiefly from the east.

The association of minor repetitions in the deposition of the early minerals with discontinuities, especially of the type noted in the Dexter vein and in the breccia ore described from the north slope of Dexter Creek valley, indicates that fracturing and fluctuations within the hydrothermal fluids dissolved and reprecipitated some of the earlier minerals. Repetitions in the sulfide sequence probably were also the result of the tapping of deeper or new sources of the mineralizing fluids.

Economically important stages in the paragenesis of the silver-bearing veins, mostly to the north of the intrusive center, were (1) formation of pyrite and sphalerite as early base-metal ore, (2) formation of chalcopyrite and tetrahedrite as cupriferous silver ore, and (3) formation of galena ore containing relatively low amounts of silver; barite accompanied both the second (copper) and third (lead) ore stages. These three stages were in many places sufficiently well separated by breaks in the mineral deposition sequence, caused by clastic injections and refracturing, that recognition of the vein structure is of value in mine development. This is best illustrated in the Bachelor group of mines (pl. 4). The events that occurred there were (1) premineral clastic injection (the Bachelor clastic dike), (2) base-metal mineralization consisting chiefly of pyrite and sphalerite, (3) interdeposition fracturing and clastic injection, and (4) deposition of quartz and barite accompanied by tetrahedrite and galena, to be followed by more-or-less barren quartz and barite. At the western termination of the veins in this group of mines, the last barite and galena were locally deposited in fractures different from those containing the high-grade silver ore. At the eastern termination of the veins toward the sources of the mineralizing fluids, depositional stages were somewhat less distinct owing to the ore containing less silver and galena and more pyrite and sphalerite. Ore in the veins can be roughly divided into zones corresponding to the three stages of ore formation mentioned above, suggesting the fractures were gradually filled from east to west, in that order. Later structural disturbances, such as intermineral clastic injection or refracturing, were less effective in producing recognizable breaks within the vein formation as distance was gained along the fractures from their easterly mineralization source. The mineral succession thus seems related both to zoning in individual veins and to regional zoning in a broad sense.

Carbonate Paragenesis

The carbonate gangue minerals associated with the ores have a general sequence of deposition paralleling the zonal distribution of ore minerals in the Uncompahgre mining district. Siderite is locally present in the higher temperature replacement deposits nearer the intrusive center, and has been reported from the American Nettie mine and in the pyritic ores of the Wanakah group of mines. It seems to have been deposited early in the sequence and was associated with the early stages of sericitization and pyritization.

The Pony Express vein in the lead-silver zone, at the eastern end of the Syracuse tunnel level in the Bachelor group of mines (pl. 4), farther north of the intrusive center, contains ferruginous rhodochrosite associated with the early deposited pyrite and sphalerite. An analysis of this mineral is given in table 13. The later galena ore stage in the same vein system contains manganocalcite as a gangue. This mineral, as determined by its optical properties, is closer to calcite than to rhodochrosite in composition. The final stage of carbonatization in nearly all the veins is either rhombohedral or scalenohedral calcite. Locally, minor amounts of dolomite and ankerite encrusted vugs in the ore. These carbonate minerals have no consistent paragenetic relations except that they are always late in any particular sequence. In some places, the earlier carbonate minerals were replaced by later ones, but in other places, only casts of the earlier carbonate minerals remain; these minerals were first coated or veined by quartz and then dissolved.

In contrast to the low magnesia content of the early rhodochrosite in the Pony Express vein, an analysis of early ankerite from the Mineral Farm lead-silver ore in the southern part of the district is given for comparison in table 13. This deposit occurs at the top of a limestone and dolomite sequence, suggesting that additional magnesia and lime may have been derived from solution of these beds at depth rather than from an igneous source. A single example, however, is not conclusive. With this exception, the predominant carbonate minerals of the district are, in general, of iron, manganese, and lime varieties rather than of the magnesia variety.

Table 13. Chemical analyses of carbonate mineral samples associated with ore deposits in the Uncompahgre mining district, southwestern Colorado.

[Analyses by U.S. Geological Survey. Chemical data, in weight percent, are from standard methods by K.J. Murata]

Sample no. Field no.	1 O-3636	2 O-06397
$CaCO_3$	54.67	2.18
$MgCO_3$	13.98	0.91
$MnCO_3$	10.54	62.59
$FeCO_3$	13.32	31.77
Insolubles	7.20	2.38
Total	99.71	99.83

Sample descriptions:

1. Ankerite, Mineral Farm mine; mixed manganiferous carbonate replacing upper part of Leadville Limestone.
2. Ferruginous rhodochrosite, Bachelor mine group; Pony Express vein on Syracuse tunnel level.

Descriptions of Mines

As previously stated, descriptions have been published in varying degrees of detail that concern the general and detailed history, development, geology, and mineralogy of some of the mines and mine groups and their respective ore deposits in the Uncompahgre mining district. However, it is neither possible nor practical, within the limits of this report, to describe in detail all the mines in the district. The mines discussed vary in size, amount of development, extent of information available, and accessibility at the time of field examination. Certain differences and unique features of these mines are described with respect to the developed ore deposits as distinguished by the local conditions of fracturing and the local sources of mineralizing fluids. Only mines that exploited the older Late Cretaceous to early Tertiary (Laramide orogeny) ore deposits are included. Unless otherwise specified, much of the historical and mine data are attributed to W.S. Burbank, who, during his field investigations from the late 1920s to mid-1930s, verbally acquired this information from knowledgeable, long-time area residents and the operators of a few, then-active mines.

Mineral Farm Mine

Location, History, and Development

The Mineral Farm mine (fig. 21, no. 35), at an altitude of about 8,500 ft, is located about a half-mile southwest of the town of Ouray on the bench at the north base of Hayden Mountain, and is accessed from the Canyon Creek road. The original group of four claims, located in 1875 or 1876 by Augustus W. Begole and John Eckles (Echols?) and worked only during the summers until the fall of 1878, was among the first to be located in this part of Colorado, and was, as stated by Fossett (1879, p. 529), "…one of the wonders of this part of the state." Through the next few years the original property was consolidated and enlarged with the addition at different times of more claims including the Miser's Dream, Miser's Desire, and Midnight.

The first ore taken from the property was packed or hauled by bull teams 150 mi across the San Juan Mountains to Alamosa, the nearest railhead, for shipment to Denver; transportation costs are said to have been $40 to $50 or more per ton, which seems low compared to costs previously quoted (see p. 5). This ore was obtained principally from stripping and quarrying operations from small, shallow pits and shafts sunk into the surface of the bench that here is a dip slope on the top of the Leadville Limestone. The property was sold in the early 1880s for a sum stated to be $75,000 (questionably $7,500 in Rice, 1980) to a Virginia-based company (Nor-

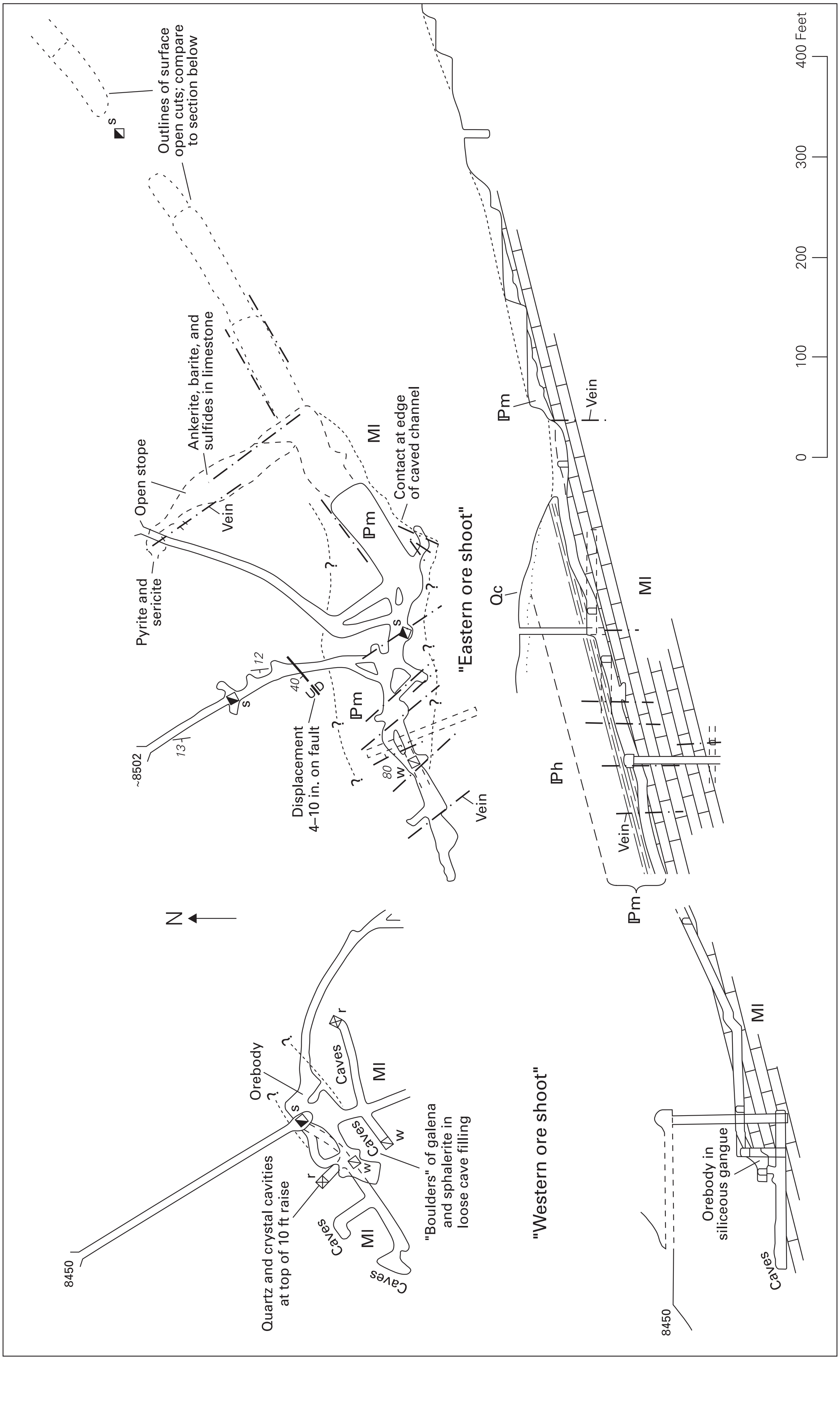


Figure 28. Plan and section of the Mineral Farm mine and orebody (modified from Burbank, 1930, p. 221). Qc, colluvium; ₱h, Hermosa Formation; ₱m, Molas Formation; Ml, Leadville Limestone; s, shaft; r, raise; w, winze; U, upthrown side of fault; D, downthrown side.

folk & Ouray Reduction Co.), which, in addition to mining, constructed and operated a nearby smelter to treat the ores, thereby reducing hauling costs. Production continued intermittently until the spring of 1886 when, according to a news item, the mine was sold to parties under the name of the Mineral Farm Mining Co. Mining operations continued for at least two years following construction of the railroad to Ouray in 1887; most of the ore was from open cuts and old workings. R.J. Lucas purchased the property, then known as the Mineral Farm Consolidated Mining Co., consolidated additional claims to it and built a new mill to treat the ores; the property was mined through an inclined shaft. This operation continued for several years with varying degrees of success, but was interrupted now and then by shutdowns because of the lack of ore, or of water for the mill, until temporarily closing in the late 1890s. B.H. DuPraw worked the property under lease for a year or so with little success, then turned it back to the owners. Retaining DuPraw as superintendent, the company retimbered an old crosscut located 400 to 500 ft west of the eastern workings, sank a vertical shaft and discovered a new orebody, which created considerable interest and resulted in the staking of adjoining ground in the hope that a large blanket deposit had been discovered; new investments in mining and milling equipment were made during development of this orebody. The mill operated until the fall of 1907, when operations were again discontinued. Within that timeframe, exploration was done below the level of and near the western end of the eastern ore shoot by means of an 80-ft-deep shaft (fig. 28). J.C. Ingersol, who examined those working about 1910, reported two drifts had been extended from the bottom of the shaft; one intersected a cross vein that was drifted on for 95 ft. This vein was in some places a gouge-filled slip and in other places an open fracture containing reddish-brown clay and calcite crystals. Various lessees apparently operated the property intermittently over the next few years. According to Rice (1980, p. 38), J. VanDaam operated the property about 1915, and built a small smelter to treat his and custom ores. Minor production is reported for the property in 1916, but apparently after 1918 only small lots of crude ore were shipped. James Braden next acquired the property during World War II, cleaned up the old machinery, and shipped it for scrap iron. King and Allsman (1950, p. 51) reported the mine was operated through 1947 by A.E. Alexander, of Ouray, but the operation was suspended early in 1948. More recently one of the adits has been cleaned up and converted to a tourist attraction.

Production

Production records are incomplete and do not exist for many of the years the mine was in operation. Before 1886, production under somewhat adverse conditions could not have been large. About $40,000 supposedly was received for ore mined after the arrival of the railroad. Combined reports of Fossett (1879) and of the annual volumes of the U.S. Bureau of the Mint (1882–1893) in table 14 indicate production values of more than $137,000, much of which was for rich silver ore from the Miser's Dream claim. Production claimed for the orebody developed through the inclined shaft and the one through the vertical shaft was $299,000 and $226,000, respectively. These claims as well as incomplete records for ore shipped since 1902 suggest the total production from the Mineral Farm mine perhaps could have been about $700,000.

Table 14. Values of early production, in dollars, of gold, silver, and lead from the Mineral Farm mine.

Year	Gold	Silver	Lead	Total
1877[1]	--	--	--	3,000
1878[2]	--	--	--	8,000
1881[3]	--	--	--	--
1882[4]	--	--	--	--
1887[5]	--	5,836	2,967	8,803
1888[6]	--	--	--	--
1890[7]	6,649	42,926	13,050	62,625
1891[8]	429	17,608	--	18,037
1892[9]	400	34,314	2,175	36,889

[1]Fossett (1879, p. 512): Smelter production, Ouray County, 30 tons treated, possibly from Mineral Farm mine property.

[2]Fossett (1879, p. 512): Norfolk & Ouray Works, Ouray.

[3]U.S. Bureau of the Mint (1882, p. 419): "…Mineral Farm…producing from 10 to 12 tons of ore per day, of a value that exceeds any ore yet extracted in this region. It is gray copper, brittle silver, and galena, averaging from 300 to 400 ounces, mill run."

[4]U.S. Bureau of the Mint (1883, p. 510): Description of Mineral Farm deposit; no production.

[5]U.S. Bureau of the Mint (1888, p. 176): Silver estimated at $1.29 per fine ounce and lead calculated at 4.5 cents per pound for 1887.

[6]U.S. Bureau of the Mint (1889, p. 117): Listed, no production recorded.

[7]U.S. Bureau of the Mint (1891, p. 137): Silver reported at $1.29 per ounce, gold at $20 per ounce, and lead at $87 per ton for year 1890.

[8]U.S. Bureau of the Mint (1892, p. 182).

[9]U.S. Bureau of the Mint (1893, p. 128).

The ore reportedly was classified as either copper ore or lead ore, and apparently there was little admixture of the two types in the ore shoots. The surface and eastern ore shoot, developed by pits, adits, and the inclined shaft, contained mostly high-grade copper-silver ore, although the northwestern prong (open stope at surface?) of this orebody was lead-zinc ore (fig. 28). Early records do not report the copper content of the ores, but a rough idea was obtained from assayed samples from the old workings. Eight samples from the eastern ore shoot, below the Miser's Dream crosscut, averaged about 2.5 percent copper, 4 percent lead, and 109 oz of silver to the ton. The western and deeper ore shoot, developed by a vertical shaft, was reported to be lead-zinc ore. Twenty-eight assayed samples from the western workings averaged 1.1 percent copper, 13.3 percent lead, and 17.4 oz of silver to the ton. Also, the zinc content was higher in this ore; two of the assays indicated a ratio of zinc to lead somewhat more than two to one. According to these assays, galena and sphalerite were more abundant at depth, suggesting a possibly telescoped sulfide zoning in this part of the ore

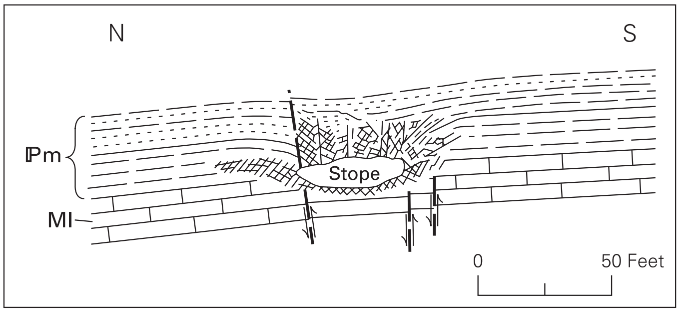


Figure 29. Generalized section through the Mineral Farm mine ore channel, at the contact between the Molas Formation (IPm) and the Leadville Limestone (Ml), showing the probable structural control of ore deposition (modified from Burbank, 1940).

channel. The gold content of all the ores was low, ranging from a trace to one ounce, and probably averaged about 0.06 oz to the ton. Lovering and others (1968, p. B112) reported that a jasperoid sample from the Mineral Farm mine contained 0.2 ppm gold. The highest grade ore taken from the mine came from the upper part of the eastern ore shoot, where it is said that large masses of "solid gray copper" ore were mined that carried about 20 percent copper and 800 oz of silver to the ton.

Geology

The shape of the eastern or discovery orebodies of the Mineral Farm mine was long and narrow; the orebodies were found chiefly in the basal beds of the Molas Formation and the uppermost beds of the Leadville Limestone. These formations have a fairly regular dip of 15°–18° W. On this dip slope, east of the inclined shaft, the Molas was largely removed by erosion, so the orebodies in the Leadville were mined from open cuts. The contact between the Molas and the Leadville is a surface characterized by numerous irregularities, of which some possibly represent the original weathered surface of the limestone where residual clay, sand, and chert accumulated and where evidently there are warps or rolls in the dip of the chert beds and narrow elongated troughs that inlay patches of chert-bearing shaly beds in the underlying limestone.

The basal beds of the Molas Formation, where unaltered, consist of deep-red, noncalcareous, somewhat sandy shale containing many angular to subangular fragments of chert derived from weathering and erosion of the uppermost beds of the Leadville Limestone. These beds, although of unusual texture and composition, are unquestionably of sedimentary origin because they occur not only at the base of the unit but also are interbedded with conglomerates, sandstones, and shales above the base. Near the mine these red beds range from 5 to 10 ft in thickness. Near the eastern orebody, the red beds have been bleached light gray to yellowish brown. Both these beds and the immediately overlying shales and sandstones have been highly silicified.

Very small remnants of ore consist of disseminated specks in the low-grade siliceous, locally jasperoid (Lovering, 1972, p. 101) casing or in the limestone near the eastern ore shoot. The mined ore consisted in part of disseminated ore and in part of solid masses of sulfide ore, the latter consisting largely of silver-bearing tetrahedrite. Specimens of this type of ore and of the massive chalcopyrite ore would suggest that deposition in the central parts of the ore shoot was effected, in part, by the filling of open cavities or honeycombed siliceous rock because the sulfides were formed upon or were intergrown with terminated quartz crystals. The orebodies, evidently a result of combined open-space filling and replacement, were from 20 to 40 ft wide and 6 to 10 ft high. Descriptions of the orebodies and statements by those familiar with the mine refer to the existence of "knife-edge" cracks that paralleled the elongation of the ore shoots and supposedly controlled the shape and position of the orebodies. Where the ore has been removed, there is little evidence of these cracks; also, they probably were confined chiefly to the ore shoots. There are, however, along the silicified borders of the channel casing a few prominent guiding fractures and many crisscrossing systems of joints (fig. 29).

Two sets of fractures occur in the rocks: one strikes east to northeast and is locally curved; the other strikes northwest and appears to be the stronger set in the mine. From the general trend of the ore shoots and from details seen in the pits and accessible mine workings, these fracture sets together with the bedding controlled the trends, dimensions, and shapes of the different orebodies. No dikes or major faults and folds are exposed near the mineralized zone. Basement structure beneath the Paleozoic rocks may have been a factor in the localization of the ore channels.

Silicification advanced through the rock in an irregular manner and was clearly influenced by the fractures, but it also transgressed fractures without regard to their presence. Silicified masses of altered chert-bearing shale were offset in places along the fractures. These relations are interpreted to suggest that the fractures were intermittently active or, being formed during early stages of alteration, preceded the introduction of the massive sulfide ores. Minor fractures do not in many places extend into the underlying limestone and cannot be traced far either horizontally or vertically. They are thought to be of local origin, and hence only of secondary importance in the control of mineralization.

Primary structures localizing the ore shoots, as stated previously, are thought to have been the major fracture sets that bounded the walls of the silicified casing in some parts of the mine. These are simple, steeply inclined breaks along which there was minor faulting or warping of the beds. Changes in dip or local oversteepening of the beds may also have been a factor of some importance.

Structural effects noted along the fractures of both the northeast- and northwest-striking sets include (1) local thickening of Molas chert beds along one wall of a fracture, which partly compensated thinning in the other wall, (2) sudden changes in the apparent displacement of the contact between the chert beds and the underlying limestone along the strike of a fracture, (3) linear trough-like depressions along certain

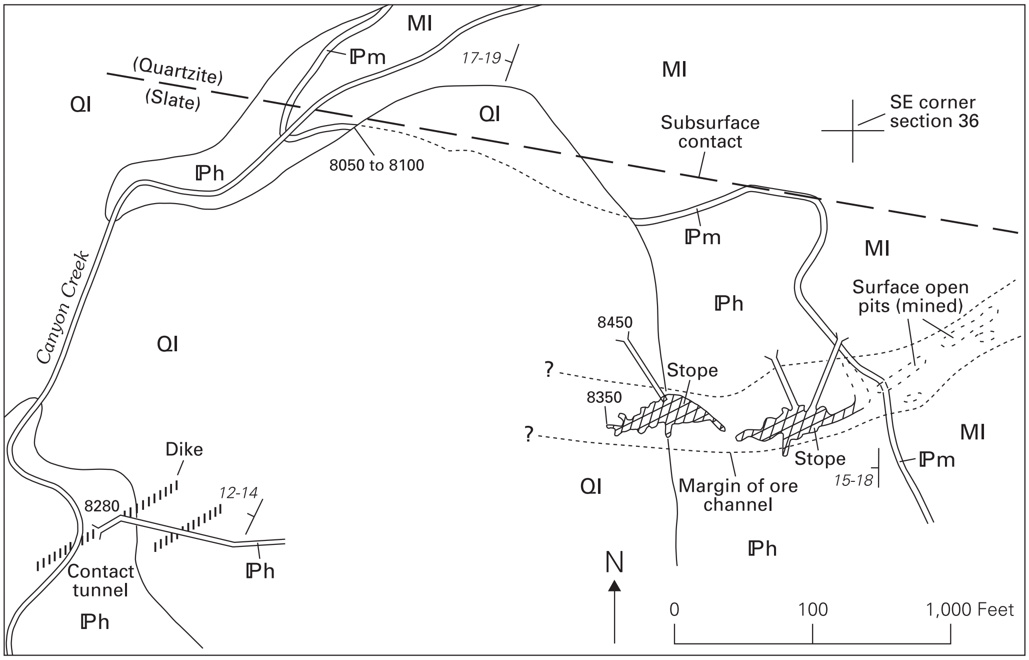


Figure 30. Plan of the Mineral Farm mine's presumed original ore channel showing two en echelon ore shoots (cross-hatched). Position of developed ground is shown relative to the subsurface contact of the Proterozoic quartzite and slate units and to dikes at the Contact tunnel (Legal Tender mine (fig. 21, no. 36)). Closed dashed lines within ore channel represent mined-out surface orebodies modified from Burbank (1940). Ml, Leadville Limestone; ℙm, Molas Formation; ℙh, Hermosa Formation; Ql, glacial and landslide debris.

fractures caused by the caving of Molas chert beds into the underlying limestone, (4) local sharp rolls, or distortions in the dip, of the chert beds involved with these different structures, and (5) local destruction of bedding in the shale. The best explanation for these features as well as for the structural characteristics of the Mineral Farm ore shoots was the dissolution of the Leadville Limestone at the base of the Molas Formation and the concurrent slumping of the shale into the void thus formed. The produced effects varied because a solution would work outward principally along one wall of a fracture at one place and from the opposite wall at another place, thereby creating changes in the apparent displacement along the strikes of the fractures. If a large amount of limestone was removed from beneath the shale, the latter would gradually be forced down into the opening by the weight of overlying rock, thus producing sharp rolls of the shale beds along the edges of the trough formed. Beds along borders of the trough consequently would have been thinned, especially if the shale was sufficiently plastic to flow laterally into the cave. This explanation satisfactorily accounts for the distortion or apparent noticeable destruction of bedding in the chert-bearing shale near the ore shoots or along certain barren or silicified fracture zones. Minor fractures of short vertical and horizontal extent, noticeable in the altered beds near the ore shoots, are thought to have resulted chiefly, if not entirely, from this local slumping and not from regional strain. Sharp, steep rolls in the "contact" near the orebodies resulted, in part, from an unconformity formed by solution and slumping. Large-amplitude folds and major changes in dip, however, probably occur and these, rather than the simple fractures, may have localized the cave formation in some places. Where the changes in dip of the limestone are small, detection is difficult because there are no easily recognizable horizons in the upper beds of the Leadville. It seems that such changes in dip might have resulted in a certain amount of slip along the contact with strata having different physical characteristics from those involved. If the strain had a strike-slip component, local fractures would have formed in one or both formations. In many instances the origin of the primary structures producing the solution channels in the contact zone is very obscure. As evident from the location of the ore, the shales of the Molas Formation rather than limestone in the Leadville Limestone provided the most permeable channel for the introduction and migration of the ore-forming fluids. Limestone immediately beneath the ore was, in general, only weakly mineralized, although it locally was recrystallized or was replaced by ankerite and sulfides. These relations suggest that the deformation producing the permeability of the channels was localized in the relatively insoluble shale rather than in the limestone, and support the concept that the channels were formed by caving.

As shown in figure 30, the northeast-trending ore channel consists of two en echelon ore shoots. The present extent of the workings indicates two possible trends to the ore channel. The northeast trend of the individual shoots has generally been assumed to be that of the ore-bearing zone, but the western trend, suggested by alignment of the southern boundaries of the two en echelon shoots, perhaps may be closer to the true trend of the channel. Figures 19*A* and 21, and the geologic map of the mining district (Luedke and Burbank, 1981), show that the mine lies only a few hundred feet above the base of the Paleozoic rocks; the trend of the mine workings appears to parallel the faulted west-northwest-trending northern limb of the compressed syncline of slate in the underlying Proterozoic Uncompahgre Formation. As previously pointed out, displacements along this trend were transmitted upward from the underlying slate layer either by bedding-plane faults and distortion of the slate beds, or by differential and lateral strike-slip movements within both the quartzite and slate along the contacts of these units. These displacements from renewed movement in the underlying Proterozoic rocks account satisfactorily for the deformation in the overlying limestones and shales and for the apparent west-northwest trend of the deeper parts of the ore channel in the Mineral Farm property.

Mineralogy and Origin of the Orebodies

Specimens from the two ore shoots are mineralogically similar, but it has been reported that the copper-silver ore from the eastern shoot was very rich in gray copper and silver, whereas the lead-zinc ore from the deeper western shoot contained only moderate amounts of chalcopyrite and silver. In addition to the two main ore shoots, small amounts of low-grade pyritic or baritic lead-zinc ore were in the limestone along the north side of the eastern shoot and near the northeastern end of the open pit. The wall rocks of the surface workings were extensively silicified.

The order of events and deposition of the minerals forming the altered rock and the orebodies was as follows: (1) solution of the Leadville Limestone beneath the Molas beds and local slumping of the chert-bearing shales, (2) silicification of the shale beds adjoining the channels and additional slumping and fracturing, (3) sericitization, ankeritization, and pyritization of both the silicified beds and the surrounding less-altered limestone and shale, (4) deposition of barite accompanied by quartz, pyrite, sphalerite, chalcopyrite, and galena, (5) deposition or recrystallization of quartz and deposition of chalcopyrite, galena, tetrahedrite, pearceite or polybasite, and calcite, and (6) additional solution of the soluble limestone beds along fractures and surrounding the highly altered bodies, and the formation of small caves lined with crystals of quartz and scalenohedral calcite.

The early solution of the rocks was followed by replacement with silica, from the altering fluids, that was substituted for the alumina, iron, potash, and other non-siliceous constituents of shales; the limestones were only weakly attacked by these fluids. Silica under-saturation of the early pre-ore fluids, which gradually became saturated with silica, suggests that at greater depths siliceous rocks may have been dissolved or replaced by other minerals. This supposition is based on similarity to observations made in the mineralized rocks of the Gold Hill area, north of The Blowout (fig. 21), where the quartzite was attacked and cavities were formed.

The earliest sulfide solutions then penetrated and replaced rocks near the silicified central channel, and also appear to have bypassed the main channel locally to form low-grade sericitized and sulfide replacement zones along the north side of the channel. As the unsilicified rocks surrounding the channel were replaced by sericite, pyrite, and ankerite, open spaces were maintained within the channel to be filled later by higher grade silver-bearing chalcopyrite-tetrahedrite ore. The silicified walls of the channel were attacked, but to a lesser extent because they had been replaced locally by some pyrite, sericite, and local masses of barite and sulfides. Possibly, the open channels were initially too choked by silicified cave breccia to accommodate the volume of the early-stage mineralizing fluids that traversed the channel for a long distance at depth; these early fluids probably deposited much of the minerals at a higher temperature before reaching the shallower positions of the channel.

Small amounts of ankerite containing a relatively high magnesia content (table 13) replaced unsilicified limestone north of the Mineral Farm ore channel. The high magnesia content possibly was derived from dolomitic limestone beds at depth in the channel.

The barite and main sulfide deposition followed that of the early gangue, but with some overlap because there was no sharp break in the mineral sequence. Examination of specimens of the extremely high-grade, massive tetrahedrite ore that filled voids in the silicified channel suggest that the later stages of sulfide deposition represent chiefly open-space filling. Both the later chalcopyrite and tetrahedrite are intergrown with terminated quartz crystals near the edge of the sulfide masses. Thus the latest ore filled large openings in the channel and the honeycombed masses of silicified breccia.

The rocks were fractured subsequent to ore deposition by northwest-striking fractures that allowed solutions capable of dissolving the limestone to flow through these fractures and around previously mineralized ground. An attempt to outline the orebody in the deeper workings encountered several caves in the less altered and weakly mineralized limestone beds that appeared to nearly surround the orebody. The caves had formed both parallel to the bedding and along vertical fractures. In some fractures and caves, particularly south of the orebody, crystals of both quartz and calcite were reported. The quartz may have been formed much earlier than the calcite; cavities in the limestone containing quartz also commonly contained traces of sulfides. It is possible, although not proved, that the earlier quartz-bearing caves formed soon after ore deposition and were the result of the dying stages of mineralization. Some scalenohedral calcite probably was deposited at this time. Some scattered masses of sphalerite or galena, previously deposited in the unsilicified parts of the limestone, were freed of their surrounding limy gangue and were found as detached blocks or boulders in the clayey material on the cave floors adjacent to the deeper orebody.

Oxidation of the ores by supergene solutions appeared to have been of minor importance other than possibly in the orebodies that were exposed on the bench east of the open cut. Chalcocite, covellite, malachite, azurite, and oxides of iron and manganese were the principal supergene minerals noted. Other than staining of the clay deposits in the caves by iron oxide, this suite of minerals has not been specifically referred to as characteristic of the cave deposits.

A ground-water origin for the Mineral Farm pre-ore caves is not considered a possible interpretation to extend the ore channel in depth, becase the beds dip 15°–18° or more west beneath the level of Canyon Creek. It is doubtful that caves formed by meteoric waters would extend to the depths thought to exist under a few thousand feet of overlying strata, particularly if those caves and associated ore deposits were formed during the Laramide orogeny as interpreted. Therefore, it is unlikely that a gently dipping ore channel would continue to great depth.

Source of Mineralizing Solutions and Zoning Along the Ore Channel in Depth

In the N. 80° W. direction assumed for the extension of the ore channel, the most likely source of the ore-forming fluids would appear to be the concealed southwest extension of the intrusive zone (fig. 18). The south edge of the zone should intersect the ore channel downdip of the beds about 2,500 to 3,000 ft west of Canyon Creek, a little more than a mile from the outcrop of the ore channel. The upper part of the Leadville Limestone there is estimated to be about 1,500 to 2,000 ft lower than the outcrop near the mine. If the ores of the Mineral Farm channel were derived from the same sources of mineralization as those in the other parts of the Uncompahgre mining district, which is likely, then the zoning of the ores in the other parts of the district may be applied to the Mineral Farm channel area. Such ore channels are characterized by the concentration of all stages of mineralization in a comparatively narrow body, as a result of overlapping or telescoping of the ores along the channel. Thus exploration might find a more complete mineralogical sequence in a channel deposit than would be expected in a vein. The Mineral Farm ore contains many of the mineral associations found in the central part of the district, but the proportions of the different sulfides correspond more closely to the lead-silver-zinc deposits of the northern sector or outer zones of the district. The development of sericite and the amount of chalcopyrite found in parts of the Mineral Farm orebody are possibly more typical of the pyritic ores of the Gold Hill type, and may be indicative of a change in depth to ores of the pyritic type that contain chalcopyrite and perhaps gold. However, chalcopyrite is found commonly in ores of both the deep and shallow zones of mineralization.

Pyritic or cupriferous gold-bearing ores may occur at somewhat greater depth along the Mineral Farm ore channel based on local conditions and comparison with other area deposits. Whether they would be economic or not can be determined only by exploration. In general, the Mineral Farm deposit at its present depth of exploration has proven to be too small to support mining of disseminated low-grade ore. The size and form of an ore channel at depth is important. There are several explanations as to why the form or cross section of an ore channel formed by rising hot solutions might change with depth. Walker (1928) cited two reasons as to why such channels might enlarge in depth: (1) the increase in corrosive power of the pre-ore cave-forming solutions toward their source, and (2) a tendency for increased deposition of silica toward the egress, which would have insulated the upper parts of the channel from further enlargement by later solutions. An increase in the corrosive power of solutions nearer their source, a concept supported by the conditions in the American Nettie mine, shows where quartzite was dissolved prior to the deposition of the ore. The effects of insulation of the channel by silicification are illustrated in the Mineral Farm mine, where much of the ore was low grade because of the high silica content. Apparently silicification in the channel was restricted to the later ore-bearing solutions, resulting in deposition chiefly in open spaces rather than by replacement. The central channel also might have changed in form at depth by the choking or clogging of the caves as suggested by the Mineral Farm channel, which was apparently choked with cave breccia, so that the earlier-stage sulfide fluids bypassed the central silicified channel to deposit sulfides by replacement in the surrounding unsilicified limestone or shale margin.

American Nettie Group of Mines

Location, History, and Development

The American Nettie group, including the O & N, Schofield, and Jonathan mines together with a few other adjoining claims, is located in the so-called Ouray “gold belt” (Endlich, 1889; Lakes, 1901), and is conveniently discussed as a unit;

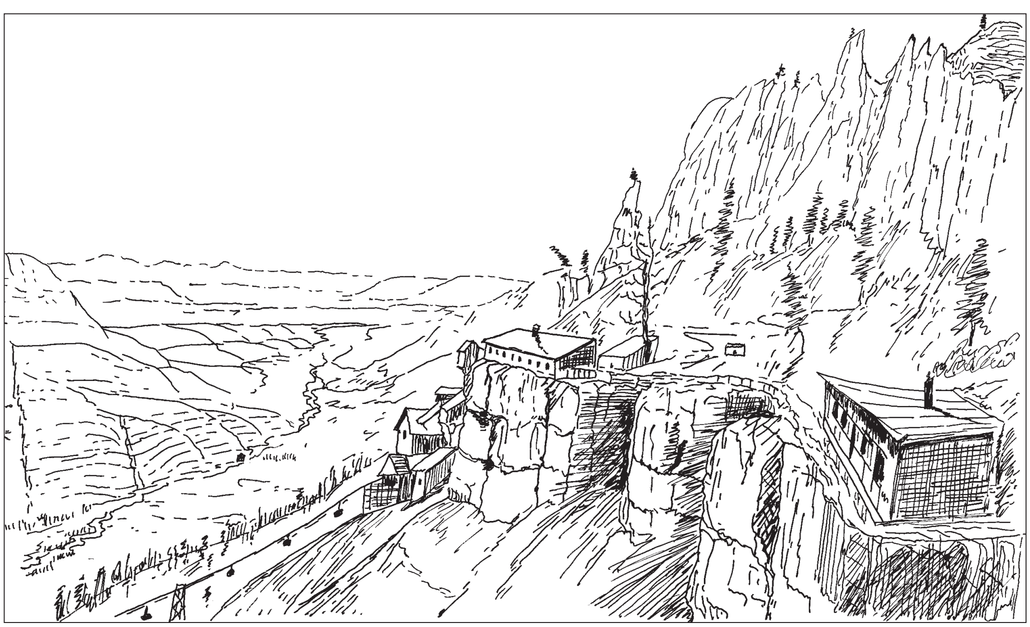


Figure 31. Sketch of view looking northwest showing the American Nettie mine buildings located high on the east wall of the Uncompahgre River canyon, north of Ouray (from Lakes, 1901).

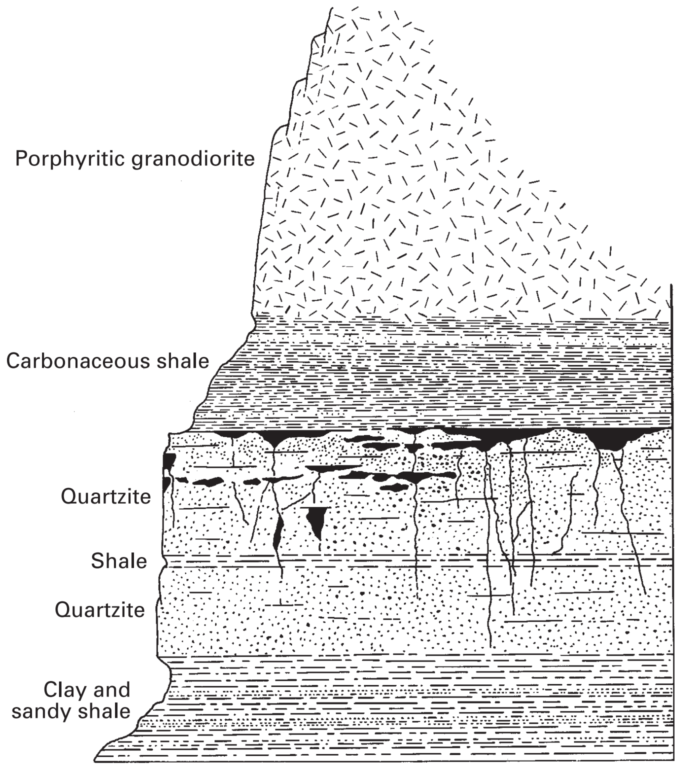


Figure 32. Generalized cross section of the cliff face at the American Nettie mine showing stratigraphic relations and the ore shoots (dark), or filled solution cavities, formed within the quartzite mostly beneath impervious barriers or partings of shale as suggested by the flat tops (from Irving, 1905, fig. 4).

Table 15. Production data from the American Nettie mine for the years 1897 and 1898.

[--, zero]

Year	1897[1]	1898[2]
Output, in tons	522	754
Average net value, in dollars, per ton	152	133
Total net value, in dollars	79,344	100,282
Profit, in dollars, per ton	79	75
Receipts, in dollars:		
Ore and mining	79,563	100,090
Smelter	564	811
Interest	559	626
Total receipt per ton	154	135
Total	80,686	101,527
Expenses, in dollars:		
Ore and mining	37,527	42,275
Office, taxes, etc.	1,788	1,780
Purchase claims	--	986
Total expenses per ton	75	60
Total	39,315	45,041

[1]American Gold Mining Co. annual report, October 1, 1897.
[2]American Gold Mining Co. annual report, September 15, 1898.

mine development tended gradually toward the consolidation of claims. Openings to these mines (Luedke and Burbank, 1981) are mostly within the Dakota Sandstone or uppermost part of the Morrison Formation at altitudes ranging from 9,400 to 9,500 ft on the east wall of the Uncompahgre River valley about 1.5 mi north of Ouray (figs. 21, 31; pls. 2, 3). Also included here and briefly discussed is the Wanakah mine group, located about 700 ft stratigraphically below and developed in the Wanakah Formation and the lower part of the Morrison Formation (fig. 21; pls. 2, 3).

Discovery of rich gold ore in quartzite on the American and Nettie claims, made in 1889, was followed by the rapid development of these properties. By 1900 or 1901 the great bulk of the ore, parts of which were phenomenally rich, had been mined out. The lower part of the Dakota Sandstone, in which most of the ore was found, crops out as a bluff 50 ft or more in height, bounded below by the talus-covered slopes of the Morrison Formation and above by the receding but steep, step-like slopes of alternating sandstone and shaly sandstone of the Dakota Sandstone and shale of the overlying Mancos Shale. Above this sedimentary interval (fig. 32) the canyon walls are composed of a porphyritic granodiorite sheet that forms cliffs and largely inaccessible slopes to an altitude of more than 10,000 ft. Discovery of the rich ores at the American Nettie mine is said to have been made near one of the many crosscutting fractures and dikes prominently exposed along the quartzite cliff. Upon breaking into the quartzite face, prospectors discovered open cavities within the rock, which were partly filled with iron oxides containing native gold and oxidized silver ore. Such ore, in an easily removable form and already concentrated by natural processes, financed development of the properties.

In May 1889, the American Nettie mine, then consisting of three claims (American, Nettie, and Schofield), was sold to the newly organized American Gold Mining Co. Production of the early mined high-grade ore, reported in July 1889 by the company, amounted to seven cars, each holding 20,000 pounds (lb), that was shipped to Pueblo and netted $23,314.40. By the end of the fiscal year, the company is reported to have paid $150,000 in dividends. Endlich (1889, p. 335), who briefly examined the mine in the fall of 1889, reported that "… nearly 200 tons of ore have been shipped by this time, which ran from 16 to 40 ounces in gold by the car, and carried some silver besides." Production continued during 1890 and 1891, although dividend payments were less than those of the first year. A mill was not constructed prior to 1891.

In 1892 the company contracted with the Edison Electric Co. to construct a hydroelectric plant to furnish power and lighting for the mine; this plant was in operation late that year. Nearly 100 men were employed by the company in 1894, but the workforce was reduced to 65 in 1895, and was reduced further in October of that year. Only a few men worked on development and mining of ore during the following winter and the first part of 1896. New orebodies apparently were developed and the workforce increased in the fall of 1896. The newly found ore was in caves in the uppermost part of the quartzite and consisted of stiff yellow mud that had to be handled several times in the process of drying before shipment. Judging from its similarity to the ore-bearing muds found in the O & N property adjoining on the north, it probably came from near the northern boundary of the main ore shoot. Dividend payments resumed in 1897. A summary statement issued for the period May 16, 1889, to October 1, 1897, reported the company had mined 6,687 tons of ore having an average value of about $140 per ton. During this period, the total receipts were $934,998 and dividends were $279,000. Annual statements issued by the American Gold Mining Co. for 1897 and 1898 are listed in table 15.

In October 1898, the company stated it was working a large body of sulfide ore having a value of $1,000 to $3,000 per car of 10 tons capacity; 6 to 8 carloads per month were being shipped to the Pueblo smelter. Smelter charges were about $7 per ton and freight about $8 per ton. This high-grade sulfide ore containing tellurides presumably came from the northeastern part of the ore shoot in the area commonly known as the "Bull Pen." About 35 men were employed at that time.

Production continued steadily in the first part of 1899. About 11 carloads were shipped monthly, but in December the property was temporarily leased to several local parties at a 50 percent royalty. The last dividend payment reported was in March 1899, and amounted to $0.07 per share on 300,000 shares, bringing the grand total of dividend payments to about $446,000.

The period of operation just reported clearly indicates considerable depletion of the high-grade orebodies. In January 1900, the company announced it would erect a concentrating plant to treat the dump and large bodies of not-yet-broken second-class ore. This new mill, operated by hydroelectric power (Brady, 1901), had a capacity of 60 tons per day and was in operation by September of that year. The automatic tramway from the mine to the mill across the Uncompahgre River valley descended 1,820 ft within a horizontal distance of about 3,400 ft; the single span across the valley from the last tram tower on the east side to the mill on the west side was 2,100 ft in length. During 1901, 25 to 50 men were employed; at full operation, 50 tons of ore daily were carried to the mill. The ore, as it came from the mine, was sorted in a room near the mine entrance and the highest grade material sacked for direct shipment; the remainder was sent to the mill, which had Wilfley tables and 20 stamps, as well as plates to catch the native gold. Operations continued from 1901 through 1903, although they were temporarily interrupted by reconstruction of the tramway and by milling difficulties. In July 1904 the stockholders voted to issue and sell treasury stock in order to finance improvement of the milling facilities, but production subsequent to 1906, other than the year 1928 when 4,000 tons of ore was milled by the Mutual Gold Mines Co., was on a small scale or sometimes nil. The value of $470,000 for recovered metals from 1905 to 1937, added to the figure of $1,464,923.35 (Cross and others, 1907, p. 18) that was the total production value from 1889 to 1905, gives a total production from the mine to the end of 1937 of approximately $1,935,000.

The American Nettie mine workings were developed by gentle inclines, drifts, and crosscuts, and total more than 5 mi along the bedding of the quartzite. The main drifts were driven along the larger fractures and dikes; the method of exploring was to drive laterals along fractures and veins that intersected the main drifts. The mine map (pl. 2) gives a comprehensive picture of the fracture pattern in the quartzite. The minor fractures and veins locally enlarged into small pockets, or led to large caves that could be entered by the miners. Oxidized ore that filled the lower parts of the caves and encrusted parts of the walls was removed with long iron scrapers; the walls were brushed and any hard crusts of ore still adhering to the walls were then barred (pried) off. The ore was immediately sacked for shipment. As depth was gained into the hill, the mining methods were changed to allow the removal of the more massive sulfide ores. Where ore entirely filled some voids in the quartzite, drifts were accordingly enlarged into rooms for mining the sulfide ore. Because the ore pockets were not confined to a single horizon within the quartzite, inclines were driven beneath parts of the main ore zone, raises and winzes were extended, and exploration drifts were driven along the larger productive fractures from different levels. The aggregate drifting was large in view of the comparatively small area of the mine. The resulting labyrinth of workings was in places confusing, even to one familiar with the mine. Downer (1901, p. 106) stated, "A map of the mine has the appearance of a maze or puzzle of some kind, so honey-combed is the quartzite by old drifts … the workings aggregate nearly six miles, and are practically on one level… ." The main or Nettie incline penetrates about 1,600 ft eastward into the hill, and considerably beyond the limits of the main ore shoot. Development toward the northeast first centered about Incline No. 39, which branches from the Nettie incline about 475 ft from the portal. During later development at the time that the concentrating plant was built in 1900, the compressor plant was placed in an offset of the Nettie incline about 1,000 ft from the portal. The mine was lighted by incandescent lamps after the construction of the first hydroelectric plant, and it was recorded in a news item of June 15, 1895, that the company had started the use of electric drills, a venture which met with little or no success.

The O & N Tunnel Co., which owned several claims north of the American Nettie mine, was organized soon after the American Gold Mining Co., and in 1893 announced that a proposed tunnel of about 2,000 ft in length was projected to cut the extension of the ore shoot already partly developed on adjoining Nettie property. Development of the O & N mine does not seem to have gotten well under way until 1895, but in 1896 the workings encountered the extension of the American Nettie ore channel (pls. 2, 3) where the O & N Tunnel Co. discovered very rich pockets of ore in the upper part of the massive quartzite beds. The ore was partly oxidized and consisted of a yellow mud, some of which was so thin as to necessitate removal in buckets. Some stoping was also done on mineralized fractures in the quartzite. During 1897 and 1898, the property had a remarkable record of high-grade production, but by December 1898 news reports stated that the mine had been worked out and all effects had been sold off. No new ore discoveries had been made in the previous several months. Prior to its final closing, an incline was driven eastward to a point about 1,800 ft east of the portal into ground stated to have been the primary objective of the tunnel. This exploration did not locate new ore shoots, and as developments on the American Nettie had already more or less defined the eastern limits of profitable ore, there was little incentive to continue the exploration.

The portal of the O & N main tunnel (crosscut) is in talus near or just below the base of the Dakota Sandstone, about 550 ft northwest of the Nettie incline portal (pl. 2). The principal high-grade orebodies were developed from several raises into the upper part of the massive quartzite beds. This tunnel and lower workings were inaccessible during this investigation.

About 1912 a lower crosscut, the Seaburg tunnel (pl. 2), was driven beneath the American Nettie mine to explore the quartzitic rocks about 700 ft stratigraphically below the orebodies in the Dakota Sandstone. Although small bodies of low-grade pyritic gold ore were encountered, this enterprise failed to develop commercial orebodies.

Development of the Jonathan mine was not as extensive as that of the American Nettie and O & N mines. Nevertheless the Jonathan mine produced high-grade ore both from pockets in the quartzite and along numerous small east-trending veins. Owing to the trend of the main ore zone more or less parallel to a dike and diagonal to the outcrop of the quartzite, the orebodies did not extend as far into the hill. The Jonathan mine was operated intermittently into the 1930s.

From 1928 to 1930, the Mutual Gold Mines, Inc., which was milling dump material and ores from the American Nettie, Iron Clad, and Bright Diamond mines, instituted an exploration program in Jonathan property in an attempt to find orebodies east of the Jonathan dike. While some ore was developed and mined along or near the Schofield vein and along lower contacts in the Dakota Sandstone and upper Morrison Formation, exploration farther to the east encountered only weakly mineralized rock.

The finding of the small, flat orebodies and vertical replacements in and near the Jonathan dike in the lower horizons of the Dakota Sandstone and the uppermost sandstone beds of the Morrison Formation, led to exploration in the 1930s of the eastern end of the adjacent Puzzle claim located near the richest parts of the original American Nettie ore shoot. A shaft was sunk along the west wall of the Jonathan dike, and exploratory tunnels were driven across and parallel to the dike near the base of the Dakota and in the uppermost Morrison sandstones, but this effort failed to find ore. A few years later, a small, flat orebody overlooked during the original development of the mine was discovered by W. McCullough and Withrow in the back of the old stopes a short distance to the south of the above-mentioned shaft. This small body contained some very high-grade ore that had been concealed by a "false back" in the original stope. After this discovery, there was little further development on the properties to 1938. Reduced operations until the mid-1940s were restricted to the shipment of small tonnages of gold-silver-copper ore and treatment of old mill tailings. Since then, there was minimal activity by lessees in the late 1950s and early 1960s.

Geology

The blanket-like orebodies in the American Nettie and adjoining mines were confined mostly to the upper 20 to 30 ft of massive quartzite beds in the lower part of the Dakota Sandstone. The miners, in general, restricted the term "upper quartzite" to this lower part that contains only a few thin shale partings; the entire formation includes, in addition, 50 ft or more of overlying interbedded carbonaceous shale and quartzite. The base of this overlying upper shale essentially forms the roof of the ore-bearing zone. There are two principal horizons at which the orebodies were most commonly found: one is just beneath the capping beds of carbonaceous shale, and the other is at or just beneath thin shale partings 20 to 30 ft lower in the massive quartzite. The relative distribution of the ore within the entire zone is inadequately known for the mine as a whole. Judging from the mined-out stopes examined, the upper contact contained the larger orebodies, particularly in parts of the eastern or downdip sections of the mine. In the updip sections and near the outcrop, the ore was perhaps more common in occurrence and thicker near the parting shales. The rocks generally dip 5°–12° N. to NE.

In these deposits, the term "ore shoot" is used to refer to an aggregate of orebodies that were individually small compared to the extent of mineralized ground. The principal ore shoot in the American Nettie and O & N mines (pl. 3*A*) was scarcely more than 300,000 ft^2 in plan. In outcrop, the mineralized channel that contained the ore shoot was 400 to 500 ft wide and trended N. 70° E. into the hill; the trend of the beds downdip in the ore shoot turned to N. 40° E. and terminated near the wall of the Jonathan dike, a distance of about 1,100 to 1,200 ft from the outcrop. Its form or shape is essentially that of a swelling, bulbous outline. Taking into consideration ground including the scattered small ore pockets and veins in the easternmost workings of the American Nettie mine and adjoining properties, the area of mineralization extended more than 1,200 ft along the outcrop of the quartzite and covered several times the area of the principal shoot of the American Nettie and O & N mines. The aggregate of small orebodies may be considered as separate shoots, but ore in the eastern workings of the American Nettie mine is perhaps an appendage or enlargement of the main shoot.

Structure

The quartzite in the American Nettie mine is cut by many joints, fractures, and minor faults, as well as several dikes. These, in conjunction with the parting and capping shale beds, controlled the localization of the orebodies. Strike and dip variations in the quartzite beds indicate the existence of terrace-like warpings and other irregularities in the regional attitude of the strata north of Ouray (pl. 1, sections *C–C′* and *F–F′*). These structures were significant in forming the fracture and joint sets, and were partly responsible for the location and trend of the ore shoots.

The Jonathan dike is exposed in all the mines (pl. 2) over a distance of more than 3,000 ft and strikes N. 25°–35° E. Except where altered, it is a dark-colored, massive porphyritic dike that differs little in composition or texture from the more common east-trending granodioritic dikes of the district. It is 25 to 35 ft thick and has an average dip of 80° E.; however, along strike in the distance between Nettie dikes Nos. 1 and 2, it is locally vertical or dips steeply west. Locally the dike mushroomed or bulged at the contact of the quartzite and overlying carbonaceous shales and sent out small sill-like apophyses. Surface exposure on the valley wall above the mines indicates that the dike cuts through the overlying Mancos Shale, the 500-ft-thick granodiorite sheet, and 15 to 20 ft more of overlying Mancos Shale (figs. 12, 21). The Jonathan dike is one of the few dikes within the district that penetrated all the pre-Tertiary formations. Like all of the older igneous rocks, it was cut by the unconformity at the base of the Tertiary San Juan Formation; at that level it is 5 to 10 ft thick. Within the mines, one or both walls of the dike commonly have been fractured and mineralized, but the ore generally is of lower grade than that found in parallel breaks or sheeted ground a short distance from the walls. The grade of the replacement orebodies in the quartzite immediately adjacent to the dike was reported to have decreased within the Jonathan mine. The richest ore occurred in pockets or flat bodies east and west of the dike but not in direct contact with it. This also was probably true in the northern part of the American Nettie–O & N ore shoot near its termination, because the largest and highest-grade sulfide orebodies at its downdip termination lay 15 to 20 ft west of the dike at the intersection of parallel and cross fractures; these orebodies apparently did not make immediate contact with the dike. It is thought that this may have resulted from local pre-ore reduction in permeability of the wall rocks immediately in contact with the large dikes. More significantly, however, the greater part of the high-grade ore came either from the quartzite west of the Jonathan dike or from near the contact with its walls. The dike appears to have acted as a barrier to lateral east-west migration of the ore-forming fluids. Fractures adjacent to the dike walls may have provided some of the principal feeding channels from depth and between horizons as well as laterally.

Another porphyry dike, the Nettie dike No. 1 (see pl. 3*A*), crops out on the face of the quartzite cliff not far from the main portal of the American Nettie mine, and within the southern part of the main ore shoot. The dike strikes S. 50°–60° E. diagonally across the trend of the ore shoot and has an average dip of 85° S. Its thickness probably does not exceed 8 ft. It is cut but not displaced by the Jonathan dike, and continues to the east where it was intersected by the Schofield tunnel of the Jonathan mine about 900 ft from the portal. A possible southeast continuation is an outcrop of a dike striking S. 30°–40° E. (pl. 2). If the latter is the Nettie dike No. 1, it has changed strike, perhaps resulting from “jumping” of the dike from one fracture to another. There are fractures in the walls of the Nettie dike No. 1 that have been stoped intermittently along the dike to some distance east of the Jonathan dike. Mineralization along the dike walls was comparatively weak and noncommercial within shale beds of the Morrison Formation where the dike was cut by the Jonathan tunnel. Where cut 800 ft below in the workings of the Seaburg tunnel, the Nettie dike No. 1 has some ore along its walls, but it is pyritic and only spottily enriched by gold.

Along the Nettie incline, the Nettie dike No. 2 (pls. 2, 3) is a clastic dike that trends almost due east and has an average dip of about 60° S. Like the other clastic dikes, it is of variable width and is composed of rock fragments that were forcibly injected into the fracture. Some of the dike matter is doubtless of local origin; in places, the bulk of it definitely was locally derived. The dike maintains its clastic characteristics to a depth of 800 ft or more beneath the American Nettie workings to exposures in the workings of the Seaburg and West View tunnels. In the Seaburg tunnel, the dike consists in part of coarse quartz and orthoclase containing much apatite, rutile, and sericite; there, it closely resembles a pegmatite. This dike, like the igneous Nettie dike No. 1, also cuts diagonally across the main ore shoot, but the distribution of the workings relative to the main Nettie incline suggests that the dike was only locally effective as a baffle or guide for the lateral migration of the ore-forming fluids. The quartzite parallel to the dike walls is strongly fractured; this fracturing clearly controlled the shapes of some stoped orebodies not far from the dike walls. Near the portal of the main incline, stopes in both walls of the dike are less extensive than those between 500 and 800 ft from the portal where the main shoot appears to cross the dike with but little deflection. The dike here was not an effective barrier to the lateral migration of fluids within the quartzite, probably because of its relative softness, its variation in thickness, and the more effective control by the open fractures in the quartzite along the principal trend of the ore channel. According to Cross and others (1907, p. 18), “It is the impression of the miners that the ore emanates from this fault breccia and makes out from it into the country rock…,” but they concluded there was no connection between the dike and the ore. Displacement along the fracture was only a few feet, and at the portal, the downthrow was toward the south.

Far to the northeast in the American Nettie mine workings, the Hultona dike and an unnamed granodiorite dike were cut by the Chipeta tunnel (pl. 2). The walls of these dikes were weakly pyritized and mineralized, but the dikes had no apparent bearing on the ore deposition in the American Nettie mine.

Additional structures are the steeply inclined fractures in the quartzite. The larger or master fractures such as the Jonathan vein extend through the strata for a considerable distance vertically; in some places, these fractures where mineralized were stoped below the Dakota Sandstone for a short distance, but deeper into the underlying shaly rocks were tight and unproductive. Nearly all smaller fractures and joints in the massive quartzite were confined to more competent or brittle rocks and did not extend into the shales either below or above the Dakota, and many did not extend through thin shale partings within the Dakota. Drifts in the quartzite, presumably driven along small guiding “knife-edge” cracks, were the customary method of prospecting. These cracks were not seen where the back of the old drift is a parting shale, yet at the drift face, were readily visible as an open fracture or even a large cavity. Because of the concentration of ore-bearing ground beneath shale partings or beneath the capping shales, many of the old drifts were thus unsatisfactory for observations of structural detail which could have been obtained during operation of the property. Except for the larger or master fractures and faults, the structural details shown on plates 2 and 3 were based on the drift patterns in many parts of the American Nettie mine complex. This is justified because many early references cite the guidance of small fractures in exploratory drifting. As may be seen on plate 3*A*, the master fractures gradually change from an approximate eastward trend in the southern part to a N. 40° W. trend in the northeastern part of the workings. Some fractures of the eastward trend are found throughout the range of workings as these belong to the district pattern as a whole rather than to local patterns.

To determine the possible relations of the fracture patterns to the structure of the sedimentary formations, approximate structure contour maps (pl. 3*B*) were prepared both on the top of the massive quartzite bed in the Dakota Sandstone and on the top of the basal beds at or near the so-called “Iron Clad contact” of miners (beds of the Pony Express Limestone Member of the Wanakah Formation). Altitudes were determined in Incline No. 39 of the American Nettie mine to the top of the winze connecting to the Chipeta tunnel, and in some of the lower workings connecting to the Seaburg tunnel and parts of the Wanakah mine workings. Base altitudes were taken from mine maps by Richard Whinnerah of Ouray, who kindly supplied us with the mine data at his disposal. Most of the underground altitudes were determined using an alidade, plane table and stadia rod, and are only of approximate accuracy. At best, the altitude data are too scattered to permit the construction of accurate contour maps, but the general relations are apparent, and were controlled on the outcrops by the topographic base map on which the geology was mapped (Luedke and Burbank, 1981). A series of terrace-like warps were superimposed upon the general northward tilt of the formations in this part of the district. These warps are diagonal to the regional strike of the rocks, and appear to trend northeast more or less parallel to the general trend of the American Nettie ore shoot and to the trend of the deeper ore shoots in the Bright Diamond (Tidwell Member of the Morrison Formation) and Iron Clad (Pony Express Limestone Member of the Wanakah Formation) “contacts” 800 ft stratigraphically below. Flexing of this type was produced perhaps by both rotation and extension that could account for fracturing of the more competent beds. Relations between fracture trends and the structure of the beds are not readily apparent. Possibly the cross flexures resulted from local uplift and subsidence roughly parallel to the margins of the northeast-trending intrusive zone that lies a few thousand feet south of the mineralized area (fig. 21; pl. 1, section *F–F′*). Many small faults, downthrown to the south, further indicate that a slight subsidence followed the initial upward surge of the intrusive bodies. The manner in which the main ore shoots in both the American Nettie and the Wanakah mines have cut diagonally across the intersecting dikes and other structures is an argument in favor of a control of permeability in the beds resulting from a linear fracture channel.

Form and Origin of the Orebodies

As already noted in the historical summary, the ore was found concentrated for the most part in replacement bodies or cave fillings along the bedding of the quartzite, and to a minor extent in vertical fractures or near the walls of dikes. As there were no orebodies of appreciable extent remaining in the mines, especially of the larger “cave types,” current knowledge of the nature of the ore in place and of its relation to the enclosing rocks was derived chiefly from older reports and descriptions of the mine. At the time of the American Nettie mine’s major development (1889 to early 1900s), it attracted much attention and consequently many observers recorded their observations in mining and geologic journals. The early records, together with what was gleaned from a somewhat unsatisfactory examination of the gutted workings (early 1930s), furnished additional evidence concerning the form and origin of the orebodies. Some pertinent observations of the earlier writers are reviewed.

F.M. Endlich (1889, p. 335), geologist with the Hayden Survey, visited the mine soon after its discovery in 1889. He observed that the ore occurred in vugs, nests, and caves that ranged in dimensions from small “bug holes” to caverns 7 or 8 ft in height and 20 to 30 ft in lateral extent. The caves were found chiefly within 20 to 30 ft of the “bituminous shales” overlying the upper quartzite bed, and many showed a “distinct shelving.” Near the caves the quartzite was found to have been cut by numerous vertical “cleavage fissures,” many of which were only cracks, but others were as much as a foot or more in width and extended below the horizon of the caves. He also noted that nearly all caves that contained appreciable quantities of ore were directly connected to vertical fractures. The ore consisted of a yellow or brown auriferous clay that filled the bottoms of the caves; the sides and bottoms of some caves were also encrusted with anglesite, cerussite, sulfides and their various oxidation products. Barite was reported to be mixed with the ore or to line some of the fractures. The gold was found native in wires of varying thickness.

Richard Pearce (1890, p. 453) described the ore that he examined as being associated with silica and mixed with an ocherous material, which had a large amount of “sesquisulphate of iron.” He also detected the presence of bismuth in nearly all samples of the ore; in one sample, he distinguished crystals of what he thought to be the bismuth telluride “wehrlite.” We presume the “sesquisulfate of iron” to be copiapite and the bismuth mineral tetradymite. The latter mineral has since been detected in the massive unoxidized sulfide ore from near the root zone of the orebody. These observations establish that the bismuth telluride and gold-bearing minerals, formed in late stages of mineralization, occupied the entire length of the central highly mineralized parts of the ore channel.

Downer (1901) examined the American Nettie mine in the late 1890s or early 1900s after the mine workings had been considerably developed. The greatest width of ore at that time was said to lie in most cases at or below the junction of the vertical "slips" (iron-stained cracks), with the shale parting about 30 or 40 ft below the top of the massive quartzite. Ore, in places, extended into the overlying shale, and was found to be wholly oxidized in one pocket and entirely sulfide in another. He listed the minerals occurring in the mine as follows: (1) in the native state—gold, silver, copper, and sulfur; (2) as sulfides—iron, zinc, lead, copper, bismuth, and silver; (3) as sulfates—iron, lead, copper, barium, and calcium; (4) as carbonates—iron, copper, manganese, and calcium; and (5) as oxides—iron, copper, and manganese. Near the top of the main ore shoot, in one or two pockets of oxidized ore, there was a porous black silver sulfide consisting of 71 to 75 percent silver associated with native sulfur; the sulfur assayed 10 oz gold to the ton.

Certain observations by Lakes (1901, p. 243–244) are thought to be particularly significant in regard to the origin of the orebodies. He noted that ore was rarely found either in the black shale above the quartzite or at its contact with the quartzite, but where the shale bulged down into the quartzite, locally large bodies of ore were likely to be found. Also, where the quartzite was locally less siliceous, it was more likely to be barren, but where the quartzite was "semi-vitreous," it was likely to have ore. He did not think that the cavities were formed exactly like those at Leadville, by substitution or metasomatic interchange of ore for rock, because there was no gradual "fading off" of the ore into the country rock; to the contrary, the ore was bounded by the walls of the cavity and when the ore, whether sulfide or oxide, was removed the surface of the cavity was round and smooth. He concluded that the cavities were formed prior to being filled by the ore, or were filled immediately on forming by the same fluids that formed them.

Although Lakes' observation that the smooth contact indicates solution and fill would not now be considered evidence in favor of his argument, there is additional evidence on the shapes of the cavities bearing on this point. Shelving of the caves as noted by Endlich (1889, p. 335) can still be seen in the mine; these cuspate forms of the intersecting shelving surfaces, which are convex outward, are known to result from solution cavities.

Lakes' (1901, p. 243) description of the mine mentioned the downward bulges of the shale over the larger orebodies lying immediately beneath, but he advanced no arguments regarding possible relations of the downward bulges to incipient caving into cavities. It is noteworthy that the large sulfide orebodies, which occurred at positions well downdip of the orebody, were unoxidized or relatively little oxidized, and that the unoxidized ore lay immediately in contact with the capping shale.

Irving (1905) favored the view that the orebodies of the mine were formed partly by replacement and partly by filling of previously formed caves. He observed, as did others, that the larger orebodies or shoots were found along the course of a fracture just beneath the black shale at the top of the quartzite, and extended outward laterally from the fracture sometimes as much as 30 ft. Near the supplying fractures, the ore formed a solid mass, but outward only partly filled the cavity, or often only lined the open space. On the extreme outer limit of the shoot, the empty cavity was lined with nothing but quartz crystals. Some of the empty cavities contained no ore whatsoever. According to Irving (1905, p. 68), "It is a saying among the miners that as soon as one finds crystals in the quartzite there will be no more ore. These empty cavities have all the characteristics of cavities produced by solution in limestone and can in no wise be distinguished from them except for the lithological character of the parent rock. There can be no question that they were produced by solution."

Irving (1905, p. 69) further stated:

> "Often a lining of honeycombed quartz is observable, as much as 4 or 5 inches in thickness, either lining the cavity or completely filling it. The cell-like spaces in this quartz are sometimes irregular, but often have the form of pyrite crystals, showing clearly that they are caused by the oxidation and removal of former masses and crystals of iron sulphide. Much of the oxidized ore was shoveled directly from the cavities into ore sacks and shipped without further sorting. More careful sorting is now necessary… .
>
> "On penetrating farther into the hill the ore gradually changes to pyrite. This is either massive, with occasional cavities into which complete crystals of pyrite project, or is composed of crystalline grains of pyrite embedded in a matrix of gray and white secondary quartz. Large admixtures of chalcopyrite and galena and other sulphides are found, among which are sphalerite, telluride of gold and silver (perhaps hessite, found usually in the Jonathan mine), molybdenite, and gray copper (probably argentiferous tetrahedrite)."

He further noted that barite frequently occurred in the sulfide ore. Fibrous bands of gypsum were found between the ore and the overlying black shales, and the sulfide ore also was more common directly beneath the black shales. The contact between the ore and the quartzite was usually sharp and showed an irregular and undulating surface often seen in replacement deposits.

Irving (1911b) recognized that the differences between the contact surfaces produced by replacement and those produced by solution were not always readily distinguishable. He thought that the intersecting concave depressions separated by sharp or slightly rounded ridges, common to solution cavities in limestone, were indicative of solution if they were sufficiently developed to form a striking characteristic of the openings, and that replacement orebodies rarely showed such intersecting concave surfaces. Concave surfaces of this kind, however, in the open caverns believed to have been produced by solutions in the quartzite, were observed in the American Nettie mine.

Irving (1911a, p. 553–554) regarded either a heavy black shale or a thinner, interbedded layer of clay shale an effective impervious barrier to quartzite replacement in the American Nettie deposit. In addition to the replacement masses in the quartzite, the filled solution cavities, and the orebodies usually surrounded by solution cavities, all showed the concave surfaces and other features characteristic of openings formed by solution. The main orebodies, however, seemed to have been formed by replacement.

The descriptions and conclusions of those who had the opportunity to see the orebodies firsthand have been combined somewhat diagrammatically in vertical sections across the American Nettie ore channel (pl. 2, sections *A–A′* and *B–B′*). These approximate scale drawings of the structural relations have been supplemented with observations made in the stopes by W.S. Burbank. These combined conclusions suggest the relations between replacement and open-cavity filling processes in the formation of the orebodies in the American Nettie mine.

The structural or textural evidence favoring open-space filling may be summarized as follows: (1) crustification of cavities lying in the intermediate and outer zones of the section across the trend of the ore channel; (2) intersecting concave solution surfaces, found in mined caves in essentially all parts of the channel except in the central orebodies in the downdip parts of the channel, where mining and subsequent caving has obscured the original relations of ore and enclosing rock; (3) downward bulges or rolls of the capping shale, as reported by Lakes (1901), where the massive sulfide bodies were in direct contact with the shale in the downdip central parts of the channel; and (4) porosity of the massive sulfide bodies shown by the projection of crystal faces into vuggy openings. This does not show necessarily that the orebody as a whole was formed by open-space fillings, but only that, in general, filling predominated during later stages of deposition.

Evidence favoring replacement is as follows: (1) concave-convex or irregular undulating surfaces of contact between the sulfides and the quartzite or shale, as noted by Irving (1911b) and seen also by W.S. Burbank, occur in the downdip parts of the orebodies near the Jonathan dike, and at contacts between ore and granodiorite, shale, or quartzite; (2) masses of quartzite, shale, and porphyry, alongside walls, fractures, or bedding contacts have been converted into massive sericite containing some quartz, pyrite, and other sulfides, especially noticeable along the Jonathan dike in the Jonathan mine, in the lower mineralized zones in the Dakota Sandstone or in the uppermost beds of the Morrison Formation; (3) quartzite surrounding the cavities in the intermediate or outer parts of the main ore channel contains disseminated crystalline pyrite or blebs or small masses of tetrahedrite and other sulfides; and (4) textures of the massive ores examined under the reflecting microscope show that a complex series of metasomatic interchanges have occurred between the earlier formed gangue and sulfide minerals and the later sulfide-bearing fluids.

From these structural relations and from the study of polished and thin sections of the altered rocks and ores, the general sequence of processes forming the orebodies is determined to be as follows: (1) solution of the quartzite, forming open cavities along the linear fracture channel, which was produced by structural disturbances connected with the emplacement or subsidence of the main intrusive bodies to the south of the mine; (2) formation of sericite, ankerite, or siderite, together with smaller amounts of rutile, anatase, apatite, titanite, and chlorite, as metasomatic replacement of quartzite, shale, or granodiorite, but principally along rock contacts or tight fractures in the downdip parts of the ore channel or along the walls of the granodiorite and clastic dikes; (3) pyritization of the altered rocks overlapping or occurring as a part of the preceding mineralization; and continuing with (4) deposition of sulfides in this order: pyrite, sphalerite, chalcopyrite, galena and lesser barite, tennantite or tetrahedrite, additional chalcopyrite locally, tetradymite, benjaminite(?), hessite, and native gold. Late quartz and calcite occur locally. The position in the sequence of the abundant barite to which Irving (1905, p. 69) refers, is not definitely known. Massive sulfide ore containing barite was entirely mined, but barite veinlets are known to have cut the early pyrite and probably accompanied the sphalerite and galena as they did in the nearby veins and in similar small deposits in quartzite beds on the opposite side of the Uncompahgre River valley. Fragmentation of the early metasomatic pyrite near igneous dike walls and along the Nettie clastic dike suggests that there was some structural disturbance after the beginning of mineralization. Structural evidence, with regard to the time of the clastic dike injection, is inconclusive because of the strong local alteration of both the dike walls and the fracture filling. A thin section of the clastic material from the dike indicates that it is composed, in part, of rock fragments that were evidently sericitized prior to fragmentation. In the Seaburg tunnel, the Nettie clastic dike consists, locally, of coarse-grained and partly sericitized quartz and orthoclase containing much apatite and titaniferous aggregates, suggestive of the early stages of the high-temperature replacement veins of The Blowout area that were formed immediately prior to and following the early pyritization. It is concluded that the fracture was reopened, probably during concurrent formation of this vein at deeper levels, or at about the time of the earliest sericitization. The clastic injections resulted, in part, from the explosive expansion of these earliest mineralizing fluids and perhaps from an explosive escape of gases from the deeper intrusive body. Minor late movements also occurred during pyritization.

The formation of the metasomatic replacement deposits and of the orebody in the central channel is interpreted as follows: fluids rising along the tight feeder fractures from depth replaced the wall rock by metasomatic interchange, but upon entering the relatively open-fractured channel in the quartzite, the fluids apparently entered a zone of relatively low pressure and probably expanded, forming a gaseous differentiate and a liquid that attacked and dissolved cavities in the quartzite. This episode was one of "hydrothermal" leaching that preceded the sulfide mineralization at many places in the mining district. As the temperature of the fluids decreased, or as the channel was plugged updip by the transported siliceous matter, the filling of the cavities by hydrothermal fluids with gangue and ore commenced. Continued constriction of the channels caused by passing fluids and reaction between the fluids and the unattacked parts of the quartzite resulted in replacement of the walls of the previous deposits formed. The open channels down the dip of the beds nearest the egress of the fluids became constricted early by the rapid precipitation when the fluids first entered the openings. This area showed the most pronounced effects of metasomatic replacement. Thus the walls of the orebodies deeper in the channel or nearer its center show the characteristics more of metasomatic replacement, as noted by Irving (1911a). It does not necessarily follow, however, that the bulk of these bodies were formed by replacement. The updip or outer zones of the channel contain much less of this type of mineralization, as the open spaces were never completely filled. The outermost zones of the channel also were less mineralized because the later sulfide-bearing fluids had less penetrating strength than those that did the leaching. In addition, the feeding fractures became more constricted with time as mineralization advanced. The more central parts of the channel probably would have received the greatest volume of migrating fluids because this was the most direct path from their entrance to their exit up the dip of the quartzite.

These conclusions are proposed with regard to the distribution of ore in the open breccias and to the shapes of the orebodies formed along the channel. The absence of ore at one place in an open breccia is not necessarily an indication that the breccia as a whole was unmineralized. The outward bulging shape of the American Nettie ore channel near the entrance of the fluids along the walls of the Jonathan dike and from nearby fractures appears to have been the natural result of local constrictions of the original open spaces and of the tendency for the fluids to have spread laterally around those early constrictions into the outer zones of the channel. Reaction between the quartzite and fluids in the downdip positions and the precipitation of minerals from the fluids became less reactive with respect to the quartzite as they passed upward into the more open spaces. Hence, filling predominated over replacement in the up-channel open spaces as well as in the outer zones. The outer zones, as noted, are characterized by quartz fillings of the early-stage mineralization that doubtless represent in part the silica previously dissolved during leaching and metasomatic exchange, and which was then precipitated outward into the open spaces. In contrast to the early comb-quartz filling of the outer zones of the channel, the inner or central zones in the updip positions are described as having smooth and relatively polished walls against which the ore lay. Minor metasomatic replacement by recrystallized and honeycombed quartz was noticeable in those walls but not in the amount found nearer the Jonathan dike.

Considerable metasomatic interchange occurred between the sulfide-bearing fluids and the already deposited minerals and gangues. The rising fluids constantly changed their metal content, demonstrating that they were more-or-less out of equilibrium with the previously precipitated sulfides. The composition of the gangues transported with the metals, however, apparently did not change in a corresponding degree; metasomatic replacement of wall rock or gangues by sulfides was less pronounced in the later stages of mineralization.

Extension of the Ore Channel at Depth

It can be seen on plate 3*A* that the principal ore channel in the American Nettie mine terminated downdip from the Dakota Sandstone outcrop in a somewhat bulbous enlargement enclosing the area along the walls of part of the Jonathan and Nettie No. 2 dikes and both parallel- and cross-fracture systems. The northwest-trending cross fractures were particularly well developed near the downdip termination of the central massive sulfide ore shoots, and cut through the Jonathan dike into the quartzite on its east wall where they were apparently predominant in the now-inaccessible deeper parts of the mine workings. These fractures were comparatively tight in the rocks beneath the level of the Dakota and contained replacement deposits very small in volume and low in grade. In the Jonathan mine, along the Dakota outcrop south of the American Nettie mine, the ore was likewise concentrated near the Jonathan dike and, in some places, the replacement bodies along the walls were minable down to the upper sandstone beds of the Morrison Formation. The decreasing amount of ore down the dip of the Dakota east of the Jonathan dike suggests that the bulk of the mineralizing fluids gained access to the beds along the line of the Jonathan dike.

The distribution of the ore shoots suggests access for two possible feeder sources of ore from depth (pls. 2, 3*A*). One source might have been along the walls of the Jonathan dike and the strong fractures north of and beneath the south-dipping Nettie clastic dike, and another might have been upward along the intersection of the Jonathan and Nettie igneous dikes. Rocks in the exploratory eastern workings of the Seaburg tunnel (pl. 2, section *B–B′*) and near the Nettie dike No. 1, stratigraphically 800 ft below the Dakota Sandstone, contained some early-stage mineralization. The sandstone of the basal Morrison Formation was converted locally into an open-solution breccia and the walls of the igneous dike were locally mineralized by replacement. The open breccia contained only minor amounts of quartz, chlorite, and carbonate and small amounts of sulfides and hematite, which were generally perched on the walls of the cavities. It appears, therefore, that the later fluids generated after those that leached the fractured rocks were for the most part diverted from these feeder fractures during later stages of the mineralization, or that the fluids passed through the fractures without precipitating ores. The main feeder fractures, if such existed, would have lain somewhere to the northeast down the dip of the Dakota Sandstone. The downward projection of the apparent ore-feeding fractures in the Dakota, along with the evidence found at deeper levels, suggests that they were somewhere near or east of the Jonathan dike.

On plate 3*A* the positions of the Jonathan, Nettie No. 1, and Nettie No. 2 dikes have been projected to intersect the Entrada Sandstone and the Pony Express Limestone Member of the Wanakah Formation. All three dikes intersect at nearly the same point on the Pony Express horizon, a little southeast of and almost beneath the intersection of the Jonathan and the Nettie No. 2 dikes on the Dakota Sandstone horizon. Thus again, the main feeding fractures at depth are suggested to presumably lie north of these intersections and east of the Jonathan dike. Those rocks, however, were not explored by any of the earlier deep workings.

Bachelor Group of Mines

Location, History, and Development

The Bachelor group, consisting of the Bachelor, Wedge, Neodesha, and Pony Express mines, is on the east side of the Uncompahgre River valley and in Dexter Creek valley about 2.5 mi north of Ouray (fig. 21). All were operated at one time as separate properties. In later years, the Bachelor and Wedge mines were operated by the Bachelor Consolidated Mining Co., and subsequently, parts of the properties, other than the Neodesha, were operated by the Banner American Mining and Milling Co. Because the geologic features are closely connected, these four mines are described together; the eastern mine workings are on the single Bachelor vein, and west of the vein split the mine workings are on both the Bachelor vein and the Pony Express vein (pl. 4). The veins and bedded deposits of this mine group are typical of the silver-lead-zinc type within the mining district.

The Bachelor group of mines (pl. 4) were developed by both adits and shafts on the east side of the Uncompahgre River valley and just along the south side of Dexter Creek valley. The principal deep openings consist of the Syracuse tunnel (fig. 21, no. 14) at an altitude of 8,040 ft on the lower slope of the Uncompahgre River valley, and the Khedive adit (Bachelor on fig. 21, no. 11) at an altitude of 8,595 ft in Dexter Creek valley about a mile east of the Uncompahgre valley. The Wedge mine (fig. 21, no. 12) was first operated through a shaft at an altitude of 9,216 ft on the flat-topped ridge between the two valleys. Openings of the Neodesha mine (fig. 21, no. 13) are on the slope above the Syracuse tunnel between altitudes of 8,600 and 9,100 ft. These workings (pl. 4) are now connected by underground shafts, drifts, and stopes, and extend about 8,500 ft east of the lower tunnel entrances in the Uncompahgre valley; the maximum vertical range of the workings is about 1,200 ft.

The earliest patent on the mine group was issued on the Pony Express claim (fig. 21, no. 15) in 1887 (Rice, 1980, p. 4); both this property and the Neodesha, on which a patent was issued in 1896, produced ore in the late 1880s. Undoubtedly, the first work on the Pony Express deposit had been started in the prominent Pony Express breccia beds cropping out on the east side of the Uncompahgre valley at an even earlier date. The richest silver ore mined from the group came from parts of the Bachelor, Wedge, and Neodesha mines; these were blind ore shoots in veins concealed by cappings of Mancos Shale and (or) granodiorite that form the top part of the ridge between the Uncompahgre River and Dexter Creek valleys. In 1892, C.A. Armstrong of Ouray, who had driven a tunnel into the hillside on the Bachelor claim, made the first strike of the high-grade silver orebodies. The Bachelor discovery tunnel (pl. 4), at an altitude of about 8,930 ft on the south slope of Dexter Creek valley, was started in the upper mudstones and shales of the Morrison Formation and encountered the Bachelor vein in the Dakota Sandstone about 550 ft from the portal. The Bachelor clastic dike and associated rich silver vein were cut in the sill of the tunnel, but were not exposed in the back because of a capping of shale on the quartzite at this level. Shortly thereafter, Armstrong, J.F. Sanders, and G.R. Hurlburt, all bachelors, formed the Bachelor Mining Co., a closed corporation, for the development of their claims which lay to the east of the Wedge claim.

Between 1892 and 1897, the Bachelor Mining Co. produced regularly from a shoot of rich silver ore that was mostly in quartzite beds of the Dakota Sandstone. During the height of production in 1895, the company was shipping about 30 cars of crude ore monthly; the production and profit sustained during this short period exceeded that of any other property in the Uncompahgre district. By 1896, the operations on the property had been gradually transferred to lower tunnels that were driven to intersect the vein at more convenient working levels. A few years later essentially all operations were conducted through the lower tunnel in Dexter Creek valley known as the Khedive adit (pl. 4). By 1899, the bulk of the high-grade ore had been mined out above the Khedive level and west of the adit at this level. As the grade of the ore became lower, a concentrating mill was constructed at the Khedive adit site to treat material from the dumps that had been discarded earlier. Prior to that time, most of the crude ore was shipped directly to the smelters; only a small amount of ore from both the mine and older dumps had been treated in a neighboring mill. Mill output was increased as the ore mined from near the Khedive level contained increasing quantities of zinc and, according to company assays, a decreasing silver content of about 9 oz to the ton. In 1902, the monthly output was about 15 to 25 carloads of concentrates; in addition, shipments of sorted, high-grade crude ore continued to be sent directly to the smelters. The company mill was equipped with crushers and rolls, jigs, Bartlett tables, a Wilfley table, slime settling tanks, and canvas slime tables, but according to Irving (1905, p. 63) a considerable loss of silver could not be avoided. As was common in mills of that time, difficulty was encountered in saving the silver values because of the tendency of gray copper (argentiferous tetrahedrite) to be converted into slime even with the most careful crushing techniques. From 1904 to

1907, the Bachelor mine was idle except for the work of a few lessees; this timeframe is considered to mark the end of the early period of development. The mine had employed, under normal conditions, from 50 to 75 men, and more temporarily. During the years of operation subsequent to 1900, the Bachelor shaft was sunk about 500 ft below the Khedive level to develop the downward extension of some ore shoots, but the amount of favorably mineralized ground decreased considerably in the alternating shales and sandstone of the Morrison Formation underlying the Dakota Sandstone.

From the time of its discovery until about 1903, the Bachelor mine, exclusive of the Wedge, Neodesha, and Pony Express mines, had a production of nearly $2 million, more than any other mine of the district. It was reported in news items for 1895 that the property had a net profit of $35,000 per month, but operations in the years of declining grade and falling silver prices materially diminished the profits.

Development of the Wedge property was started not long after the discovery on the Bachelor, but according to news items, an extension of the rich Bachelor ore shoot was not encountered until 1896. This development was started by a vertical shaft that was sunk about 200 ft; some drifting was done before encountering the main ore shoot which extended to within about 130 ft of the surface near the shaft. In 1898, the Wedge shaft was connected with the Khedive level of the Bachelor mine (pl. 4). Operations by the Wedge Mines Co., formed by J.B. Farrish, E. Richards, and L.W. Ross in December 1898, after purchase of the property from the former owners for a sum said to have been $40,000, continued until January 1900, when the mine was closed. The company regularly employed between 50 and 75 men, and during 1899, nearly 100. Production from the Wedge is not known, but it was considerably less than that from the Bachelor during its first period of operation. Based upon the stoped area of the Wedge mine and upon the length of its operations compared to the Bachelor, production during this period is estimated to have been approximately $1 million. The high-grade ore was similar to that in the western part of the Bachelor mine.

The Neodesha property, on the western extension of the Wedge vein, apparently contained only a small part of the high-grade ore shoot. The rake of the ore shoot toward the east brought its base much higher stratigraphically on Neodesha ground; development on the vein in the Morrison Formation below the Dakota Sandstone does not appear to have found orebodies. This property was purchased and operated by the Florence Mining and Milling Co. in 1889, but exploitation by this company was unsuccessful. In 1899, a good orebody was said to have been found; the property then was operated under lease, employed about 20 men, and produced about 7 tons of ore daily. No record of the total production exists, but it undoubtedly was small compared to that from the Wedge and Bachelor properties.

The vein in the Pony Express mine is a southern split of the Bachelor vein (pl. 4); the bulk of the ore from this mine was obtained from bedded deposits in or near the Pony Express Limestone Member of the Wanakah Formation, stratigraphically lower than the deposits in the Bachelor, Wedge, and Neodesha mines. Shipments of ore from this property, first recorded in 1888, were made over a considerable period of time. Between 1893 and 1896, occasional shipments of 5 to 8 carloads per week were reported, but the production apparently not was continuous. The property was equipped with a mill by 1897. The Pony Express vein narrowed into the hill and the ore locally decreased both in quantity and grade at cross faults; little development was done beyond 600 ft from the outcrop.

The next important period of development of these properties, not so much for their productivity as for delimitation of the mineralized ground, began in 1924 after the consolidation of the Bachelor and Wedge properties. The Syracuse tunnel, intended for development of the mines at depth and as a main haulage way, was started in October 1924 and eventually was connected to the Bachelor shaft by a crosscut and raise (pl. 4). Ore was blocked out along the Pony Express vein and in the roll or bedded deposit in the Pony Express breccia as well as in the Bachelor vein above the tunnel level. However, production from these deposits had to be postponed because of unfavorable metal prices as well as the small size and moderate grade of the blocked-out orebodies. Work was suspended in 1929.

G.A. Franz, Jr., and associates, who operated the Banner American mill (fig. 21, no. 16) between 1931 and 1938, extended some of the mine workings higher in the upper Bachelor Consolidated property through the Khedive adit. The Khedive level also was extended about 800 ft east beyond its previous heading, and crosscuts were driven both north and south to explore for parallel veins in this mine (pl. 4). Some ore was produced both in the Bachelor vein and in some of the parallel veins, but owing to a large amount of shale in the Dakota Sandstone at this horizon, the veins contained only small and irregular ore shoots. This work, being mainly of an exploratory nature, was abandoned finally in favor of pushing the development on the Pony Express vein at lower levels. From 1933 to 1937, when operations were suspended, the Banner American Milling Co. essentially mined out the ore on the Syracuse tunnel level east of the Pony Express property in ground previously developed by the Bachelor Consolidated Co. The steep vein in this part of the property ranged from 6 in. to 3 ft in thickness; ore in the roll was about 4 ft thick in most places. Silver values in this vein decreased from west to east, from a maximum of 50 oz to about 5 oz per ton of ore; lead and zinc content ranging from 3 to 10 percent occurred in about equal amounts. The ore mined during this period was locally of good grade and width. The shoot at the contact narrowed into the hill and was locally impoverished near the large cross faults at the eastern end of Pony Express ground (pl. 4). Ore in the vertical vein was narrow and stoping was limited vertically to the massive sandstones at this horizon. Under these conditions and because of the extensive distance required to reach and handle the ore in proportion to its volume, mining costs rose prohibitively. The modern flotation-type mill of 100-ton capacity made a good recovery according to the operators. The main product was a lead concentrate that contained the bulk of the silver.

The mining property was worked by J.R. Sonza from 1942 to 1946, and then by the American Zinc, Lead & Smelting Co. during 1947 (King and Allsman, 1950). From mid-1951 to mid-1952, the Bachelor mine was operated by the Bachelor Development Co. of Ouray (J.R. Sonza and K.M. Quirk) through the Khedive adit under a Defense Minerals Administration contract. The extent of mining developments within this mine group subsequent to 1952 are unknown, except to note that some development took place at the Bachelor and Pony Express mines during the mid- to late 1950s.

Production and Grade

The total production from the Bachelor, Wedge, Neodesha, and Pony Express mines prior to about 1905 was estimated by local authorities to be between $3,500,000 and $5 million. It is thought, however, that the lower figure is more nearly correct. As already noted, the combined production from the Bachelor and Wedge mines prior to this time was estimated to have been roughly $3 million. Production from the Neodesha mine was small, but most of the ore was high grade. The production from the Pony Express mine was almost entirely of lower grade ore, and the volume of stoped ground markedly decreased eastward into the hill. It is probable, therefore, that the production from these two properties prior to 1905 was between $500,000 and $700,000.

The grade of the early mined silver ore from the Bachelor and Wedge mines ranged from $20 to $75 per ton (Irving, 1905, p. 62); locally, however, extremely rich pockets of nearly pure ruby silver (pyrargyrite) were encountered. The value of ore in the eastern and lower parts of the Bachelor ore shoot was closer to $10 per ton. Ore from the Pony Express mine was said to have averaged nearly $30 per ton, but this value apparently did not hold up throughout the ore shoot. Some ground blocked out above the Syracuse tunnel level contained ore, but milling returns suggested that only with considerable selection of the ore and sacrifice of tonnage could the mill feed be kept near the values mentioned.

Geology

The rocks enclosing the ore deposits in this group of mines range from the upper part of the Cutler Formation (Permian) to the basal part of the Mancos Shale (Cretaceous), a thickness of about 1,200 ft. The most productive parts of the veins were in the quartzitic beds in the Dakota Sandstone and the upper 300 ft of the underlying Morrison Formation. Another productive zone, only 100 to 200 ft thick, occurred in the basal Morrison Formation, Wanakah Formation, Entrada Sandstone, and Dolores Formation; it is estimated that this zone yielded about one-quarter of the total value of production.

The strata dip as much as 20°–30° S., but average about 5°–10° ESE. to locally south within a narrow zone along the east-striking vein system in which the regional northerly dip of the beds has been flattened to reversed. The average component of dip within the plane of the vein, however, varies between 3° and 8° E. In addition, the south side of the plane was slightly down-faulted. This local flexing probably resulted from subsidence related to intrusive igneous activity, such as noted in the area of the American Nettie deposit. These bedding attitudes, as well as changes in the physical characteristics of the rocks, were important in the localization of the ore and in the rake of the ore shoots. The upper Bachelor-Wedge-Neodesha ore shoot rakes eastward more steeply than the dip of the beds because of the local change in dip and certain structural features of the vein resulting from the deflections in dip. The ore shoots in the Pony Express vein system plunge essentially with that of the rocks. The lower ore shoots were chiefly at and near the intersection of the vein with the limestone breccia in the Pony Express Limestone Member of the Wanakah Formation, a bed of exceptional permeability. Except very locally in parts of the Wedge and Bachelor mines, shale walls were generally unfavorable or much less favorable to the deposition of ore in the fractures than where the walls were of more competent sandstone. On the other hand, shale beds and partings influenced the localization of rolls or deflections in the attitudes of the fractures, thus producing structures locally favorable for ore deposition.

In the eastern part of the workings on the upper or Khedive level, the main Bachelor vein strikes N. 80°–83° E., and dips from nearly vertical to 80° S. (pl. 4). Between the Bachelor and Wedge shafts, the vein is essentially vertical according to Irving (1905, p. 61), and at places dips about 80° N. according to Ransome (1901, p. 227). No detailed level maps of the old workings were available and as these workings were not accessible, local changes in the dip of the vein in relation to the stopes could not be determined. In the extreme western part of the Neodesha property, the main vein crops out on the slope of the Uncompahgre River valley and dips from vertical to 80° S. About midway between the Bachelor and Wedge shafts, as traced in the upper levels (pl. 4), the fracture system splits, forming two branches. The south branch, the Pony Express vein, strikes about N. 78°–80° E. and dips between 50° and 80° S. The north branch, or so-called Bachelor-Wedge-Neodesha "split," consists of a series of gradually diverging breaks that forms two veins separated by about 50 to 70 ft near the Wedge shaft and widens to a fractured zone about 200 ft in width at the extreme western end of the Neodesha property. Here, also, the two main branches of the vein are separated by about 200 ft (pl. 4) on the Syracuse tunnel level.

The main fracture includes the north branch over nearly its entire length, from the easternmost workings to its western outcrop on the Uncompahgre River valley wall, and is occupied by the Bachelor clastic dike that was described by Ransome (1901), Irving (1905), and Spurr (1923). The Bachelor dike where seen underground ranges from a narrow seam to 3 or 4 ft in thickness. The walls of the dike are sharp particularly on the Syracuse tunnel level beneath the horizon where the dike was mineralized. In the uppermost workings, the dike as well as the enclosing fracture pinched out in the Mancos Shale and terminated abruptly in a zone of extremely contorted and broken shale. As previously discussed (p. 33–34), the dike was formed by explosive injection from depth and contained debris both from shales in the Dakota Sandstone as well as from rocks at greater depths (fig. 16). The Bachelor dike extends beneath the level of the deepest mine workings. Westward beyond Lake Lenore the fracture has been filled by an intrusive igneous dike (fig. 12).

There are differences of opinion as to when the Bachelor clastic dike formed in relation to the vein filling. Both Ransome (1901) and Irving (1905) concluded that the dike was emplaced prior to the formation of the Bachelor vein. Irving (1905, p. 61) stated that the vein formed subsequent to the solidification of the clastic dike, as it broke across the dike from one side to the other or was enclosed entirely within it. Also, the faulting on the vein, about 7 ft, was observed only along certain parts of the vein.

Spurr (1923, p. 843–844), thinking he was dealing with an inverted vein-filling sequence, had the clastic dikes injected between stages of his so-called metalliferous veindikes. He first filled the vein fracture with silver-barite ore—the Bachelor vein—then split it open again to be filled with upwelling dark mud derived from the underlying formations. What formed the fluid part of the dike was the mineralizing solutions of his first ore stage because some parts of the dike were impregnated by sulfides and other parts pierced by veinlets of ore identical in character with the principal vein-filling; the mineralization antedated intrusion of the persistent black clastic dike, known to the miners as the Bachelor dike. Spurr (p. 844–846) further noted breccia injections of the same age elsewhere in this group of mines were gray instead of black because they lacked the black shale fragments characteristic of the Bachelor dike. The gray breccia is hard, siliceous, and occurs frequently, but not always, alongside the veins; its habit shows that it is not a fault breccia, but an injection breccia. From the breccia dike, sheets intrude bedding planes of the country rock. This was noted especially in connection with the Neodesha vein where the breccia is 3 to 10 ft wide. The breccia is barren, but does contain fragments of the barite-silver ore of the first vein period; it also contains fragments of vein-quartz. He concluded that the gray siliceous breccia and the black shaly breccia of the Bachelor dike were probably the same injection. An attempt was made to re-examine Spurr's conclusion that the Bachelor dike must have been injected after the Bachelor and Wedge ore shoots were formed, but all evidence that can now be seen is decidedly to the contrary and instead confirms the conclusions of Ransome (1901) and Irving (1905). Because most of the ore had been mined from the Bachelor and Wedge ore shoots at the time of Spurr's examination in 1909, he had less opportunity to observe the geologic relations than Ransome and Irving, both of whom examined the deposits when they were being mined.

The gray siliceous breccias seen by Spurr in the Neodesha and Pony Express mines were apparently different from the black breccias of the Bachelor dike because of the differences in composition, general color, and texture as well as in time of injection. The actual observations of the several authorities, therefore, need not lead to conflicting interpretations. W.S. Burbank examined the Bachelor dike where it was unmineralized both on the Syracuse tunnel level and at places in the eastern parts of the Bachelor mine on the Khedive level; he also examined the dikes in parts of the Pony Express and Neodesha workings and concluded that not one but several injections of clastic debris occurred. The Bachelor dike, wherever seen, was very distinctive in appearance, and the size and arrangement of the fragments varied little from its exposures in the north workings of the Neodesha mine to those 800 or 900 ft below and several thousand feet to the east on the Syracuse tunnel level. At no place were fragments of previously formed vein material found other than sparse pyritized or silicified fragments that might have had a very deep-seated origin. Fragments of schist and other rocks of deep-seated origin, however, were common. Many gray to black shale fragments that have been broken across the cleavage were also conspicuous. Had this dike been intruded subsequent to the formation of the silver-bearing veins, there is no question that fragments of the previously formed veins should be fairly common, because the Bachelor and Wedge ore shoots had a significant longitudinal and vertical extent along the path of the injection. This injection, from great depth, has the same age as many other pre-mineral clastic dikes in the district.

The Pony Express vein, as seen both along the Syracuse tunnel level and in the eastern parts of the Pony Express mine, contains definite siliceous gray clastic dikes corresponding in appearance to those described by Spurr (1923, p. 843–849). They range from mere stringers in the vein walls in the eastern workings to dikes several feet in width in the western workings. The dikes were not seen in contact with sulfide ore because mining had obliterated their relations to the former orebodies in the westernmost Pony Express workings. Dikes exposed on the Syracuse tunnel level have features suggesting that they formed during intermineralization epochs. At one place, abundant fragments of silicified wall rock and sphalerite were included in the breccia, whereas galena and tetrahedrite, late minerals in the normal vein sequence, were deposited between the fragments or partly replaced the matrix of the fragmental material. Spurr's sketches (1923, p. 845, figs. 157 and 158) of relations in the Pony Express mine show (1) fragments of a clastic dike included in baritic vein matter, and (2) a 2-ft-thick clastic dike cutting a barite vein containing chalcopyrite and tetrahedrite. Where the dike was seen by W.S. Burbank in this mine, fragments of quartz, silicified rock, and locally derived shale and sandstone were abundant in contrast to that of the true Bachelor dike; it was thought that most of this material had been torn from the walls at, immediately below, or east of the places where observed. The dike lay directly against the wall of hard, siliceous, low-grade vein matter and, as a consequence, contained few if any recognizable fragments of the massive vein sulfides. Those observations, combined with those of Spurr (1923), Ransome (1901), and Irving (1905), suggest strongly that the Bachelor dike was injected prior to the main period of vein formation. Explosive pulsations of the mineralizing fluids, however, continued intermittently into the later stages of vein formation and formed the intermineral clastic injections, of which all of the clastic material was of relatively local origin. These intermineral clastic dikes apparently attained considerable thickness toward the west, 3 to 10 ft in the Neodesha mine and 2 ft in the Pony Express mine, according to Spurr (1923, p. 846 and fig. 158), whereas the dikes scarcely exceeded 1 ft in the eastern Pony Express mine and are scattered in occurrence farther west on the Khedive and Syracuse tunnel levels. It may be concluded that the westernmost dike accumulations were gradually built up by a series of pulsations. The possible factors that produced this condition are as follows: (1) the vein fractures were gradually filled from the east toward the west by the mineralizing fluids, (2) reopenings of the fractures, connecting to the surface, released the pressure on the mineralizing fluids that resulted from more feeble structural disturbances with lapse of time, and (3) the temperatures of the later vein-forming fluids were lower and consequently the positions of sudden pressure release migrated toward the egress of the fluids with lapse of time.

Sequence of Vein Formation

The general sequence in the formation of the dikes and veins as determined from structural relations and crustification was (1) opening of the Bachelor main fracture and the injection of the pre-mineral Bachelor clastic dike, (2) reopening of the Bachelor dike and formation of the Pony Express vein split, with beginning of mineralization in somewhat variable order, (3) pyritization, sericitization, and formation of ferroan rhodochrosite (mostly in the easternmost parts of the vein system) followed by quartz and sphalerite (with some galena, chalcopyrite, and tetrahedrite), (4) intermineral clastic injections followed by chalcopyrite, tetrahedrite, pearceite, and galena overlapping in deposition with barite or quartz gangue, (5) additional chalcopyrite with some pearceite and calcite veining earlier sulfides, and finally pyrargyrite(?), and (6) barren barite, quartz, and rhombohedral and scalenohedral calcite and locally barren quartz. The principal barite gangue was deposited during stage 4 and commonly was associated with either copper-silver minerals or galena, chiefly in the westernmost workings. As noted above, stage 4 also was interrupted by one or more clastic injections that formed the siliceous ore-bearing clastic dikes. The most prominent dike in the eastern Pony Express vein on the Syracuse tunnel level followed the major deposition of pyrite and sphalerite that contained minor chalcopyrite, tetrahedrite, and galena. It in turn was followed by the bulk of the galena and additional chalcopyrite and tetrahedrite.

It was not possible to confirm Spurr's conclusion (1923, p. 843) that the sequence of mineral deposition in the Bachelor and Pony Express mines was inverted, the higher grade silver ore being early and followed by pyrite, sphalerite, and galena, although barite was most abundant in the late rather than early stages. Bastin (1923, p. 70–73) did not mention evidence for an inverted sequence; he considered that pearceite and tetrahedrite, which are intimately intergrown (see fig. 27), were essentially contemporaneous with galena, sphalerite, and chalcopyrite and therefore were primary. He also noted that the primary ore was cut by small veinlets of simultaneously deposited pearceite, calcite, and chalcopyrite.

Further evidence for the repetition and inversion of mineral deposition was supplied by a crustified vein on the lower levels of the Pony Express mine, which in the westernmost workings had the following sequence from the wall inward to the open vuggy center: (1) the silicified sandstone wall, (2) a layer of quartz crystals and sphalerite, chalcopyrite, and galena, (3) a layer of dark-banded fine-grained quartz that was deposited upon and cemented the partly brecciated layer 2, (4) a thin layer of chalcopyrite, tennantite, and galena merging with massive intergrown galena and barite, and (5) some late barren barite in the open central vugs. The bulk of the barite and galena here were later than the main silver mineralization, but here as elsewhere, the first-stage sphalerite together with associated chalcopyrite and galena formed earlier than the silver-bearing minerals. It appears, therefore, that there were at least two principal as well as possibly other minor repetitions of deposition in the veins. The earliest base-metal sulfides were apparently more abundantly deposited in the eastern part of the mine where the ore was sphalerite-bearing and lower grade, whereas the later mineral sequences were more abundant in the westernmost parts of the fracture system. This, as previously stated, suggests that the veins were progressively filled from the east to the west and that certain minerals were dissolved and reprecipitated. Other reprecipitated minerals consisted of minute crystals of nearly all the common sulfides found coating vugs in the ores or open spaces in the barren fracture. The general sequence, disregarding details, is (1) early base-metal sulfides with pyrite and sphalerite predominant, (2) copper-silver minerals predominant and minor base-metal sulfides, with or without barite, and (3) barite and galena with other minerals in minor amounts. The emphasis of the copper-silver deposition during the intermediate stages of mineralization is characteristic of most of the silver deposits in the northern part of the Uncompahgre district, and accounts in part for the intermediate position of the rich silver-copper ore in the ore shoots of the Bachelor-Wedge vein that was bounded on both sides and below by lower grade ores. In veins in the central area of the mining district, gold rather than silver was the more valuable metal deposited with the copper, except in the American Nettie mine where both gold and silver were concentrated. Thus, as distance was gained away from the centers of mineralization and as the ores were derived from deeper and deeper sources, silver became the predominant precious metal of the intermediate stage of mineralization, almost to the exclusion of gold. The deposition of barite following the release of pressure is also thought to have resulted from the oxidation of sulfur at or near the sources of the mineralizing fluids.

Localization and Form of Ore Shoots

The principal ore shoots were localized in the vein within the more competent rocks. The highest grade ores from the upper part of the Bachelor-Wedge ore shoot (indicated as stoped) were found in the Dakota Sandstone, but this shoot narrowed downward into the upper parts of the Morrison Formation eastward toward the Bachelor shaft. Structural control of this shoot in shale of the upper Morrison could not be determined because that part of the mine was inaccessible. It is possible that the pre-mineral Bachelor dike and the steep dip of the vein in this part of the mine may have been factors contributing to an open fracture. The vein along the dike in the upper workings ranged from 6 in. to 2 ft wide, but in places the ore was more or less mixed throughout the dike over a width of 3 or 4 ft. Eastward in the upper parts of the mine above the Khedive level, the distribution of ore became more and more irregular owing, in part, to the increase in the amount of shale in the Dakota Sandstone. The easternmost mine workings were too high in the stratigraphic section to find continuous or large bodies of ore although some small bodies of relatively good grade were encountered. It is presumed that the fracture along which the ore-bearing fluids gained access to the main Bachelor-Wedge ore shoot plunged to the east and connected to lower shoots along beds in the Pony Express Limestone Member of the Wanakah Formation. The feeding fractures between the upper and lower mineralized horizons probably extended for some distance east of the Khedive shaft.

The Pony Express channel, as noted, was localized chiefly by the relatively high permeability of the limestone breccia horizon, which as discussed on page 19, was due to dissolution of primary gypsum and the subsequent collapse, breakage, and cementation of the clay sheaths that surrounded each gypsum nodule, thereby forming a very permeable breccia. The lateral spread of the fluids resulted in ore shoots, as bedded deposits that varied from 20 ft to over 100 ft in width and from zero to 15 ft in thickness. A large part of the ore in the shoot lies along the bedding of the Pony Express Limestone Member. The Pony Express vein, however, west of where it split from the Bachelor vein, was mineralized above and below the limestone breccia beds. Ore shoots in the steeper vein are comparatively narrow, ranging in width from less than 6 in. to a maximum of 2 to 3 ft. In the bedded deposits, the ore channel apparently increased markedly in width west of the nearly vertical cross-fault that intersects the beds west of the junction of the Syracuse tunnel drift with the Pony Express vein (pl. 4). To the west of this fault, most of the ore came from the bedded deposit, whereas to the east, the bedded deposit was comparatively narrow and most of the ore came from the steeper vein. The grade of the ore throughout the lower shoot was less than that in the western and upper parts of the Bachelor-Wedge ore shoot. At the east heading of the Syracuse tunnel drift on the Pony Express vein, the Pony Express Limestone Member contains a low-grade, rhodochrosite-bearing siliceous ore that is relatively high in zinc and low in silver; the vein was evidently choked by the precipitation of early-stage minerals within the breccia. There also was considerable replacement at this horizon, which in general appears to have increased in importance compared to fracture filling toward the east.

In addition to the localization of ore in steep fractures and permeable strata, ore was concentrated in a special type of vein structure, known by the miners as a “roll”; ore formed as a bedded deposit at several horizons in the upper ore shoot. Three prominent rolls in the Morrison Formation, one 50 ft or less below the base of the Dakota Sandstone in interbedded shales and sandstones and two at about 250 ft and 350 ft, respectively, beneath the upper roll, are shown on some early maps of the mine workings. The exact stratigraphic horizons of the two lower rolls is not known, but by projecting the generalized section of the Morrison Formation upon the mine section it would appear that they lie in shales just above or below thick sandstone beds. A roll is commonly present in the Pony Express beds. Within the Bachelor and Wedge mines, the clastic dike whether accompanied by a vein or a barren fracture was offset at the rolls. These structures, shown in sections *A–A′* and *B–B′* (pl. 4) and in figure 23, resulted primarily from the lateral offsetting of the steep fracture generally at contacts between competent and incompetent beds such as sandstone and shale or within shale beds. According to those familiar with development of the mine, these structures were nearly continuous for distances of 2,000 to 3,000 ft in the Bachelor and Wedge mines. Between the offset ends of the vertical parts of the vein the beds were fractured, and the ore filled the flat fractures or replaced the fractured beds. According to Irving (1905, p. 62) ore in the rolls mainly filled open spaces.

The rolls in the veins and dikes must have formed under special conditions as they are not common in veins that traversed horizontally bedded deposits. Because of the reversal of dip of the beds to the south along the east-trending Bachelor fracture system, in contrast to the regional dip to the north, the upper part of the vertical fracture was offset updip to the north or relative to the lower part. The amount of the offset ranges from 10 to 20 ft in the Bachelor vein and is more than 50 ft locally in the Pony Express vein. The bedding fault or fracture between the offset parts of the vertical fracture does not appear to connect with other bedding faults or fractures above or below in nearby beds. The amount of offset may vary considerably within short distances longitudinally. The vertical fracture, in effect, was refracted by its traverse through rocks of different physical characteristics. The apparent deformation and concurrent bending of the beds to the south perhaps aided in producing offsets of the magnitude found.

The Bachelor dike does not commonly follow the rolls in the Bachelor mine; also, the top of the dike appears to have been cut off sharply at the bottom of the roll as if by a fault. There was very little ore in the Bachelor-Wedge ore shoot beyond the two ends of the vertical dike, other than ore in small stringers. The vertical vein immediately above and below the rolls commonly contained lenses of high-grade ore but was not much thicker than normal.

At places in the Pony Express beds, particularly at its extreme western termination, ore extended beyond the limits of the vertical vein, especially on the updip sides. The ore channel there was 100 to 120 ft wide, and alteration extended even farther. The fracture apparently was not offset more than 50 to 60 ft (pl. 4, section *A–A′*; fig. 23*B*). The moderate reversal in dip of the beds probably contributed to the width of the roll as well as to the local fracturing of the limestone breccia beds. The permeability of the limestone breccia beds provided open space in addition to that resulting from the fracturing. Replacement appears to have been more intense at this horizon than in the steeper vein, but the bulk of the replacement material was mostly barren gangue rather than ore. The parts of the breccia in the Pony Express Limestone Member that escaped much of the sulfide mineralization consisted of an open network of silicified fragments which contained small crystals of late quartz deposited in the openings; this material was at least as porous as the original limestone breccia. This suggests that early in the mineralization stages the limestone breccia fragments were incipiently silicified, but that the process was apparently interrupted by the leaching of the remaining limestone, forming a skeletal siliceous breccia. Brecciation and leaching most likely occurred during a period of pressure release such as during the intermineral clastic injections or at the very beginning of mineralization. The dark-colored, fine-grained quartz of the porous breccia is similar to that deposited in the fractures during the pre-ore stages of mineralization that accompanied or immediately followed the periods of intermineral clastic injections, such as stage 3 of the sequence in the lower levels of the Pony Express mine. Movements on fractures or cross faults may have accounted locally for the barren open breccia by locally diverting the movements of fluids. There is barren rock in the eastern parts of the Pony Express mine near some of the larger cross faults.

Calliope Mine

Location, History, and Development

The Calliope mine is north-northeast of Ouray (fig. 21, no. 8) near the confluence of Dexter and Mill Creeks about 2 mi east of the Uncompahgre River valley. The lower or Iowa Chief tunnel level (pl. 5) is at an altitude of 8,620 ft on the north side of Dexter Creek, opposite the Khedive adit of the Bachelor mine. The Calliope vein contained the most important orebodies of this mine, which was brought into production by Adam Herzinger in the 1880s and prior to 1890 produced high-grade silver ore having a value of several hundred thousand dollars as reported in Henderson (1926, p. 185). In 1889, this property and the James V. Dexter mine were consolidated and the Calliope Mining Co. was organized. After formation of the company, development of the Calliope mine until about 1900 was said to have been somewhat erratic; no reliable production records exist for that period. A mill, constructed in 1896 to treat the lower grade ores, was operated during the last few years of the company’s ownership. In 1900, the original Calliope interests were sold to a group of men from Chicago under an agreement to extend development of the property.

Early development of the property was from levels above the Iowa Chief tunnel; the latter was extended eastward beneath the upper workings in 1909 and completed in 1911. Raises were connected to the upper levels, and ore was then stoped from the eastern parts of the vein. The lower workings were eventually extended farther east, but records or maps of the extent of these workings were unavailable and the workings were inaccessible. Ore shipments made between 1916 and 1919 were principally from the eastern extension, according to smelter records. Subsequently, the property was worked by lessees from time to time, but by the late 1950s the tunnels were caved and the buildings torn down with little likelihood of further activity.

Geology

The Calliope vein strikes between N. 85° E. and S. 85° E., dips on the average about 60° S., and occupies a fault with the south side downthrown only a few feet. Ore shoots within the vein were chiefly in the Dakota Sandstone, locally converted to quartzite, and partly in the irregularly

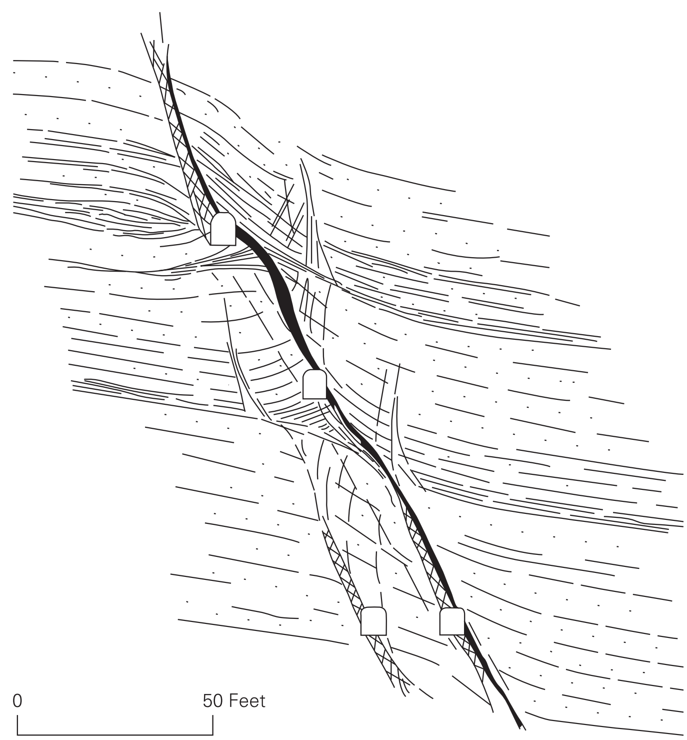


Figure 33. Diagrammatic sketch showing a possible interpretation of the splitting, with depth, between the mine’s tunnel levels in the lower part of the steeply south-dipping Calliope vein. The rolls in the vein were accompanied by contortion and lateral injection of the carbonaceous shale interbeds. Cross-hatched bands represent ore-bearing vein and mineralized seams; solid bands represent ore-enriched part of the vein.

shaped sill-like body of porphyritic granodiorite that had intruded into the basal part of the overlying Mancos Shale. The vein in the Morrison Formation below the quartzitic sandstone beds of the Dakota was commonly tight and yielded little ore. Strata in the vicinity of the mine workings dip 7°–10° E. to SE., but locally near the veins there are short south-dipping flexures of 25°–30° or more.

The Calliope vein lies along a broad, generally east-trending flexure that is about 3,000 ft in width and includes the parallel Bachelor and Wedge veins, 1,300 to 1,500 ft to the south. Beds within this flexure dip southeast toward the intrusive axis to the south, a reversal of the regional north dip away from the San Juan Mountains uplift.

The early Tertiary erosion surface is at an altitude of slightly more than 9,000 ft near the outcrop of the Calliope vein, so that in places the ore-bearing beds have been truncated. The ore in the porphyritic granodiorite sill above the quartzite was stoped up to the unconformity at the base of the San Juan Formation, but the vein did not extend into the overlying Tertiary volcanic rocks. This fact and the abrupt termination of the stopes, particularly those in the granodiorite, at the base of the volcanic rocks (pl. 5) clearly indicate a pre-San Juan age for the Calliope mineralization. This is one of the few localities within the Uncompahgre mining district where these relations clearly are shown. In many of the district's mines, intervening beds of Mancos Shale between the productive parts of the veins and the erosion surface show little or no fracturing within the shale beds, thus providing inconclusive evidence in this matter.

The James V. Dexter vein, which intersects the Calliope vein, strikes N. 25°–30° E. and consists of a series of relatively tight, minor steeply-dipping fractures within a zone of 60 ft or more in width (pl. 5). Ore shoots in the Dexter vein were not as regular in distribution along the fracture zone as those in the Calliope vein; the larger shoots were replacement bedded deposits near the top of the Dakota Sandstone or in sills and irregular offshoots of the porphyritic granodiorite body. The ore in this vein was reported to have contained more lead and zinc than that of the Calliope vein, but other than the small orebodies mined near the portal of the Dexter tunnel, there was little development of these cross veins. Where the N. 25°–30° E. fractures cross the Calliope vein, they tended to split but cut through it sufficiently to indicate that they underwent some minor late movement. North of the Calliope vein, the Dexter fractures are barren or only weakly mineralized; also, the intensity of fracturing decreases in that direction. The only known reported production from the Dexter vein is about $69,000 for the year 1887.

Localization and Form of Ore Shoots

The beds adjacent to the Calliope vein were locally sharply flexed, evidently during formation of the main fracture, but in most places have only moderate to slight displacement. The Dakota Sandstone consists here of several alternating quartzite and shale layers, so that where the fractures pass through the shale interbeds in the raise above the Iowa Chief tunnel level, the wall rocks are sharply flexed and the vein is tightened, as shown diagrammatically in figure 33. The carbonaceous shale beds have been highly distorted, and comminuted shale appears locally to have been forcibly injected between the thinner quartzite layers.

The fractures tend to "roll" where they pass through the different rock layers, and at these rolls the fractures are split, so that at several places there are two roughly parallel veins (fig. 33), locally called the north and south veins. At the easternmost end of the accessible workings on the Iowa Chief tunnel level, there are two well-defined, south-dipping veins; according to notations on a few old mine maps, north and south veins also were indicated in the upper levels. It was not possible to determine if these veins were continuous between levels, but it is doubtful they were continuous for great distances either vertically or longitudinally from one part of the mine to another.

Clastic injections along the walls of the south vein on the Iowa Chief tunnel level consist of a highly silicified and indurated mass of quartzite and shale fragments. Just as in the Bachelor and Pony Express veins, these clastic injections were produced by explosive expansions of the pre-ore mineralizing fluids. Their effect in the Calliope vein, especially in and near the shale interbeds, was to plug the openings and locally divert the later ore-forming fluids to more open splits of the vein. Replacement ore in the clastic material or in the tight, shaly parts of the vein was commonly low grade.

The largest bodies of ore appear to have been localized beneath or in the porphyritic granodiorite body that was sufficiently competent to maintain open fractures above the Dakota Sandstone beds. The eastern limit of the upper orebody is assumed to mark approximately the contact between the Mancos Shale and the granodiorite body, as the configuration of the stoped block is somewhat similar to the surface exposure just south of the mine workings (pl. 5). More definitive conclusions about the localization of the ore cannot be made because the only accessible workings were the main levels and parts of the raise at the east end of the section shown on plate 5.

There is, however, a suggestion based on the mine workings (pl. 5) that the N. 85° E. strike of the fracture near the shaft (altitude 8,915 ft) at Mill Creek curves slightly toward the east to south of east, thus resulting in a more favorable trend of the vein. This curve in the strike, forming a south-facing concavity in the plane of the Calliope vein, may have been controlled to some extent by the local east-southeastward dip of the flexure, the S. 60° dip, and the small vertical displacement. Horizontal displacement of the fracture walls is not considered necessary to produce openings along the trend of the plane of the fracture, whereas vertical changes within it may have accounted for the more productive stretches along the vein.

Mineralogy of the Vein

Early ore produced from the Calliope vein was reported to consist of galena, brittle silver (stephanite), and native silver. Although it is possible that brittle silver may have been present in the near-surface ore, the silver-bearing samples obtained and examined from accessible lower workings consisted of tetrahedrite and polybasite associated with pyrite, sphalerite, chalcopyrite, and galena. The polybasite was found only in microscopic amounts. Tests identified both antimony and arsenic, the former predominating; a moderate amount of copper usually was detectable. Polybasite, or pearceite, was probably the principal silver mineral, the same as was found in the Bachelor and Pony Express veins. Where silver occurred in the upper levels, stephanite perhaps was formed and the ore there enriched in silver; the reported native silver was probably of supergene origin. Other than minor repetitions within the mineral sequence, ores of the Calliope vein, like those of the Dexter vein, had no unusual features. Quartz and a small amount of brownish rhodochrosite accompanied by pyrite and sphalerite were early in the paragenesis, followed by the principal introduction of chalcopyrite, tetrahedrite, and galena. The quartzitic wall rock of the Calliope vein was recrystallized and locally replaced by pyrite, sericite, and sphalerite; some late carbonate accompanied the introduction of galena. Both quartz and calcite formed late veinlets in the ore.

Newsboy Mine

Location, History, and Development

The Newsboy mine (fig. 21, no. 4) is a consolidation of the older Slide and Newsboy properties on the east side of the Uncompahgre River valley about 3.5 mi north of Ouray, between altitudes of 8,400 and 9,300 ft. The main productive zone of the mine was between the altitudes of 8,400 and 8,700 ft, in beds ranging from the base of the Entrada Sandstone upward through the Wanakah Formation into the lower part of the Morrison Formation. The Scotsman claim, oldest of the Slide group, was located in October 1880 and patented in 1883; the Slide and several other claims were patented in 1891. This property was worked profitably by Frank Butterfield until the slump in silver prices in 1893 that contributed to its shutdown (Rice, 1980, p. 7). The Slide group was sold in the 1890s to an eastern syndicate which formed the Slide Mining Co. M.S. Corbett, owner of the Newsboy claim, which included an extension on the main veins east of the end line of the Scotsman claim, started development higher on the slope in beds in and beneath the base of the Dakota Sandstone. This work failed to disclose sufficiently large orebodies to justify extensive operations. Later development of both properties was continued through the lower tunnels, and in 1900 or 1901, the properties were consolidated under the name of the Newsboy Mining and Milling Co. Details of the reorganization and development of the properties were not available for this report, nor were the properties investigated; production records prior to 1895 also were not available. It was reported that at times 15 to 30 men were employed on each property, and that an appreciable production of high- and low-grade silver-lead ores was made from both properties prior to consolidation.

There are three principal development tunnel levels (pl. 6): the lower or Emerson tunnel at an altitude of 8,445 ft, the Contact tunnel at 8,515 ft, and the Ward tunnel about 140 ft above the Contact tunnel. The lower tunnel, in the Entrada Sandstone, is about 2,700 ft long according to the records of Mineral Survey 17331, made in September 1904. The Contact tunnel is about 1,650 ft long according to the records of J.H. Tumbach, lessee, and the Ward tunnel is possibly 750 to 800 ft in length. A shaft sunk on the Newsboy claim by Corbett, 180 to 200 ft deep according to different records and in stratigraphically higher beds in about the middle of the Morrison Formation, reportedly failed to discover ore. About 400 to 500 ft of workings both in and just below the Dakota Sandstone opened only small bodies of ore. In addition to the larger tunnels, there are a few shorter tunnels or cuts both at intermediate levels and beneath the lower or Emerson tunnel. These include the 350-ft-long tunnel of the Army-Navy mine (fig. 21, no. 3), about 600 ft lower in beds in the Cutler Formation, which had a recorded production of 5 tons of ore valued at $1,091 (Steven and others, 1977, p. E75–E76).

The Newsboy Mining and Milling Co. continued mining and development for several years subsequent to consolidation, but in 1905 it was unable to meet expenses and a lease of the property was granted to Fred Herzinger. Herzinger's work was confined to extracting ore from the Contact tunnel level and reopening the lower Emerson tunnel. In 1906, he assigned this lease to J.H. Tumbach who, according to his report to the secretary of the company in 1909, extended the Contact level 228 ft during the term of the lease. Tumbach's additional development work above this level found a body of ore lying east of the old workings that extended up into the miners' "lower quartzite" bed. The extent of this work is shown on plate 6, but the position of the new workings is given relative to a 76-ft raise above and near the breast of the Contact tunnel as it existed when company work ceased, rather than relative to the tunnel portal; for this reason, the true position of the workings may be slightly different than as shown on plate 6. Tumbach reported that about 400 tons of ore were mined in the 1910s, which had an average value of $37.50 per ton after freight and treatment charges. He later extended one raise in an attempt to find a continuation of the ore shoot, but this development failed.

The uppermost mine workings, just below and within the Dakota Sandstone, failed to disclose appreciable bodies of ore, suggesting that perhaps the main ore channels in this part of the Uncompahgre mining district occur mostly lower within the basal and middle Upper Jurassic beds.

Production

Complete records of production for this mining property are not available; however, production estimates extend from $400,000 upward. With the exception of only a very few years, ore even in minor amounts was produced from 1895 to the early 1920s, and then sporadically into the early 1940s. According to Steven and others (1977, p. E75), the official recorded production from the Newsboy mine was 1,895 tons of ore valued at $71,595, but company records showed considerably more ore had been mined, as stated above.

Geology

As shown by Luedke and Burbank (1981) and on plate 6, the two principal veins of this group of mines are the southern or Newsboy vein and the northern or Scotsman vein. The Newsboy vein has an average strike of N. 83° E. and dips nearly vertical to steeply north. The Scotsman vein, evidently productive only in the westernmost workings, there dips 65°–85° S. toward the Newsboy vein. Both veins possibly may be splits from one main fracture at depth. West of and beneath the mine workings, the northern fracture within the Cutler Formation also is occupied by a fine-grained latite dike. In the now accessible few hundred feet of the westernmost workings, the most productive parts of both veins extend from the lower part of the Entrada Sandstone upward for somewhat more than 200 ft into the lower part of the Morrison Formation. In general, the most productive horizon was the “lower quartzite,” here a 25- to 35-ft-thick indurated quartzitic sandstone in the Tidwell Member at the base of the Morrison Formation. The formations dip only a few degrees to the east, so that the entire Contact tunnel is within the breccia beds in the Pony Express Limestone Member at the base of the Wanakah Formation (pl. 6). The most productive horizon of the veins was within these beds, owing to a tendency for the fracture to roll slightly and to the formation of bedding deposits in the permeable breccia. As shown on plate 6, both veins have rolled to the south, the Scotsman vein more so than the Newsboy vein. Toward the east the Newsboy vein was found to roll near the top of the “lower quartzite” bed and the ore was cut off sharply at this roll. In addition, according to Tumbach, the upward extension of the fracture was entirely lost in the eastern workings. A crosscut driven north from one of the raises within the Tumbach lease area (pl. 6) intercepted a fracture 52 ft north of the Newsboy vein above the “lower quartzite” bed. Tumbach believed this to be one of several parallel fractures, such as the Scotsman, but it was barren.

Several cross fractures, such as those shown near the portals of the tunnels, diagonally cut across the western part of the Newsboy vein (pl. 6). These cross fractures appear to have locally influenced distribution of the ore in the different rocks as noted previously in the Pony Express and Neodesha mines. Tumbach reported that one cross fracture about 1,400 ft from the portal of the Contact tunnel appeared to have cut off the main ore shoot above this level; his subsequent work found a small body of ore farther east. In the lower or Emerson tunnel, it was reported that ore was mined both east and west of this same cross fracture in the Entrada Sandstone. The vein ranges from a few inches to several feet in width, averaging less than a foot; the ore was of higher grade than that found along the bedding channels or rolls.

Where the fractures rolled in and near the Pony Express beds, the bending and resultant fracturing of the beds tended to widen the zone of fractured and mineralized rock. In addition, the ore “made out” into the limestone breccia beds from 15 to 20 ft or more from the main fractures; however, within the accessible mine workings extending inward for about 400 ft, the width of ore in the flat part of the channel was less.

Mineralogy

Ore in the Newsboy vein consisted primarily of pyrite, sphalerite, galena, tetrahedrite, and chalcopyrite in a gangue of barite and quartz. Associated with the tetrahedrite was a small amount of the silver-bearing minerals polybasite or pearceite, or both, containing antimony, arsenic, and a trace amount of copper as determined by microchemical tests. Ankerite, manganocalcite, and calcite were the common carbonate minerals recognized. Within the mineral sequence, pyrite and sphalerite were deposited first; galena accompanied and followed barite. Polished sections of the ore show that these early minerals were locally veined by late chalcopyrite and tetrahedrite. Still later, covellite and chalcocite, evidently of supergene origin, were formed in the ore nearer the surface. However, other than for ore mined near the surface, secondary enrichment appeared to have been negligible. Quartz, sericite, ankerite and some barite constitute the earlier formed gangues, and in places preceded the bulk of the sulfides. Quartz and barite, however, also formed late in cavities in the ore, especially along the main bedding channel. Sericite was associated mostly with the pyritic ore. Limestone breccia and sandstone beds were more intensively silicified, particularly near the better grade ore. The most common oxidation products of the minerals, found in the bedded deposits as much as several hundred feet from the surface openings, were limonite, malachite, azurite, and manganese oxides.

Señorita Mine

Location, History, and Development

The Señorita mine (fig. 21, no. 1) is about 4 mi north of Ouray on the east side of the Uncompahgre River valley, at an altitude of about 8,600 ft. Like the Newsboy and Black Girl (fig. 21, no. 2) mines, the principal or only important ore zone lies in the Jurassic rocks extending upward from the Entrada Sandstone into the lower part of the Morrison Formation. Little historical information is available concerning this property. According to Rice (1980, p. 7), the property had various owners over the years including A.W.F. Warde, who “…made a living but never grew wealthy;” his daughter, Mrs. Huffnagle, of Ridgway (fig. 1), inherited the property and granted a number of leases over the years. All of the mining activities apparently were limited. Three development tunnels are shown on plate 7, but only the main or intermediate level in the breccia beds of the Pony Express Limestone Member of the

Wanakah Formation was examined in detail during this study. This tunnel is at an altitude of 8,589 ft and extends about 770 ft eastward along the mineralized zone.

Production

Prior to 1900, ore was reported to have been mined in 1893 from the large stope in the limestone and breccia beds of the Pony Express Limestone Member that extends from 200 to 365 ft east of the portal (pl. 7), and the ore mined had a value of $40,000 or $50,000. Production was sporadic after 1900 but continued to the 1960s.

Geology

The Señorita vein consists of a series of discontinuous mineralized fractures, strikes almost due east, and dips steeply north. Where the fractures cut the Pony Express beds, the roll is gently downward toward the north (pl. 7), opposite in direction to that of the more steeply-dipping rolls in the veins in mines to the south. Regionally, the strata dip gently north away from the San Juan uplift, and as exposed within the mine workings, which are on the east side of the Uncompahgre axis, have little or no eastward tilt. The beds, however, have minor warps where the roll's trend was intersected by cross fractures and minor faults. The larger orebodies were localized at the level of the roll along the limestone and breccia beds of the Pony Express Limestone Member, but the steeper part of the fractures below and above this level locally contained vein deposits.

Within the "lower quartzite" (in the Tidwell Member) at the base of the Morrison Formation where seen in the upper tunnel level, the Señorita vein strikes N. 80°–85° E. and dips 68° N. The ore there consisted of galena and barite similar to that found in the intermediate-level workings, but the vein was much narrower.

The lower tunnel, which is mostly in morainal debris, was not examined. Fractures within the Cutler Formation below this level are relatively weak and difficult to trace westward. About 2,000 ft west of the mine, in a lower cliff exposure, there is a fracture that strikes about N. 78° W., parallel to the lower tunnel, and dips nearly vertical; this fracture contains a few quarter-inch-thick stringers of barren quartz and barite, but the north side was displaced down about 7 ft. Parallel to and about 90 ft to the south of this fault, there is a zone of vertical calcite stringers. Still farther to the west, this break was not seen in outcrops of the Cutler Formation.

On the steeper slope of the hill above and east of the mine, moderate soil cover, dense piñon-juniper forest, and local slide debris obscure any possible extension of the Señorita vein; a few hundred feet above the mine is a large landslide mass composed of the Dakota Sandstone and San Juan Formation. It is doubtful that the vein extended upward and eastward or was mineralized. Furthermore, the history of development of other mines in this area (known locally as Carbonate Hill or Newsboy Hill) suggests that the only productive part of the Señorita fracture zone was along, just above, and mostly below the base of the Morrison Formation. The ore channel thus had a comparatively short vertical extent and, similar to the other ore channels in this area, followed the inclination of the beds for an indefinite distance to the east. The sources of the ore fluids evidently lay toward the east, as suggested by the regional distribution of ore deposits in the mining district.

Plate 7 illustrates, by position of the larger stopes, the localization of the ore mainly in beds of the Pony Express Limestone Member of the Wanakah Formation but also in the overlying Bilk Creek Sandstone Member and in the underlying Entrada Sandstone. Fractures above the line of the roll tended to feather-out locally, but did not contain sufficient ore to warrant stopes between the main and upper levels. Ore in the Entrada Sandstone, however, was of high-grade tetrahedrite type and locally was stoped along the vein for 15 to 20 ft below the main level. The productive part of the vein was narrow, being commonly less than a foot in width, although the enclosing sandstone was silicified and locally impregnated with sulfides near the vein walls. The vein matter was barite and quartz with some tetrahedrite and other sulfides. These features are similar to those reported for the vein in the Black Girl mine to the south, where the high-grade tetrahedrite ore also was found mostly along the vein within the Entrada Sandstone.

Along the roll, the ore impregnated the limestone breccia in the Pony Express Limestone Member for a maximum width of 25 to 30 ft. For the entire width and length of the workings shown on plate 7, the breccia (fig. 25*B*) was silicified and small vugs were lined with quartz, barite, and calcite crystals as well as with scattered crystals of sulfide minerals. In the breast of the tunnel, ore in the roll was evidently of a lower grade than that taken from the western stope at this horizon; it also was very siliceous but did contain some barite. Massive barite and some associated ankerite, partly oxidized, were exposed along the down dip of the roll, and where the beds were brought up to the level of the drift, the minerals were deposited in the highly silicified Entrada Sandstone. This contact suggests that some disturbance separated the two stages of mineralization; the baritic ore contains fragments of the silicified material. This may have resulted either from renewed movement along the fracture zone or from local slumping of the beds incident to processes of hydrothermal leaching and development of cavities. In the silicified rocks in the face, there are impregnations and small veinlets of quartz, chalcopyrite, and tetrahedrite. Galena and some sphalerite were associated with the baritic ore; this ore is said to average 4 or 5 oz of silver. The bulk of the deposit contained sparse sulfide minerals.

Mineralogy

Microscopic examination of polished sections of the ore reveal no common hypogene minerals other than those that can be recognized with the naked eye, except for minute blebs of polybasite or pearceite with the tetrahedrite. Some minute crystals of pyrite were embedded in some of the chalcopyrite and also were associated with sphalerite. Microscopic relations suggest the galena crystallized late, supporting the concepts noted elsewhere in the mine. The ore contained a little covellite and chalcocite. Barite and quartz were intergrown with all the sulfide minerals, which other than pyrite, had grown on barite or quartz crystals in drusy cavities of the ore. The associated carbonate minerals include some ankerite, manganocalcite, and rhombohedral and scalenohedral calcite. Even near the breast of the workings, the manganiferous carbonates have been oxidized to brownish or blackish sooty oxides of iron and manganese, especially in the more porous or vuggy parts of the ore throughout the mine.

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