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STRUCTURAL CONTROL OF ORE DEPOSITION IN THE UNCOMPAHGRE DISTRICT OURAY COUNTY, COLORADO

WITH SUGGESTIONS FOR PROSPECTING

BY

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STRUCTURAL CONTROL OF ORE DEPOSITION IN THE UNCOMPAHGRE DISTRICT, OURAY COUNTY, COLO.

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ABSTRACT

The Uncompahgre mining district, covering about 15 square miles in Ouray County, southwestern Colorado, lies at the western margin of the San Juan Mountains. The geologic formations range from pre-Cambrian to Tertiary in age. They comprise a basement series of sedimentary rocks upturned and deformed along the margins of ancestral mountain uplifts of late pre-Cambrian, late Paleozoic, and late Cretaceous or early Eocene age. All the deformed sedimentary rocks were beveled by erosion in early Tertiary time, and middle to late Tertiary volcanic rocks were deposited on them. The pre-Cambrian rocks include about 8,000 feet of quartzites and slates, and the Paleozoic and Mesozoic rocks about 5,000 feet of limestones, sandstones, and shales. The basal volcanic rocks near the district are chiefly andesitic tuff-breccia, which is overlain by lava flows, and the entire volcanic group is nearly a mile thick. The volcanic formations were only slightly tilted and faulted in late Tertiary time.

The principal ore deposits are associated with cross-cutting and laccolithic intrusions of granodiorite or quartz monzonite porphyry of late Upper Cretaceous or early Eocene age. The ores were deposited chiefly in the Paleozoic and Mesozoic sedimentary strata through a stratigraphic range of about 4,500 feet and lie beneath the early Tertiary unconformity, which in places truncates some of the uppermost early Eocene(?) deposits. There are also younger ore deposits of late Tertiary age mainly in the overlying volcanic formations but also to a lesser extent in the sedimentary rocks near the south margin of the Uncompahgre district. The deposits of the older Uncompahgre center of eruptive activity, which are considered in most detail in this report, have an estimated production of $10,000,000 to $12,000,000.

The ore bodies of the Uncompahgre center range from contact-metamorphic deposits of low grade, through pyritic base-metal deposits containing silver and gold tellurides and native gold, to silver-bearing lead-zinc deposits. These are zoned about the center of eruptive activity.

Ore deposition about the Uncompahgre center is largely governed by structural trends and axes of uplift established mainly in the late Paleozoic period of deformation, but also in part by structure lines established in late pre-Cambrian time. These older structural movements were renewed and accentuated during the late Mesozoic or early Tertiary deformation at the time of the igneous intrusions. There are two main structural axes in the district, a north-northwesterly axis of uplift, called the Uncompahgre axis, which extends outward from the margin of the mountains, and an intrusive axis of northeasterly trend, which parallels that of the Mesozoic and Paleozoic mountain uplifts north of the district. The two axes cross near the center of eruptive activity and divide the district into four

structural divisions within which conditions of mineralization vary in accordance with their relation to the structural axes and to the intrusive center.

The sources of the ore-forming solutions lay along the northeasterly intrusive zone and appear genetically related to the igneous rocks. The solutions evidently rose from depth along the line of the intrusive zone, and then moved outward laterally in the sedimentary formations in paths that generally conformed to the dip of the strata and towards the Uncompahgre axis of uplift. Along the Uncompahgre axis the solutions gained access to shallow tensional breaks that permitted their escape more directly upwards again towards the surface. Most of the channels of mineralization along the bedding of the sedimentary rocks and in fissures have an eastward trend or one somewhat diagonal to this, controlled in general by predominant directions of fissuring or flexing of the rocks.

The contact-metamorphic and most of the pyritic gold-bearing deposits lie in the central parts of the district within a mile or so of the crossing of the axes and of the position of the main cross-cutting eruptive vent. The silver-lead-zinc deposits lie from 1 to 4 miles from the crossing of the axes and are found chiefly in the northern and southern divisions of the district. Inasmuch as the bulk of the solutions that formed this class 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 divisions of the district do not contain appreciably large deposits of silver-lead-zinc ore. The ore deposits include both tabular bodies and shoots of less regular shape that lie more or less conformably with the bedding and fissure deposits. In many places different forms of deposits are closely associated.

Suggestions for prospecting in each of the four divisions are based on the varying conditions of mineralization, which are controlled by nearness to the intrusive contacts, nearness to zones of shallow tensional fissures, prevailing directions of faults, folds, and fissures in the sedimentary rocks, and the permeability and other favorable physical or chemical properties of the rocks.

It is concluded that the northern and southern divisions of the district are in future exploration the most likely to yield discoveries of new ore channels and to disclose the longer extensions of ore channels already known. The largest and highest grade deposits, most of which are in the northern division of the district, have already been either partly developed or nearly exhausted. This is a consequence of the fact that these higher grade deposits lay in a zone close to the Uncompahgre axis of uplift and that the canyon of the Uncompahgre River, which follows the line of this axis, has exposed the mineralized rocks to the best advantage for mining operations. Future prospecting consequently will be directed mostly towards the sources of the solutions and away from the Uncompahgre axis into zones in which higher temperature mineralization prevailed and lower grade deposits were formed.

The ore deposits of late Tertiary age are chiefly silver-lead-zinc veins in the volcanic formations, and their centers of mineralization lie either to the south or to the east of the Uncompahgre district. The sedimentary rocks along the south margin of the district also enclose a few deposits of late Tertiary age, but in general the younger veins are absent in the northern parts of the district where the older sedimentary rocks are much thicker.

Structural control of ore deposition about the Silverton center is briefly reviewed, and the principles are applied to deposits in the southern part of the Uncompahgre district. A few deposits related to the Cow Creek center east of the district are mentioned.

INTRODUCTION

A revision of the structure and stratigraphy of the Uncompahgre mining district, a restricted division of the larger Ouray district, was published in 1930 after two seasons of field work near Ouray and in the mountains to the southwest.[1] Since that time the base map of the Uncompahgre area has been extended to the north and east, the geologic field work has been completed, and a final report is nearing completion. In order that the practical results may be made available, particularly those bearing on structure and its control of ore deposition, the condensed conclusions are published here in advance of the final report. The revised geologic map cannot be published at this time, but an outline of the main structural features is indicated on plate 53, which is on the same scale as the Ouray folio map [2] and hence may be used in conjunction with it as an oversheet.

The localities of special interest that will be referred to repeatedly in this report are shown in figure 32, which gives the general geologic setting of the Uncompahgre district and shows its geographic and geologic relations to other districts in the region. The Uncompahgre district differs from the others near it in that it contains deposits that are related largely to a late Cretaceous or Eocene center of mineralization and also to centers of late Tertiary mineralization, whereas the others are related only to the late Tertiary centers. The center of late Cretaceous or early Tertiary mineralization is closely associated with the center of laccolithic intrusion and local uplift, which extends throughout the Uncompahgre district but is partly concealed by late Tertiary volcanic rocks. The centers of late Tertiary mineralization include the Silverton center and the Cow Creek center. Local districts related to the Silverton center and of particular interest in this report are the Mineral Point and Poughkeepsie Gulch district, Red Mountain, Telluride-Sneffels, Hayden Mountain, and Eureka. Other districts related to the late Tertiary centers and shown in figure 32 are the Mount Wilson, Ophir, and Lake City districts. Districts not shown in the figure include the Arrastra Basin and Cunningham Gulch districts near Silverton.

The Uncompahgre mining district in Ouray County, Colo., at the western border of the San Juan Mountains, as restricted in this report, covers an area of 15 to 20 square miles along the Uncompahgre River canyon and its tributaries. The principal ore deposits in the Paleozoic and Mesozoic sedimentary formations were formed in late Upper Cretaceous or early Tertiary time. Associated intrusive igneous rocks are represented by early Tertiary erosion remnants of a laccolithic mountain group and by underlying crosscutting intrusions.

1 Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc. Proc., vol. 12, No. 6, 1930.

2 Cross, W., Howe, E., and Irving, J. D., U. S. Geol. Survey Geol. Atlas. Ouray folio (No. 153), 1907.

The ore deposits and their enclosing rocks are overlain uncomformably by middle to late Tertiary volcanic formations and are now exposed only along and near the deep canyons of the Uncompahgre River system where it emerges from the mountains onto the Colorado plateau.

The San Juan Mountains, ranging in altitude from 9,000 to 14,000 feet, are composed mainly of a series of mid- to late-Tertiary volcanic breccias, flows, and intrusive rocks that accumulated to an original

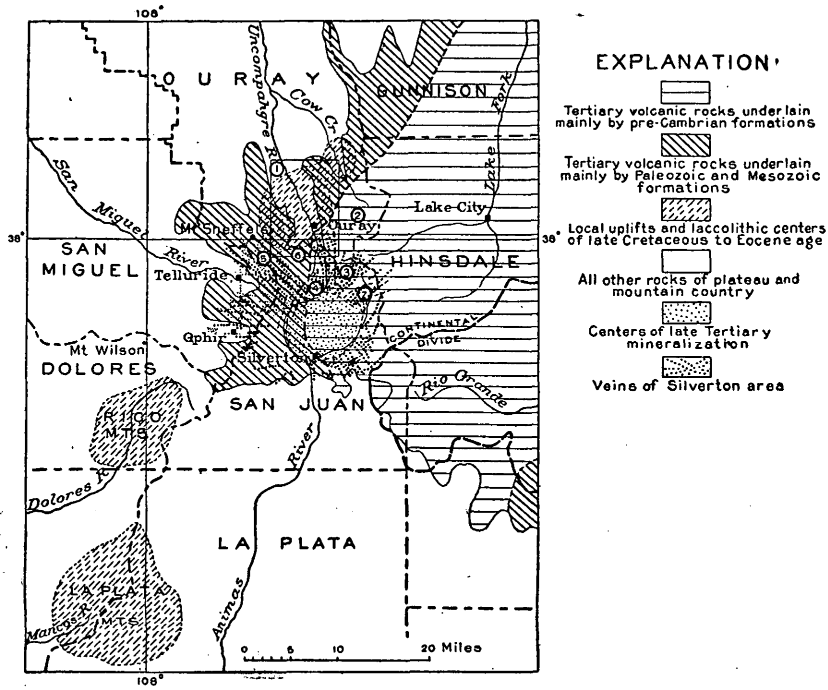


FIGURE 32.—Index map of the Uncompahgre district and western San Juan Mountains. 1, Area included in structure map of Uncompahgre district, plate 53; 2, Cow Creek volcanic center; 3, Mineral Point and Poughkeepsie Gulch; 4, Red Mountain; 5, Telluride-Sneffels; 6, Hayden Mountain; 7, Eureka district.

thickness of a mile or more.[3] In the main central parts of the mountains these volcanic rocks rest directly upon a pre-Cambrian basement composed of granite, schist, and sedimentary rock, but in a peripheral zone around the western border these rocks are underlain by outward-dipping sedimentary rocks of Paleozoic and Mesozoic age (fig. 32). In places within this peripheral zone the basement rocks are sharply deformed and faulted, but in the plateaus west of the mountains they are for the most part only slightly tilted or faulted. The relations of the different formations near the mountain borders indicate that the mountain uplift has had a complex geologic history and that ancestral ranges were partly conformable with the present

[3] Cross, W., and Larsen, E. S., A brief review of the geology of the San Juan region of southwestern Colorado: U. S. Geol. Survey Bull. 843, pp. 50–91, 1935.

outline of the group in both late Paleozoic and late Mesozoic time. In comparatively recent times the large rivers rising in the mountains have cut deep canyons and thus reveal the relations between the older and younger mountain structure. Along the Uncompahgre River near Ouray the rocks are exposed for a depth of more than a mile beneath the surrounding summit level of the younger mountains. Three major erosion surfaces separating important geological and structural units may be recognized in the Uncompahgre district: (1) between the Paleozoic and pre-Cambrian formations, (2) between the Mesozoic and Paleozoic formations, and (3) between the Mesozoic and Tertiary formations. Of these the third, which may be called the Telluride erosion surface, is the most significant with respect to the ore deposits of the region, for the period of mineralization represented by the principal deposits of the Uncompahgre district took place shortly before the development of this surface. The Tertiary volcanic eruptions, however, were followed by a second period of mineralization, which has affected both the older and younger rocks, so that deposits of both epochs are to be found in the same rocks in places near the Uncompahgre center. The problem of distinction between the deposits of the two epochs is simplified by the fact that the Uncompahgre center is not close to the main centers of late Tertiary mineralization and that the bulk of the younger deposits are found in the volcanic formations. The Uncompahgre ore deposits are distinguishable however, by means of their general structural relations to the pre-Telluride center of intrusion and deformation, or by the more direct evidence of their truncation by the erosion surface.

The late Tertiary areas of mineralization cover several hundred square miles adjacent to Ouray, Telluride, Silverton, and Lake City (fig. 32). One center lies between Ouray, Silverton, and Telluride, and another west of Lake City. These younger deposits in the volcanic rocks have yielded the bulk of the mineral production of the western San Juan Mountains, and, since 1870, they have produced in excess of $250,000,000; however, the younger veins considered in this report have been productive only to a minor degree, as they lie in the outermost zone of productivity. Deposits of the Uncompahgre district belonging to the older period of mineralization have had an estimated total production since 1870 of nearly $12,000,000. The exact production is not known, because the early records are incomplete and segregation of the county production records according to this age grouping can be made only for the period since 1900. Suggestions for prospecting the deposits of the older epoch of mineralization in each of the structural divisions of the district are included to illustrate the nature of typical problems within each division rather than to represent results of an exhaustive consideration of the possibilities of individual prospects. An appraisal of the relative economic feasibility of the explorations, therefore, is not the first consideration and moreover is outside the proper field of this report; however, it may be emphasized that the Uncompahgre district is one of small magnitude—less than $15,000,000 in total production and known reserves—and that chances are small that new discoveries will very much change its economic status.

STRATIGRAPHY

The bedded geologic formations of the district and comparisons of nomenclature that has been used are given in the table on pages 195, 196. The nomenclature in this report is essentially the same as that in the preliminary report referred to above, except for the restriction of the name Ouray limestone to the dolomitic limestone beds of Upper Devonian age [4], the introduction of the name Leadville limestone for beds containing Mississippian fossils that lie just above the Ouray, and the use of the name Lower La Plata sandstone of miners for the lower member of the La Plata sandstone of Cross and others. The stratigraphic limits of the Upper Jurassic Morrison formation are based upon correlations with the section in Utah as made by Baker, Dane, and Reeside.[5]

The local subdivisions of the Morrison formation were made by the writer.

[4] Kirk, E., The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, p. 224, 1931.

[5] Baker, A. A., Dane, C. H., Reeside, J. B., Jr., Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183, pp. 21-24, 1936.

Bedded formations of the Uncompahgre district

	Age	Names used by Cross and others in Ouray folio, No. 153, 1907	Names used locally	Names used in this report	Thickness (feet)	Character
Tertiary.	Miocene (?).	San Juan tuff.	San Juan or andesitic breccia of miners.	San Juan tuff.	1,800–3,000	Chiefly andesitic and latitic volcanic debris. Near the base is well stratified tuff, in part conglomeratic. Tuff-breccia in upper part.
	Oligocene (?).	Telluride conglomerate.	Telluride conglomerate.	Telluride conglomerate.	0–50	Mostly a coarse conglomerate containing pebbles and boulders of granite, schist, quartzite, porphyritic igneous rocks, and Paleozoic and Mesozoic sedimentary rocks. Locally thin limestones and shales.
Mesozoic.	Upper Cretaceous.	Mancos shale.	Mancos shale.	Mancos shale.	0–1,200	Dark gray marine shale with thin beds of limestone. Basal beds, a foot or less in thickness, of pebbly texture, phosphatic, with chert and sandstone pebbles, and shark teeth.
		Dakota sandstone.	Upper or Dakota quartzite of miners.	Dakota (?) sandstone and quartzite.	135–150	Gray or rusty brown quartzose sandstone with shale partings, and locally carbonaceous shales in middle and upper part. Basal sandstone contains chert pebbles. Beds altered to quartzite in areas of strong mineralization.
	Upper Jurassic.	McElmo formation.	McElmo formation.	Shale member of Morrison formation.	350–400	Mostly variegated shales, with green colors predominating except where altered; also red and brown shales and yellowish to gray sandstones. Near top sandstone beds contain chert pebbles like those in basal Dakota (?) sandstone.
			Lower quartzite of miners (25 to 30 feet only).	Sandstone member of Morrison formation.	250–300	White or gray sandstones interbedded with red-brown and green shales, and thin limestones. Basal sandstone 25 to 30 feet thick, locally altered to quartzite, and constituting the lower quartzite of miners.
		La Plata sandstone.	Upper La Plata sandstone. Pony Express limestone or contact of miners.	Wanakah member of Morrison formation.	85–125	Divisible into three units; the basal unit a dark bituminous shaly limestone, overlain by limestone breccia derived from disintegration of gypsum-limestone complex; constitutes Pony Express beds of miners. The middle unit a sandstone, soft and friable, with clayey layers near top; mostly even-bedded; constitutes Upper La Plata sandstone of local use. Upper unit chiefly green and brown shales, with green sandstone locally at base; thin beds and lenses of limestone; widespread layers of chert beds near top.
			Lower La Plata sandstone of miners.	Lower La Plata sandstone of miners.	45–80	Very massive friable white sandstone, distinctly cross-bedded in upper part; cliff-forming; more even bedded in lower part, with layers of coarse and fine grains.
	Jurassic (?) and Upper Triassic.	Dolores formation.	Dolores formation.	Dolores formation.	40–100	Fine-grained bright-red sandstones, sandy marls, and shales. Contains beds of limestone pebbles or pebble-conglomerate. Locally quartzose pebble beds near base.

Bedded formations of the Uncompahgre district—Continued

Age		Names used by Cross and others in Ouray folio, No. 153, 1907	Names used locally	Names used in this report	Thickness (feet)	Character
Paleozoic.	Permian.	Cutler formation.	Cutler formation.	Cutler formation.	0–2, 100	A series of bright-red sandstones, pinkish grits, and conglomerates, alternating with sandy shales and earthy reddish limestones.
	Pennsylvanian.	Hermosa formation.	Hermosa formation.	Hermosa formation.	1, 400–1, 600	Near base greenish sandstones and dark marine shales with thin interbedded fossiliferous limestones. The middle and upper parts contain thick beds of arkosic grits with interbeds of shale and limestone.
		Molas formation.	Molas formation.	Molas formation.	40–60	Red calcareous shale and sandstone with pebbles of quartzite and chert and interbedded conglomeratic layers containing many chert pebbles. Also pebbles of underlying Mississippian limestone.
	Mississippian.	Ouray limestone.	Ouray limestone.	Leadville limestone.	180–230	Lower part predominantly dark-blue-gray or brownish-gray limestone, with sandy layers near base. Upper part mostly coarser-textured clastic limestone with interbeds of reddish shale. Locally, thin bedded cherty and ferruginous limestone at top.
	Upper Devonian.			Ouray limestone (dolomite).	65–70	Mostly gray, buff, white, fine-textured dolomite or dolomitic limestone; layers of pinkish clastic limestone with Upper Devonian fossils locally.
		Elbert formation.	Elbert formation.	Elbert formation.	35–50	Thin-bedded buff dolomitic limestones, with interbedded sandstone, and calcareous shale.
Pre-Cambrian.		Uncompahgre formation.	Uncompahgre quartzite and slate.	Uncompahgre formation.	5, 000–8, 000	Massive to thin-bedded quartzite with minor shale partings; in wide bands alternating with slate or shale bands. Quartzites, white, pink, and brownish to dark-gray; slates and shales or schist layers, rusty-brown or black.

SUMMARY OF GEOLOGIC HISTORY AND DEFORMATION

The geologic history of the western San Juan Mountains is characterized by four major periods of deformation that in general represent the closing epochs of the four major divisions of geologic time. The lines of the pre-Cambrian structure are known only in fragmentary form near the Uncompahgre district, but beginning with the late Paleozoic deformation the succeeding lines of deformation tended in part to follow those of the earlier. In general also the intensity of deformation decreased in the successive periods, although the greatest changes in form and intensity were between the late pre-Cambrian and the late Paleozoic. The pre-Cambrian formations were deformed in at least two periods and intruded by large bodies of granitic rocks, but only a last period of compression and close folding is represented in the district. This is the only period of strong compression to which the rocks of the district were subjected, for the succeeding periods of deformation were characterized chiefly by vertical uplift or by doming accompanied by the production of typical monoclinal folds, tilted strata, and faults. The later Tertiary deformation shows the structural types characteristic of volcanic activity. Igneous activity, which was at a minimum or nonexistent in the late Paleozoic, increased in Mesozoic and Tertiary time and culminated in widespread fragmental eruptions, effusions of lava, and intrusions accompanying stocks in late Tertiary time.

The history of deformation, especially with reference to the Uncompahgre district and its vicinity, may be summarized as follows:

Pre-Cambrian.
- Compression and close folding of strata forming pre-Cambrian ranges.
- Intrusion of diabase or lamprophyre dikes.
- Peneplanation prior to deposition of Paleozoic sediments.

Late Paleozoic.
- Ancestral domal uplift of San Juan Mountains with local subordinate radial axes of uplift in Uncompahgre district. Development of Ouray fault and monoclinal folds.
- Peneplanation prior to deposition of Mesozoic sedimentary strata.

Late Mesozoic and early Tertiary.
- Renewal of domal uplift of mountains, following in part lines of ancestral uplift, but with westward extension of uplifted area.
- Intrusion of granodiorite porphyry and related rocks forming laccolithic intrusions at margin of the uplift (Uncompahgre center).
- First period of mineralization (Uncompahgre center).
- Development of the Telluride erosion surface.

Tertiary.
- Deposition of the Telluride conglomerate on parts of Telluride erosion surface.
- Eruption of San Juan tuff and other volcanic formations.
- Development of late Tertiary volcanic centers, including the Silverton caldera, with intrusion, faulting, and local tilting. Probably coincident with regional tilting of the major San Juan Mountain block.
- Late Tertiary period of mineralization following or concurrent with above.

Minor postmineral deformation, glaciation, and recent erosion of mountains to their present form.

The sharp swing in the trend of the late Paleozoic uplift from nearly north, south of Ouray, to N. 35°–40° E., north of Ouray (fig. 32 and pl. 53), is probably one of the more significant of the major structure lines in reference to their bearing on the local structure of the Uncompahgre center. This structure line is shown in a general way on figure 32 by the dashed boundary between the pre-Cambrian basement and the outward-dipping Paleozoic and Mesozoic rocks. The boundary is concealed in large part beneath the volcanic rocks and represents essentially the truncation by the Telluride erosion surface of the contact between the pre-Cambrian and Paleozoic formations. The concealed parts of the contact are represented by nearly straight lines connecting the exposed contacts because at most places where the structure is exposed there is a narrow zone in which the beds dip sharply away from the pre-Cambrian core of the mountains. This zone in the Uncompahgre district is 2 to 3 miles wide (pl. 53, sec. *A–A′*), and within this distance the Paleozoic formations rise nearly 4,000 feet as a result of the late Paleozoic uplift. Where the change in trend occurs in the Uncompahgre district (pl. 53) a radial axis of uplift crosses the southern part of the district diagonally from southeast to northwest, forming a northwestward-plunging anticlinal nose in the Paleozoic formations (axis *P–P′*, pl. 53). With the renewal of uplift in late Mesozoic time the radial axis was reactivated, but in the form of a more gentle arching of the exposed rocks, as represented in cross section *B–B′* and by the axis *M–M′*, plate 53. The zone of peripheral deformation of the sedimentary mantle, however, was extended for 8 miles or more from the exposed edge of the pre-Cambrian core, and the sharpest uplift was formed at the north end of section *A–A′* where the strata plunge steeply towards the northwest. For convenience the axial line of the structural features of different ages represented by the radial uplifts and by associated parallel fissuring and faulting will be referred to as the Uncompahgre axis from its coincidence with the local trend of the Uncompahgre Valley.

The zones of monoclinal folding and faulting have likewise undergone successive periods of deformation. This succession of disturbances is illustrated by the Ouray fault and by other faults nearby that lie in the pre-Cambrian basement and may represent lines of weakness that originated in pre-Cambrian time. The greatest recognizable movement along the Ouray fault line occurred in late Paleozoic time. It involved in some places a sharp monoclinal folding of the Paleozoic limestone, and in others a dip-slip of about 600 feet as shown by the beds that abut against the pre-Cambrian mass. With renewal of uplift in late Mesozoic time the fault zone was reactivated with a resulting reflection of the fault line in the overlying Mesozoic formations by a zone of minor flexing and faulting, across which there is very little net displacement. At the same time the faults that parallel and coincide with the axis of the pre-Cambrian syncline south of the Ouray fault were also reactivated, and the sedimentary rocks overlying the synclinal trough of pre-Cambrian slate were locally warped or faulted. These features are illustrated by cross sections in plates 53, section *A–A′*, and 54, *E* and *F*. Two of these sections cross the line of the Uncompahgre axis, and the net effect of the different periods of deformation is to tilt the beds increasingly away from the axis, commonly more sharply on the east side than on the west. The effect of tension on the crest of the arch may perhaps be indicated by the slumping of the overlying beds towards the slate core of the pre-Cambrian syncline on both limbs, as shown in plate 54, *E* and *F*.

The term "flexure" is applicable to many of the different kinds of deformation resulting either from combined faulting and folding or from local irregular slumping and tilting of the strata. It will be used in this sense in preference to the more specific terms "monoclinal fold" and "structural terrace" and in contrast to the unmodified term "fold" that is ordinarily applied to structural features produced by compressive stresses. The flexure is commonly independent of other similar nearby features, as it is produced by local forces, which in this district have been applied in steeply inclined directions.

The northeasterly trend of the Paleozoic and Mesozoic uplift north of the latitude of Ouray may also have influenced the development of another major structural trend of the Uncompahgre district in late Cretaceous or early Eocene time. This trend is represented by a northeastward-trending zone of dikes and the associated feeding channel of the laccolithic bodies just north of Ouray. The dikes and fault lines of this zone have not been differentiated on plate 53 for simplification of the structure map but are exposed for a distance of about 3 miles. This zone is referred to as the intrusive axis and parallels the line *I–I′*, which denotes its southeast boundary. Parallel to it on the north are several minor flexures that are reverse with respect to the principal monoclinal folds that parallel the margin of the uplift, as they either dip southward or in some degree have modified the regional tilt of the formations away from the mountains. The two principal flexures of this kind are represented in plate 54, *A* and *B*, and in plate 53, section *A–A′*. These flexures are believed to be approximately correlated in their time of development with emplacement of the intrusive rocks, but whether the flexing has resulted from local subsidence brought about by movements of the intrusive magma or from a minor settling of the mountain uplift as a whole cannot be demonstrated. Some evidence, however, favors the second suggestion.

The intrusive rocks, which consist of dikes, sills, laccoliths, and small plugs or necks, are divisible into two principal groups. Most of the dikes, sills, and laccolithic masses center about a neck or small stock just east of the Uncompahgre Valley near the junction of the intrusive axis and the Uncompahgre axis. The small neck together with some of the larger connecting dikes clearly represents the feeding channels for at least some of the laccolithic bodies that spread out above at the horizon of the Mancos shale and together formed a composite laccolithic dome. The original extent of this laccolithic dome cannot be entirely reconstructed because of the extensive erosion during the formation of the Telluride erosion surface. Some of the laccolithic bodies, however, now stand above the general level of this surface as erosion remnants or monadnocks.

A second group of intrusive rocks occupies a series of eastward-trending fissures in the northern part of the district (see pl. 53). These rocks are mostly dikes, but a few narrow plugs are represented along the trend lines of the dikes.

Slight renewals of movement along some of the fault lines occurred in late Tertiary time after the burial of the older rocks beneath the volcanic formations, but in general, as may be seen from plate 53, section *A–A′*, the Telluride erosion surface and the San Juan tuff that overlies it have been only slightly deformed in this area.

ORE DEPOSITS

DISTRIBUTION AND METAL CONTENT

LATE CRETACEOUS OR EOCENE DEPOSITS

The ore deposits of late Upper Cretaceous or Eocene age surround the Uncompahgre center of eruptive activity. Deposits that are definitely correlated with this period of mineralization extend from the vicinity of Ouray northward to Cutler Creek, a distance of 4 or 5 miles, and eastward from the Uncompahgre Valley for at least 2 or 3 miles. A fringe of deposits extends along the west side of the valley, but the intensity of mineralization decreases more abruptly westward than eastward. The deposits that extend for about 2 miles southward from the intrusive axis on both sides of the Uncompahgre Valley have not been so productive as those of the northern area. The central productive area represented by several large groups of deposits, such as those of the American Nettie and Bachelor mines, covers about 4 or 5 square miles northwest of the intrusive axis and east of the Uncompahgre Valley.

On the basis of their metal content the ores may be divided into four groups: (1) magnetite-pyrite ores containing a little copper and

LIST OF MINES AND PROSPECTS OF THE EARLY TERTIARY EPOCH (UNCOMPAHGRE)

NORTHERN DIVISION

1. Wanakah (Bright Diamond, Iron Clad, and others.
2. American Nettie group.
3. { Great Western. / Mayflower tunnel.
4. Memphis.
5. Pony Express.
6. Bachelor, Wedge, Neodesha.
7. El Mahdi.
8. Calliope (Dexter, Iowa Chief).
9. Little Eva (?) and others.
10. Black Silver, Champion.
10a. Ely tunnel.
11. Newsboy, Slide, and others.
12. Black Girl.
13. Senorita.
14. Plezy.

WESTERN DIVISION

15. Grey Eagle, Speedwell.
16. { Rock of Ages. / Grand View.
17. { Plutus. / Sampler.
18. Morning Star.
19. Stenographer.
20. Teller.
21. Red Rose, Gem, Float, Queen of Ouray, and others.

SOUTHERN DIVISION

22. Mineral Farm, Miser's Dream.
23.(?) Forest Belle, Grey Squirrel.
24. Trout and Fisherman.
25. Columbine.
26. Legal Tender.

EASTERN DIVISION

27. Skyrocket.
28. Samoa.
29. Valley View and Cascade group (Cascade Creek)
30. Lone Widow.

LIST OF MINES AND PROSPECTS OF THE LATE TERTIARY PERIOD (SILVERTON AND COW CREEK)

AMPHITHEATER AREA

31. Portland, Denver, and others.
32. Oak Street.
33. Aspen, Leadville, Boulder.
34. Rose.
35. Dyke, Germania, and others.

BEAR CREEK AREA

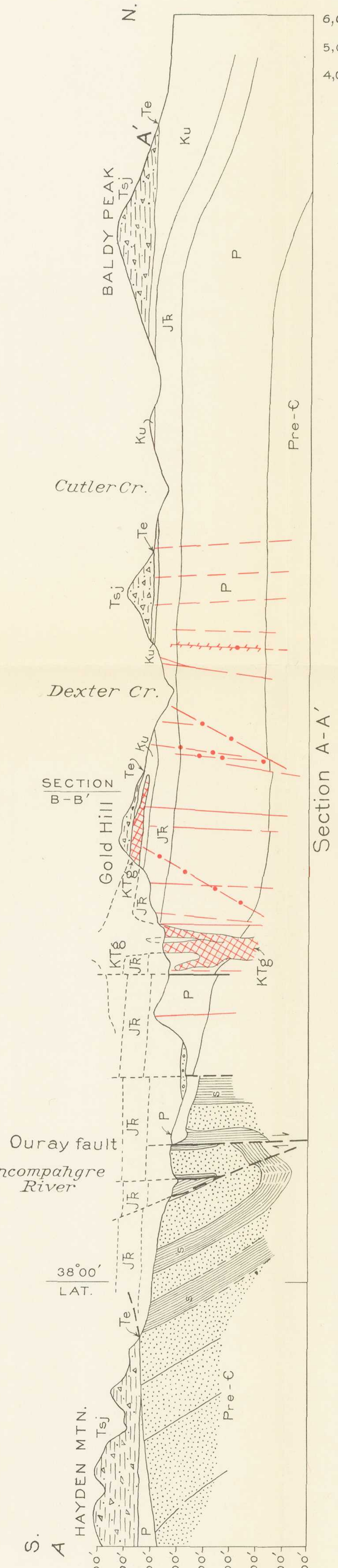
36. { Silver Queen, and others. / Grizzly Bear.

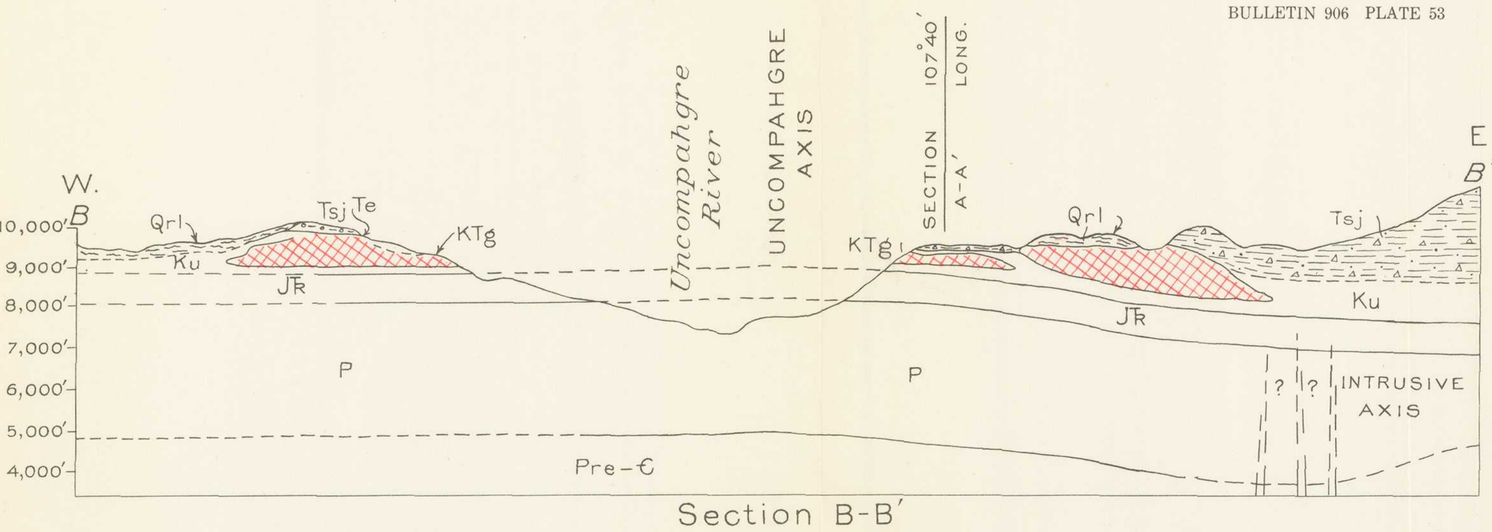
HAYDEN MOUNTAIN SECTOR

37. Combright group.
38. Sutton group.
39. Dunmore group.
40. Ores and metals, manganese.
41. New Mineral Farm.
42. Thistledown.
43. Lloyd group.
44. Japan-Moslem.

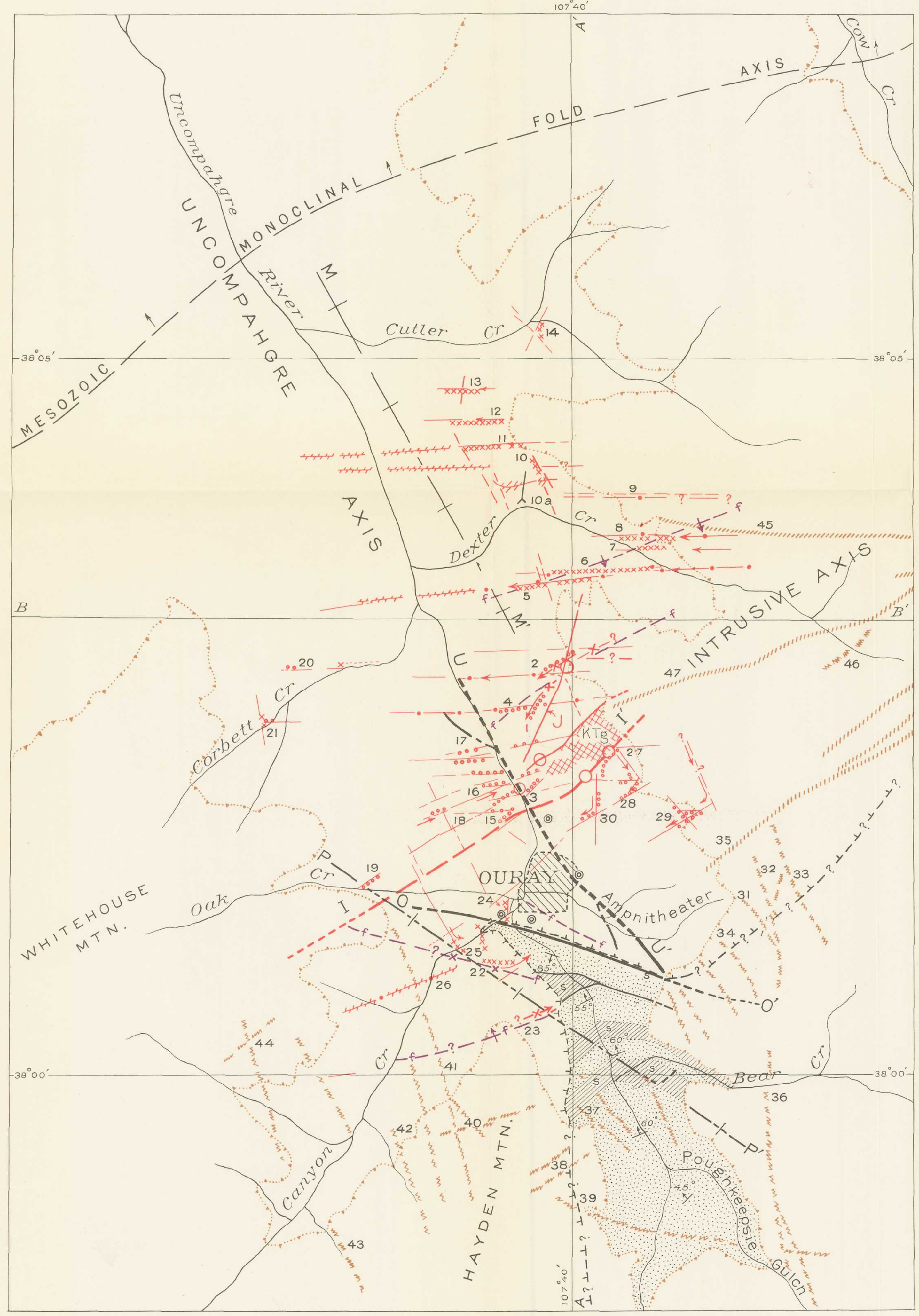
DEXTER CREEK AREA

45. Calliope dike.
46. Sunday.
47. Dike of Bridalveil Creek





Section B-B'



STRUCTURE MAP OF THE UNCOMPAHGRE DISTRICT, OURAY COUNTY, COLO.

By W. S. Burbank

1939

0 1 2 3 4 5 Miles

0 5,000 10,000 15,000 20,000 25,000 Feet

EXPLANATION OF STRUCTURE MAP

GENERAL FEATURES

Boundary of Tertiary formations.

Boundary of Paleozoic formations. (Inferred extension beneath Tertiary formations shown by question marks)

Outcrops of pre-Cambrian quartzite.

Outcrops of pre-Cambrian slate.

Position of recent hot springs

STRUCTURAL FEATURES OF LATE TERTIARY AGE

Late Tertiary veins.

Late Tertiary dikes of the Cow Creek center.

STRUCTURAL FEATURES OF PRE-CAMBRIAN TO EARLY TERTIARY AGE (IN PRE-TERTIARY FORMATIONS)

Fissures and clastic dikes (with dots) with moderately inclined mineralized channels or veins (Inferred direction of movement of solutions shown by arrows)

Fissure, dike, or fault zone, with steeply inclined mineralized channels.

Bedding channels of mineralization showing inferred direction of movement of solutions.

Flexures or fault-folds.

Igneous dikes and plugs of the silver-lead zones of mineralization.

Jonathan dike.

Dikes of the intrusive axis and of gold zones of mineralization (except Jonathan dike) not differentiated from fissures.

KTg Cross-cutting intrusive igneous rocks of the Uncompahgre center. (Laccolithic bodies and sills not shown)

I—I' Southeast boundary of intrusive zone.

U---U' Uncompahgre "break."

M—M' Radial axis of late Mesozoic uplift.

O---O' Ouray fault.

P—P' Radial axis of late Paleozoic uplift.

60° Strike and dip of beds of Uncompahgre formation

EXPLANATION OF GEOLOGIC SECTIONS

Qrl Recent landslide debris.

Tsj San Juan tuff, with Telluride conglomerate locally present beneath it (Tertiary)

Te Telluride erosion surface (early Tertiary).

KTg Quartz monzonite and granodiorite porphyry, quartz diorite, and related igneous rocks (late Cretaceous or early Tertiary).

Ku Upper Cretaceous formations.

JR Jurassic and Upper Triassic formations.

P Paleozoic formations.

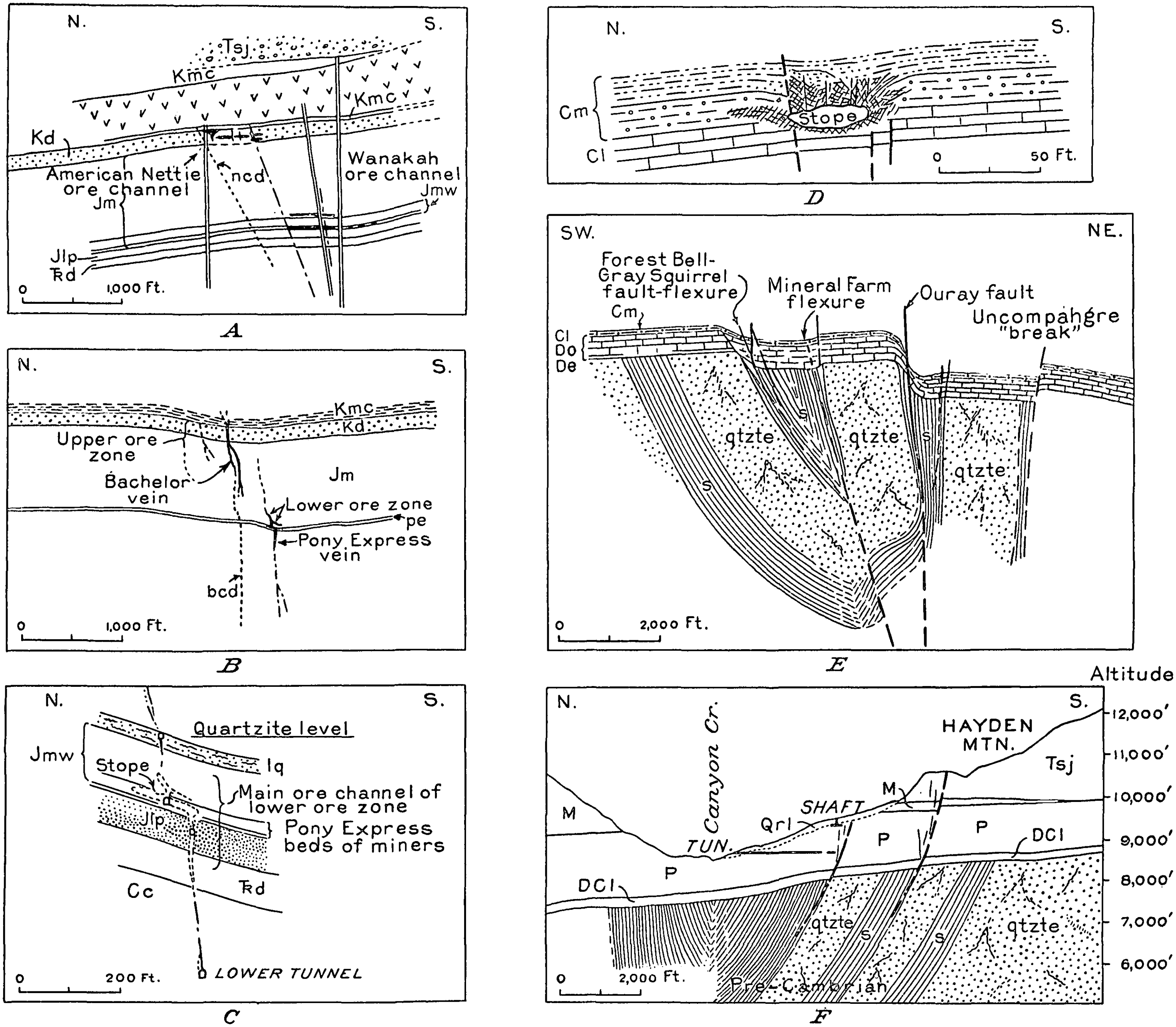
Pre-Cambrian quartzite.

Pre-Cambrian slate.

EXPLANATION OF MINERAL DEPOSITS

Gold ore.

Silver-lead ore.



TYPES OF STRUCTURAL CONTROL OF ORE DEPOSITION.

A, Generalized section through the American Nettie-Wanakah flexure and ore channels. *B*, Generalized section through the Pony Express and Bachelor veins and flexure. *C*, Section through the Pony Express vein and bedding channel. *D*, Section through the Mineral Farm ore channel, at contact of Molas formation and Leadville limestone. *E*, Idealized section in southern part of district, with restoration of eroded parts of the lower Paleozoic limestone; shows relations of the main faults and folds in the pre-Cambrian basement to faults and flexures in the immediately overlying Paleozoic limestones. *F*, Section approximately through the New Mineral Farm mine on the north slope of Hayden Mountain; approximate position of concealed syncline in slate beds of Uncompahgre formation is indicated; tunnel on north-south vein is nearly parallel to plane of section.

Qrl, Quaternary and Recent landslide and morainal debris; Tsj, San Juan tuff; Kmc, Mancos shale; Kd, Dakota (?) sandstone locally altered to quartzite; Jm, Morrison formation, which includes the Pony Express limestone breccia of miners (pe) and the lower quartzite of miners (lq); Jmw, Wanakah member of Morrison formation; Jlp, lower La Plata sandstone of miners; Ꞧd, Dolores formation; M, Mesozoic formations undifferentiated; Cc, Cutler formation; Cm, Molas formation; Cl, Leadville limestone; DCl, Devonian and early Carboniferous limestones; Do, Ouray limestone; De, Elbert formation; P, Paleozoic formations, Molas, Hermosa, and Cutler, undifferentiated; s, slate, and qtzte, quartzite of Uncompahgre formation; ncd, Nettie No. 2 clastic dike of miners; bcd, Bachelor clastic dike.

gold; (2) pyritic ores containing copper and gold; (3) pyritic base-metal ores containing native gold, with gold and silver tellurides; (4) siliceous and baritic ores containing silver, lead, and zinc, but commonly little gold. The gross productivity of the different groups increases in about the order named, but perhaps group 3, because of its relatively rich deposits, has returned the most on small investments. Individual mines producing from the richer silver veins of group 4 have had the highest gross productivity.

The pyritic deposits of the first three groups are present on both sides of the Uncompahgre Valley and are clustered chiefly within a mile of the intrusive center. The deposits of this group that are richest in gold and silver lie east of the valley and north of the intrusive center and axis. Deposits of the fourth group, valuable chiefly for lead and silver, lie outside the zone of highly pyritic ores. Silver-lead ores are found both north and south of the intrusive center, but the northern area near Dexter Creek is by far the most productive. The gold content of the siliceous and baritic silver-lead ores is low, and lead is commonly low in the pyritic ores, whereas zinc is common in both types though concentrated mostly in the outlying deposits. Silver-rich minerals of the gray-copper group are present in both the silver-lead ores and in the higher-grade pyritic base-metal ores and form the most widely distributed of the valuable minerals.

There is very minor concentration of gold in the Telluride conglomerate, possibly of placer origin and derived from the gold deposits of this epoch of mineralization. These placer (?) deposits, which lie entirely north of the Uncompahgre district in the north-central part of the Ouray quadrangle north of Baldy Peak (pl. 53, sec. *A–A′*), have not proved to be of economic value.

LATE TERTIARY DEPOSITS

The late Tertiary ore deposits within the area covered in this report are related, with few exceptions, to centers of mineralization that lie several miles to the south or southeast.[6]

The late Tertiary veins found around the margins of the Uncompahgre district include mainly (1) base-metal ores with manganiferous carbonates that contain moderate to small amounts of gold and silver, (2) baritic silver-lead ores with low to moderately high silver content, and (3) siliceous low-grade silver-gold ores. The first two groups, which in places are represented by compound veins containing both types of ore, are found along the southern margin of the

[6] Ransome, F. L., Economic geology of the Silverton quadrangle: U. S. Geol. Survey Bull. 182, 1901. Burbank, W. S., Vein systems of Arrastra Basin and regional geologic structure in the Silverton and Telluride quadrangles, Colorado: Colo. Sci. Soc. Proc., vol. 13, No. 5, 1933; Geologic guides are sought for ore development: Eng. and Min. Jour., vol. 136, No. 8, pp. 386–392, 1935.

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district and are outliers of the mineralized zones south of the district shown on figure 32. These are related to centers of mineralization that occupy the central part of the Silverton quadrangle and have been described in the reports cited above. Besides these main groups there are fluorite-bearing veins and small low-grade siliceous silver-gold veins in the Hayden Mountain area southwest of Ouray (fig. 32, No. 6). The only Tertiary deposits that do not appear to be related to centers of mineralization south or southeast of the district are those associated with the Cow Creek center (fig. 32, No. 2). They are represented by the siliceous gold-silver veins in San Juan tuff in the Dexter Creek area northeast of Ouray, and possibly by one or more veins east of Ouray.

There are also placer concentrations of recent age along the Uncompahgre Valley, but these have not proved to be of much economic consequence.

MINERALOGY

In the accompanying tables the principal ore and gangue minerals of both older and younger periods of mineralization and some more prominent secondary or supergene minerals are classified according to the principal metallic groups present. The less common minerals in each group are enclosed in parentheses.

Late Cretaceous or Eocene deposits

Primary (hypogene) metallic minerals

Contact-metamorphic deposits (magnetite-pyrite)	Pyritic deposits (copper-gold and base-metal, with gold and silver tellurides)	Siliceous and baritic deposits (silver-lead-zinc)
Magnetite.	Pyrite.	Galena.
Pyrite.	Chalcopyrite.	Sphalerite.
Chalcopyrite.	Sphalerite.	Pyrite.
Specularite.	Galena.	Chalcopyrite.
(Galena).	Tetrahedrite (arsenical).	Tetrahedrite (argentiferous).
(Sphalerite).	Tetradymite.	Pearceite.
(Gold).	Hessite.	Polybasite.
	Benjaminite or cosalite (?).	Pyrargyrite.
	Gold.	Proustite (?).
	(Molybdenite).	
	(Calaverite (?)).	
	(Petzite).	
	(Specularite).	

Late Cretaceous or Eocene deposits—Continued

Primary (hypogene) gangue minerals

Contact-metamorphic deposits (magnetite-pyrite)	Pyritic deposits (copper-gold and base-metal, with gold and silver tellurides)	Siliceous and baritic deposits (silver-lead-zinc)
Andradite.	Sericite.	Quartz.
Hornblende (cummingtonite?).	Quartz.	Chalcedony.
Actinolite.	Chlorite.	Chert.
Epidote.	Calcite.	Jasper.
Quartz.	Siderite.	Barite.
Calcite.	Barite.	Rhodochrosite (ferruginous).
Thuringite.	(Dolomite).	Ankerite.
Stilpnomelane.	(Rutile).	Manganiferous calcite.
Chlorite (Prochlorite?).	(Anatase).	(Dolomite).
Apatite.	(Apatite).	Calcite.
Rutile.		
Siderite.		
(Anatase).		
(Zircon).		
Secondary (supergene) minerals		
Limonite.	Limonite.	Limonite.
Clay minerals.	Goethite.	Wad.
Goethite.	Jarosite.	Azurite.
Jarosite.	Copiapite (?).	Malachite.
Chalcocite.	Clay minerals.	Chrysocolla.
Covellite.	Chalcocite.	Native silver.
Malachite.	Malachite.	Argentite.
Azurite.	Azurite.	Chalcocite.
	Cerussite.	Covellite.
	Gold (?).	(Proustite ?).[1]
	Hydroussulphatesofiron, copper, and other metals.	(Chalcopyrite).[1]
	Gypsum.	Sulfur.
	Sulfur.	Calcite or aragonite.
	Native copper.	

[1]Supergene origin debatable; possibly both supergene and hypogene.

Late Tertiary Deposits

Primary (hypogene) metallic minerals

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

[1] Reported.

ORE DEPOSITS OF THE UNCOMPAHGRE CENTER

GEOLOGIC RELATIONS AND PARAGENESIS OF THE DEPOSITS

All the ores of the Uncompahgre center were formed after the emplacement of the intrusive igneous rocks, but they are genetically related to the igneous rocks by structural features and by certain features of the vein sequence described below. From the structure and stratigraphy of the late Cretaceous and early Tertiary sedimentary rocks, it is inferred that the shallower deposits may have been formed at a depth of a mile or less beneath the surface. The shallow cover seems to be revealed by events related to the formation of the ore deposits which are not ordinarily recognized in similar deposits formed at greater depths. The most significant of these special features are the numerous intrusions of clastic dikes and the emplacement of certain ore bodies in the sedimentary rocks by the filling of caves rather than by metasomatic replacement.

The clastic dikes afford evidence also 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 have been described by Ransome,[7] Irving, Spurr, and Burbank. The commonly accepted conclusion as to the origin of the Bachelor dike was first propounded by Spurr. The writer concurs in the essential features of the explanation—that the dike is a true injection and not a fault or friction breccia and that it was formed by the injection of clastic material torn from the walls of the fissure in depth and propelled upwards (diagonally or laterally in places) by expanding gases or vapors genetically related to the igneous and mineralizing activity. Further study of the numerous examples found in the district has shown that some clastic dikes are closely associated with eruptions of igneous rocks, whereas many are locally independent of igneous rocks. Some were clearly formed between early and late stages of vein deposition and are therefore most closely associated with the formation of the ore deposits. These are believed to have been formed by sudden expansion of mineralizing solutions, during reopenings of the vein fissures. Some typical mineralized fissures were filled in turn with igneous dikes, major amounts of premineral injected clastic material, and finally by vein material and minor amounts of intramineral clastic material. This is the normal order throughout the district, though not fully represented in all veins.

In the central part of the district near intrusive contacts, the mineral sequence began in a few places with the development of contact-metamorphic silicates, minor amounts of magnetite, and pyrite. In most parts of the district, however, the silicate stage was lacking and mineralization began by 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 fissures and the deposition of specularite, by local intramineral clastic injections, by an interval during which cavities were formed in the rocks by hydrothermal leaching. Deposition of the principal sulphide and gangue minerals followed.

In places hydrothermal leaching attained considerable importance, for large cavities were formed by solution along the bedding planes in both sandstone and limestone. Some of these cavities were never completely filled and now contain only thin crusts of mineral crystals, but others were partly or completely filled with the higher-grade ores while the adjacent wall rocks were apparently being replaced by lower-grade ores. Two especially noteworthy examples are the bedding-channel deposits of the American Nettie mine in the Dakota (?) sandstone, which has been changed to quartzite, and the manto or channel deposits of the Mineral Farm mine in the Leadville

[7] Ransome, F. L., A peculiar clastic dike near Ouray, Colorado: Am. Inst. Min. Eng. Trans., vol. 30, pp. 227-236, 1901. Irving, J. D., op. cit. (Geol. Folio 153), p. 17. Spurr, J. E., The ore magmas, pp. 843, 844, New York, 1923. Burbank, W. S., op. cit. (Colo. Sci. Soc., vol. 12, No. 6), pp. 195-200.

limestone and Molas formation. Irving[8] recognized that some of the ore bodies of the American Nettie mine were probably formed by cavity filling of this kind, though he considered replacement to be the dominant process. If the entire body of altered rock and the lower-grade pyritic bodies of the ore channel are taken into consideration, the total volume of replaced rock doubtless greatly exceeds the open space that was filled with ore. The process of cavity formation is believed to be similar in nature to that described by Lasky[9] as having occurred in the veins of the Virginia district of New Mexico. Evidence obtained in the Ouray district indicates that the release of pressure on the mineralizing solutions, believed responsible for their leaching activity, could have been brought about either by renewal of fissuring, by an abrupt change in the permeability of the rocks, or by changes in the back pressure existing in permeable formations as a result of relatively impermeable barriers. In the American Nettie mine it is noteworthy that the largest spaces formed by leaching lie west of the Jonathan dike barrier and that most of the cavities occur along small cracks or fissures in the quartzite. The Jonathan dike represents the last cross-barrier between the apparent sources of the solutions and the Uncompahgre axis, which is believed to represent the zone or break through which the solutions finally escaped (pl. 53). Release of pressure on the solutions is thought to have caused boiling or vaporization of the original saturated solutions, so that the distillate was sufficiently acid or undersaturated with rock constituents to affect considerable solution of the channel walls. Whether the distillate consisted of gas or of vapor and partly recondensed solution is conjectural, but the fact that silica was carried away in considerable volume suggests the presence of a condensed medium in some proportion. Under either condition, saturation was rapidly attained, as a certain proportion of the silica dissolved from the sandstone was reprecipitated in the pores of the rock short distances from the main channels of mineralization, and the immediate walls of these channels became converted to a massive hard quartzite, which was obviously 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 of nearness to an ore channel. Induration of the sandstones, or their conversion to quartzite, and silicification of limestones preceded the main period of sulphide formation.

In the gold belt, quartz, ankerite or siderite, and sericite were the principal gangues deposited with the early sulphides. The general order of mineral deposition was pyrite, chalcopyrite, sphalerite, tetra-

[8] Irving, J. D., op. cit. (Geol. Folio 153), p. 18, 1907.

[9] Lasky, S. G., Hydrothermal leaching in the Virginia mining district, New Mexico: Econ. Geology, vol. 31, No. 21, pp. 156–169, 1936.

hedrite (with some additional chalcopyrite), tetradymite, benjaminite (?), galena, hessite, and finally native gold. Although hessite was the principal telluride, small amounts of petzite and possibly calaverite were formed 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 the galena-bearing ores, or formed in relatively late barren veins with quartz. Scalenohedral calcite also formed late in cavities, though less abundantly than in the silver belt.

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. Although shales and sandstones were not as strongly attacked as in the gold bed these beds were locally leached. In the second mineral stage ankerite or ferruginous rhodochrosite, sericite, and pyrite formed by replacement. With the possible exception of the early metasomatic pyrite, barite preceded the bulk of the base-metal sulphides, which were deposited in the order: pyrite, sphalerite, chalcopyrite and tetrahedrite, pearceite and galena, and locally pyrargyrite. Some rhodochrosite or manganiferous calcite also accompanied the late base-metal sulphides. As may be noted by comparing this sulphide sequence with that of the cupriferous or pyrite ores of the gold belt, noteworthy 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 sulphide sequence. In the silver belt, quartz, a little barite, and scalenohedral calcite formed as late barren gangues.

In many deposits the zoning of the ore bodies or shoots conforms to the general sequence of mineralization, as pyritic, cupriferous, and zincy ores are found nearest the sources, the high-grade tetrahedrite-bearing silver ores in an intermediate position, and baritic ores of low sulphide content farthest from possible sources of mineralization. Evidence with regard to overlapping of the different sequences, beginning with the igneous dikes and extending through the clastic injections to the mineral stages, suggests that mineralization started first in the inner pyritic or gold belt and that the sulphide ores of the outer or silver zone were formed later. Thus the ultimate sources of the ore-forming solutions may have migrated with the passage of time from their earliest position near the apex of the intrusive bodies at the crossing of the structural axes to positions very much deeper in the crust along the extensions of the intrusive axis to the northeast or southwest. This possibility bears directly upon the question of whether the zoning in depth corresponds with the lateral or areal zoning of the deposits. The writer inclines to the view that the areal and depth zones do not correspond exactly, and it is unlikely that the most distant facies of mineralization will change in depth to deposits like those now found in the inner zone surrounding the shallower intrusive bodies.

FAVORABLE ROCKS

The most favorable host rocks of the ore deposits possess physical or chemical properties that in combination with the structural features and processes of mineralization tend to yield a maximum of available open space. The formation of open spaces is not dependent solely upon fissuring or fracturing of the rocks but upon the chemical activity of the mineralizing solutions. As noted above, the maximum leaching powers of the solutions appear dependent in part upon position relative to structural features and indicate that low pressure favored leaching. Other conditions being equal, the more permeable rocks appear most susceptible to leaching. The formation of pre-ore caves in limestone seems to require less intense chemical attack than in sandstone, for caves in limestone are found farther from the center of mineralization. Where replacement rather than solution and subsequent filling has been dominant the conditions were more complex, but in general the rocks most susceptible to leaching appear also to be susceptible to replacement. Replacement processes appear less selective close to the eruptive center, and the grade of ore is low because the temperature was too high to favor the deposition of the most valuable ore minerals. The minerals that replace the rocks most extensively include all the pre-ore alteration products, such as carbonates, sericite, quartz, and chlorite minerals. Of the sulphides, pyrite and sphalerite most commonly accompany these products, but the later sulphides show a distinct preference for open-space filling or for replacement of earlier-formed sulphides. Hence where the earlier sulphides, particularly pyrite, have replaced host rocks so as to form massive sulphide bodies, these in turn act as the host of the later solutions. Some of the highly pyritic low-grade sulphide bodies formed by replacement of limy beds near the center of mineralization were later enriched locally by gold-bearing solutions that followed zones of fissuring.

The presence of less permeable confining beds tends to localize mineral deposition. Confining strata are not necessarily required to form ore bodies in sedimentary rocks, but in the Uncompahgre district the less permeable beds that cap and underlie the sedimentary rocks have restricted the circulation of ore-forming solutions to channels nearly conformable with the bedding of the rocks. Channel or ore channel here applies to the main conduits along which shoots of ore are found. Shoots in the favorable sedimentary rocks, where form and distribution are controlled by bedding or permeability of the rocks, will be referred to as bedding deposits. Most but not all of these conform to the bedding. In many ore channels of the district vein and bedding deposits occur together and are confined to a small vertical range. As there are gradations between and variations in the proportion of vein and bedding deposits within the same mine, many ore deposits in the district cannot be classified readily according to form. If the controlling break is a cross-cutting fissure and the rock can maintain clean fissures with 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 along these beds. The descriptions of the favorable rocks given in the following paragraphs show that in many places the rocks immediately above or below an unconformity possess properties favorable to the formation of bedding deposits; also, that the thicker formations of the district, such as the Hermosa, the Cutler, and the middle part of the Morrison contain few favorable beds.

Elbert formation.—There are few if any productive deposits in the Elbert formation, which consists of alternations of thin sandstones or quartzites with dolomitic limestones and shales; however, one example of a low-grade deposit is found in the dolomitic or limy sandstones of this formation in the southern part of the district. Though associated with fissuring of late Tertiary age this deposit suggests that under more favorable conditions similar beds might be locally mineralized. The sandstones of the formation except that at the base are not very permeable as they are filled with dolomitic or limy cement. As the shales, on the whole, are too thin to provide very effective confining beds, channels along the bedding are not likely to be extensive.

Contact of the dolomitic Ouray limestone and Leadville limestone.—Where traversed by fissure veins in the southern part of the district, especially near the Ouray fault, the dolomitic Ouray limestone is locally mineralized and recrystallized, but it contains no known large deposits. Locally at the contact with the overlying Leadville limestone are small bedding deposits near fissures, but production from this zone is small. Some unfilled or partly filled solution cavities, however, are found along this same contact even where vertical fissuring is relatively feeble. Although not highly productive, the zone may have potential importance.

Contact of Leadville limestone with Molas formation.—The contact of the Leadville limestone with the Molas formation is one of the favorable contact zones within the lower Paleozoic group of formations, but production from it has come mainly from one mine, the Mineral Farm. At this mine, the upper part of the Leadville limestone is coarse-textured and clastic and is overlain unconformably by 5 to 10 feet of the red chert-bearing shales of the Molas formation. Mineralization along the contact was localized by small flexures or rolls along which fractures in the top of the limestone permitted leaching by hydrothermal solutions. Slumping of the overlying shale into small

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caves leached in the limestone produced sufficient fracturing to localize some ore in the basal part of the shale as well as in the top of the limestone. However, where the pre-ore caves in the limestone were not so choked with shale debris, conditions were apparently more favorable for the formation of larger and better-grade ore bodies. In these the ore was formed beneath an arch of silicified shale. It filled spaces among the shale fragments, and also partly replaced the altered shale and the limestone. The beds of shale with interbedded sandstone or conglomerate that immediately overlie this contact provide an impervious cover. These beds are in turn overlain by a considerable thickness of shaly strata in the lower part of the Hermosa formation.

The limestone beds in the ore zone not only are coarsely clastic but also contain porous sandy layers that add to their permeability. In this respect they are in marked contrast to the massive finely crystalline beds in the lower part of the Leadville limestone. Between the ore zone and these lower beds the formation consists of thick clastic limestone beds separated by discontinuous beds and partings of reddish shale. Except for the discontinuity of their shale partings these limestone beds are similar to those of the ore zone, and it is conceivable that they may be favorable to ore deposition at any place where the supply of ore-forming solutions was more than sufficient to replace beds close to the contact or where the ore channel for any cause passed through them.

Near the Mineral Farm deposit and along Canyon Creek there has also been post-ore leaching of the limestone, either around the edges of ore shoots or along fissures. This leaching action was the result of comparatively recent hot-spring waters or of descending surface waters and is not to be confused with the pre-ore leaching described above.

Hermosa and Cutler formations.—Very few of the beds in the upper Carboniferous formations are especially favorable to ore deposition. Most of the sandstones consist of poorly sorted grains and are too shaly or too micaceous to be very permeable. The massive arkosic sandstones in the upper part of the Hermosa and some thick sandstone beds in the Cutler formation are fairly permeable and contain small gold-bearing replacement veins near the center of mineralization. Their ore shoots, however, are confined mainly to sandstone or porphyry walls, and in the more shaly beds the same veins are commonly of little or no value.

As the Hermosa formation in the Uncompahgre district is closer to the early Carboniferous highland from which its detrital material was derived, it contains fewer and smaller limestone beds there than in the Rico Mountains, where the limestone and gypsum beds have been strongly mineralized and contain the principal ore bodies of the Rico district. Near the central part of the Uncompahgre district some of the thin limestones and associated black limy shales have been replaced by small pyritic deposits, but these have not proved commercially valuable except where they have been enriched along fissures by late gold-bearing solutions. Only small ore shoots have been formed in this way.

Beds near base of Upper Jurassic.—Several beds near the base of the Upper Jurassic formations are widely mineralized. Between the base of the lower La Plata sandstone of the miners and the base of the sandstone member of the Morrison formation are 150 to 200 feet of sandstone, shale, and thin limestone beds. The lower La Plata sandstone is made up of wind-blown sand of relatively fine grain and consequently is not highly permeable, but it contains vein deposits, and in places the underlying Dolores formation does also.

The Pony Express beds of the miners, which overlie the lower La Plata sandstone, consist of 10 to 25 feet of bituminous limy shale and a limestone breccia. The limestone breccia is a very permeable bed that owes its peculiar texture and structure to the selective solution of gypsum from a deposit of limestone-bearing gypsum. The small interstitial lenses of limestone in the original deposit have slumped so as to form a bed of breccia as much as 20 feet thick, although the original unit was 50 feet or more thick. The resulting bed is not only highly permeable, but, because it is a carbonate, it has reacted readily with the ore-forming solutions and consequently forms an ideal site for the deposition of ore. The breccia bed is commonly mineralized where cut by veins, and bedding deposits from a few to 10 feet thick and from 10 to 100 feet wide have been formed along some of the ore channels. Commonly, however, the deposits are of lower grade than associated fissure veins, for the breccia has caused precipitation of gangue as well as ore minerals, and the sulphides may be widely disseminated through the altered breccia. Near the intrusive center massive pyritic sulphide bodies have been formed at this horizon. At places in the silver-lead zone the highly bituminous shales at the base of the breccia have precipitated high-grade copper-silver ores, but the shoots formed commonly do not extend more than 12 feet from the feeding fissures.

The regional development and extent of the Pony Express limestone breccia are of economic interest. The breccia attains its maximum thickness of about 25 feet towards the north and west, but towards the east it becomes thin and discontinuous and is represented by thin beds of silty sandstone or of limy and silty shale. East of the Uncompahgre Valley and south of Dexter Creek, in the northern division of the Uncompahgre district, the thickness and permeability of the beds decrease markedly towards the southeast. This condition bears on possible extensions of mine developments in this direction and will be referred to again in connection with ore channels affected.

Except for 15 to 20 feet of fine silty sandstone forming the upper La Plata of the miners, the 60 to 70 feet of beds above the limestone are predominantly shale with a few very thin beds of limestone. The shales are commonly void of mineralization throughout. The next overlying sandstone bed, the basal unit of the sandstone member of the Morrison formation, is mineralized in many parts of the district. This sandstone ranges from 18 to 25 feet in thickness, and because of its original permeability has been commonly altered to quartzite in the central parts of the district. The bed is locally called by the miners the lower quartzite to distinguish it from the Dakota or upper quartzite, which is about 700 feet stratigraphically above it. The lower quartzite contains a large number of small bedding deposits in the central part of the district, and, like the Dakota (?) quartzite, has been subjected to hydrothermal leaching. The bed is capped by a few feet of shale or limy shale and is overlain locally by a thin limestone bed that rarely exceeds 4 or 5 feet in thickness. This limestone bed, which has been replaced by sulphides in the Wanakah mine and at other nearby places, is known as the Bright Diamond or upper contact at this locality.

Dakota (?) sandstone.—The Dakota (?) sandstone in the district is composed for the most part of several massive permeable sandstone beds separated by thin layers of shale that locally thicken to prominent shale members. The shales in the lower part are commonly gray or greenish, whereas those in the upper part are highly carbonaceous. The top 50 feet of the formation consists in places of predominantly black carbonaceous shale with thin dark carbonaceous sandstones. Beds above the first thick carbonaceous shale are commonly considered to belong to the capping shale and locally are not clearly distinguishable from the Mancos shale that overlies them unconformably. These capping shales mark essentially the upper limit of the mineralized sedimentary beds in the district. It was along them and the basal part of the Mancos shale that most of the laccolithic bodies in the district were intruded. Near strongly mineralized zones the Dakota (?) sandstone has been converted to quartzite, and in the immediate vicinity of the larger ore channels the beds are entirely recrystallized.

Near the center of the district the sandstones were subjected to replacement by ore and to hydrothermal leaching, and the richest ores were deposited in the resulting caves. The parting and capping shales tended to confine the zones of mineralization to several prominent horizons. As the Morrison shales beneath are relatively impermeable, bedding deposits are mainly confined to the zone of massive beds in the quartzite, although locally thinner sandstones in the uppermost part of the Morrison are also mineralized. Where the silver veins cross the upper part of the Morrison formation, productive deposits have been formed but the sandstones are not as well mineralized as those in the Dakota (?) quartzite.

The quartzite beds attain a thickness of 100 to 150 feet. As they are relatively brittle and are overlain and underlain by incompetent shale formations, minor flexing or tilting has locally formed complex fracture systems that provided incipient channels for the lateral movement of the mineralizing solutions. A linear channel of this nature appears to have localized the principal ore bodies of the American Nettie mine, which contained the highest-grade gold deposits in the district.

Dikes and other igneous bodies.—Dikes, both clastic and igneous, commonly form wall rocks of the veins. The denser igneous rocks are not very favorable to replacement, and, where mineralized fissures follow the walls of dikes, the dikes may have been essentially unaffected although the more permeable parts of the adjacent sedimentary walls have been replaced by ore. Where the sedimentary walls are shaly, however, and the dike rock has been fissured or shattered, the dike material in preference to the shaly rock has been replaced by ore. Numerous clastic dikes, which have been more readily fractured and appear to have a greater natural permeability than the igneous rocks, are partly replaced by ore. In some, such as the Bachelor clastic dike, the vein matter locally occupies the entire width of the dike in preference to the sedimentary walls. Fissure or replacement veins in the larger igneous bodies near the intrusive center or in the laccolithic rocks are commonly small. Sill rocks enclosed in shale have been locally replaced by ore, as in the Calliope mine, but the ore bodies found in these rocks are small.

The granodiorite and quartz monzonite porphyries of the central intrusive neck contain disseminated pyrite, and, together with the surrounding envelope of sedimentary rocks, are otherwise altered to form the discolored patch locally known as the blowout. The exposed igneous rocks in the blowout do not contain sufficient disseminated chalcopyrite or gold to be mined. There are deposits of disseminated chalcopyrite, however, near similar eruptive centers nearby, as in the La Plata Mountains,[10] and the possible presence of copper deposits beneath the exposed parts of the blowout deserves some consideration; however, as local conditions have not been favorable to secondary enrichment, deposits of this kind are not likely to be of value as copper ore, unless other valuable metals are also present.

STRUCTURAL CLASSIFICATION AND CONTROL

The classification of deposits presented below is based on major and minor structural features. The outstanding structural feature

[10] Eckel, E. B., Copper ores of the La Plata district, Colorado, and their platinum content: Colo. Sci. Soc. Proc., vol. 13, No. 12, 1938.

is the crossing of the northeastward-trending intrusive axis and the northwestward trending axis of uplift, which with its parallel lines of rupturing extends along the Uncompahgre Valley. This crossing divides the district into four parts, each of which is characterized by minor structural features (pl. 53). The nature and significance of the major structural features will be indicated before discussion of the minor features, which have largely controlled the distribution, sizes, and shapes of the ore bodies.

The major intrusive axis lies along the middle of a zone about 2,000 feet wide with a strike of N. 55°–60° E., where it crosses the Uncompahgre Canyon. This zone, the southeast boundary of which is shown by the line I–I′ on plate 53, contains a number of dikes and irregular intrusive bodies of quartz monzonite porphyry, granodiorite porphyry, and quartz diorite. To both the northeast and southwest the zone is concealed by overlying younger Tertiary volcanic rocks, but there can be little doubt that rupturing of the rocks along this zone was of major magnitude and extended deep into the crust. As illustrated in figure 32, the trend and position of the intrusive zone evidently is related to the northeastward-trending Paleozoic and Mesozoic fronts of the ancestral San Juan Mountains north of the latitude of Ouray.

The Uncompahgre axis cuts diagonally across the trend of the intrusive zone and has an average strike of N. 25° W. As indicated in the general structural features this axis marks the trend of several parallel or slightly divergent components, the oldest of which dates from the late Paleozoic uplift of the mountains. These are marked on plate 53 by the symbols, P–P′, M–M′, and U–U′. The first two are radial axes of uplift or folding evidently related in their position and trend to a change in direction of the Paleozoic and Mesozoic mountain fronts as shown in figure 32. The line U–U′ marks a break of the sedimentary strata along the main axis, and its nature is indicated by the presence of faults or of abrupt changes in direction or amount of tilting of the strata, as shown on geologic sections across the valley (pl. 54, *E*). The strongest discordance in structure along the Uncompahgre break is near the intrusive zone, whereas towards the south the break appears to feather out into the north wall of the Ouray fault. North of the intrusive zone the break passes into a gentle anticlinal axis in the Mesozoic strata (see sec. B–B′, pl. 53).

The break lies along an axis of crustal tension, and near its intersection with the intrusive zone the younger Mesozoic formations were evidently breached by cross-cutting intrusive bodies. The main feeding channel of the laccolithic bodies lies along the east side of the break, and near it and the intersection of the axes the sedimentary formations have been highly altered by mineralizing solutions. These solutions must have passed upwards towards an ancient land surface along strong fissures or fracture zones that reached to the summit of the laccolithic dome. Elsewhere the Upper Cretaceous shales together with the laccolithic intrusive bodies appear to have formed a blanket that was relatively impermeable to the upward passage of mineralizing solutions. Evidence derived from the study of mineral deposits shows also that mineralizing solutions moved in general towards the Uncompahgre break from both sides of the valley. In the northern part of the district at places more distant from the main axes many mineralized channels have a low inclination, about the same as the enclosing strata, and zoning of the deposits indicates that solutions moved in general from east to west. Associated clastic dikes were also intruded in paths inclined upward towards the west. Thus it appears that the intrusive zone contained a high-pressure source of mineralizing solutions and that the Uncompahgre axis was the principal low-pressure zone towards which the solutions moved.

The four major divisions of the district, separated by the two axes, are designated the northern, southern, eastern, and western. The northern division is by far the most productive, having yielded more than 80 percent of the district's total output. The relative productions of the other divisions are not known, but the differences are not significant. The significant feature is that, as compared with the northern division, the productivity of deposits in the eastern and western divisions declines at comparatively short distances from the intrusive zone. In the southern division conditions are intermediate between these extremes. These differences evidently result in part from the dominant directions of secondary structural control.

In all divisions of the district there are several systems of fissures and dikes, most of which appear to be secondary features related to the main structural axes. In both the northern and western divisions the principal veins and dikes trend eastward and intersect the line of the intrusive zone at an acute angle of about 30°. This system is also represented in the other divisions. Most of the fissures are steep or dip towards the intrusive zone. As many of them contain igneous and clastic dikes as well as vein matter, it is apparent that in time of origin they are closely related to the intrusive activity. Possibly the fissures resulted from tension in the rock masses on either side of the intrusive zone, such as might have been produced by lateral shifting of the crust along the zone. Thus if the northwest side moved northeastward relative to the southeast side, the fissures would be comparable in their setting to tension or feather joints, such as are formed on a minor scale in the walls of faults. The practical importance of the system is that it appears to have furnished the main deep-seated long fissures that tapped both the igneous and mineralizing reservoirs.

Another prominent system represented in all divisions of the district trends more or less parallel to the Uncompahgre axis, but individual fissures range in strike from north to N. 40° W. and commonly have a steep dip. As contrasted with the eastward-trending system, the individual fissures are discontinuous, locally overlapping en echelon, and except for those within or close to the intrusive zone, they do not commonly contain igneous dikes. Some of them are locally mineralized, but many contain mostly the later barren gangues, and a few contain vein matter of late Tertiary age, for these also cut through the San Juan tuff. The distribution of this system along the Uncompahgre axis, the discontinuity of individual fissures, and their lack of dikes except near the crossing of the intrusive zone suggest that the system is of relatively shallow tensional origin and was formed by stretching along the crest of the Uncompahgre arch. In most places at least the fissures failed to tap the primary sources of mineralizing solutions. As some fissures near the intrusive zone contain dikes the system originated early, but, following the Uncompahgre mineralization, fissuring along the Uncompahgre axis must have been renewed even to late Tertiary time.

In the southern and eastern divisions of the district the directions of fissuring are more diverse than represented by the two principal systems described above. In part this may result from interfingering of the Uncompahgre systems with those of late Tertiary age, which became stronger towards the south. On the other hand effect of the structural control of the basement rocks is increasingly apparent, especially in the southern division. Thus some of the fissures and flexures in this division parallel the general easterly trend of the folds in the pre-Cambrian basement. Other structural features of diverse trend are related to renewals of movement along some of the older fault lines. This noticeable increase of inherited structural lines in the southern division is in part a natural result of exposure of the older formations along the uplift but also probably in part a concentration of these renewed movements along the hinge line of the Paleozoic uplift.

Flexures and their associated complex fracture systems also constitute important structural features controlling the form and distribution of some ore bodies. In the northern division the two most pronounced flexures trend northeastward but somewhat more eastward than the intrusive zone, so that if continuous they would intersect the intrusive zone at a more acute angle than the east-west fissures (pl. 53). Along these flexures the formations were warped downward towards the intrusive zone, resulting either in a reversal of their normal dip away from the mountains or in a local flattening of the normal dip. The more competent beds such as sandstone, quartzite, or limestone were complexly fractured and thus provided either potential bedding channels for mineralizing solutions or zones of relatively low pressure connecting with the Uncompahgre axis at the west. The most productive ore bodies in the northern division of the district are associated with these flexures. Flexures in the southern division of the district are related to old lines of weakness in the pre-Cambrian basement and affect chiefly the lower Paleozoic formations.

The two major district axes in conjunction with the main eastward-trending systems of fissuring and flexing control to a large degree distribution of the deposits between the four district divisions. The bulk of the mineralizing solutions originating at places along the intrusive zone sought the most direct paths from the deep sources to lower-pressure zones along the Uncompahgre axis and hence traveled westward in the northern division and eastward in the southern division along the east-west lines of fissuring and flexing. The eastern and western divisions thus appear to have been deprived of the main bulk of the solutions, except near the crossing of the axes, where pressures existing tended to force the solutions to rise steeply within or along the border of the intrusive zone until permeable channels or fissures were encountered that permitted direct escape towards the Uncompahgre axis or break. In the eastern division the mineralizing solutions in part appear to have traveled southward along fissures or dikes paralleling the Uncompahgre axis until these intersected other fissures or fractured zones that trend westward towards the axis. For the reason that those fissures belonging to the Uncompahgre axis system are comparatively shallow tensional breaks, the largest deposits in the eastern division lie in the Dakota (?) quartzite that forms the uppermost competent member of the sedimentary column. Deposits in the lower favorable beds are confined to positions very close to the edge of the intrusive zone.

Large deposits of silver-lead ores of this epoch have not as yet been found in the eastern and western divisions but are confined to the northern and southern divisions. As noted in discussion of the mineral zoning, solutions that formed this kind of ore evidently originated at places distant from the crossing of the main structural axes, and hence it seems likely that the bulk of these solutions traversed east-west channels in the northern and southern divisions. If other avenues of egress existed for these solutions there is little probability that they will be discovered, for they must lie considerable distances northeast or southwest of the intersection of the axes, where the older formations are deeply buried by the Tertiary volcanic rocks. Confinement of most of the known silver-lead deposits to the northern rather than to the southern division indicates some lack of symmetry in the igneous or structural framework. Possibly the northwest side of the intrusive zone was the one more strongly fissured by the east-west system, or, conceivably, the intrusive zone was more strongly developed to the northeast than to the southwest.

The structural classification of deposits in the district is made as follows:

1. Northern division: Deposits within and north of the intrusive zone and east of the Uncompahgre break or axis; associated with
   - (*a*) intrusive contacts,
   - (*b*) flexures of northeasterly trend and associated fissures and dikes;
   - (*c*) fissures and dikes mainly of easterly trend.
2. Western division: Deposits within and north of the intrusive zone and west of the Uncompahgre axis or break; associated with fissures and dikes of easterly to northeasterly trend.
3. Southern division: Deposits south of the intrusive zone and west of the Uncompahgre axis or break; associated with
   - (*a*) flexures and faults of general easterly trend,
   - (*b*) fissures of northerly or northwesterly trend.
4. Eastern division: Deposits south of the intrusive zone and east of the Uncompahgre break; associated with
   - (*a*) intrusive contacts,
   - (*b*) fissures and dikes, mostly of east-northeast and north-northwest trend.

NORTHERN DIVISION

GENERAL FEATURES

The northern division contains the larger gold-bearing pyritic, base-metal, and silver-lead deposits. The gold-bearing deposits lie in the southern part of the division, mostly within a mile of the intrusive zone. Some of them are small fissure deposits within or near the intrusive zone that contain mainly pyrite and chalcopyrite with lesser amounts of sphalerite and other sulphides. Within the intrusive zone some small veins contain these sulphides and also magnetite and hematite. The larger gold deposits lie along the bedding of favorable sedimentary rocks, particularly in the basal Upper Jurassic zone and in the Dakota (?) quartzite. They contain larger sulphide deposits than the fissures, and the richer of them, such as those of the American Nettie and adjoining properties, also contain gold and silver tellurides and silver-bearing tetrahedrite. The gold-bearing bedding replacement deposits in the Upper Jurassic beds overlap the relatively barren contact-metamorphic deposits that border the intrusive zone, so that the different classes of these deposits cannot be easily separated for description.

The silver-lead deposits of this division lie from a mile to more than 3 miles north of the crossing of the district axes. They are mostly veins, but with associated bedding deposits, and the main channels of mineralization are confined to a lower zone in the basal Upper Jurassic strata and an upper zone in and just below the Dakota(?) sandstone. Veins that lie along and south of Dexter Creek are strongly mineralized in both the upper and lower zones, but those that lie north of the bend of Dexter Creek are mineralized mainly in the lower zone. The principal valuable sulphides of these veins include galena, tetrahedrite, and such silver minerals as pearceite and pyrargyrite. The proportion of pyrite and sphalerite in the deposits commonly increases eastward, especially in veins that lie south of and along Dexter Creek.

DEPOSITS ASSOCIATED WITH INTRUSIVE CONTACTS

The principal contact-metamorphic deposits are found within 1,000 to 2,000 feet north of the contact of the central intrusive neck, and within favorable beds that range stratigraphically from the upper part of the Hermosa formation to the lower part of the Morrison formation. Owing to the position of the contact zone near a pre-Triassic flexure of the Paleozoic beds in this division of the district, and to later disturbances attending intrusion of the igneous rocks, the beds have a wide range in dip, are locally tilted steeply, and are cut by numerous dikes, fissures, and faults (pl. 53, section A–A′). However, the principal known deposits of economic interest lie in the slightly or moderately inclined beds above the base of the Triassic.

The contact-metamorphic deposits consist mainly of calcic silicates, magnetite, and hematite, which, together with the sulphides present, make a suite of minerals characteristic of deposits formed at high temperature in a limestone environment. The sulphides that accompany these contact-metamorphic minerals and constitute the ore were introduced into the beds later than the silicates. Copper and other base metals have not been found in sufficient quantity in most of these sulphide deposits to make large bodies of ore, and the deposits have been mined mainly where they have been fractured and in turn enriched by late gold-bearing solutions. The sulphide bodies, found mainly in limestones, constitute only a small fraction of those rock bodies near the igneous contacts that have been subjected to contact metamorphism in the broader meaning of the term.

The gold-bearing contact-metamorphic ores, which form a type even more restricted within the pyritic sulphide deposits of this class, are represented in the district by only one known deposit of appreciable size—that of the Wanakah property. The superposition of the different structural and mineralogical processes that appear to have been involved in the formation of this deposit is somewhat out of the ordinary, and, significantly perhaps, gold deposits of this kind are among the less common types found in the western United States.[11] Thus in reference to the Wanakah deposit, processes that were operative throughout its formation tended progressively to limit the body of rock affected by the several stages of mineralization. Conditions

[11] Knopf, Adolph, Pyrometasomatic deposits in ore deposits of the Western States (Lindgren volume) Am. Inst. Min. Met. Eng., pp. 553–555, 1933.

favoring silicatization of rocks and dissemination of pyrite were the most widespread. The relatively few and thin beds of limestone present in the sedimentary series greatly restricted the next main stage of mineralization, during which the massive replacement bodies of pyritic base-metal ores were formed. Finally, special structural factors and an apparent shift in position of the source of the solutions further restricted the hypogene enrichment of the sulphide ore by

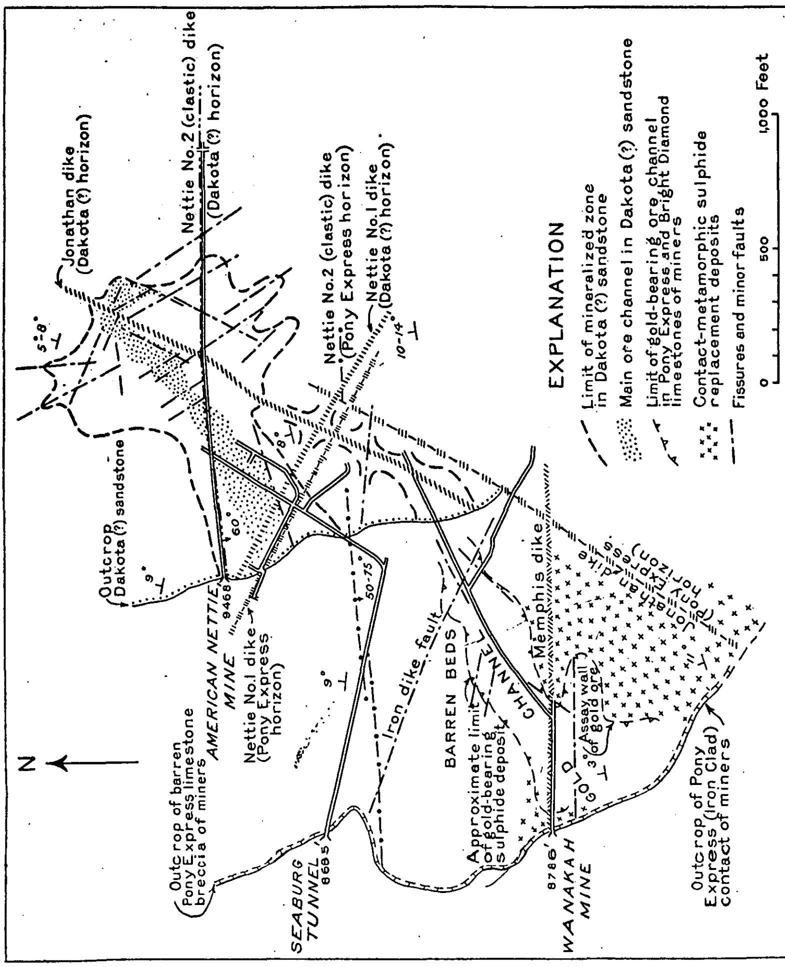

FIGURE 33.—Plan of ore channels in the American Nettie and Wanakah mines, with principal development tunnels.

gold. The gold-bearing deposits are described in this structural group mainly because of the characteristic contact-metamorphic minerals found in close association with certain parts of the gold ore, though, in fact, the gold content seems dependent primarily upon channels of mineralization more closely related to the next following group of deposits, which are not considered of contact-metamorphic origin. These relations will be described in the paragraphs that follow.

The most productive deposits belonging to the contact-metamorphic class are those of the Wanakah group (pls. 53, No. 1, 54, *A*, and fig. 33). These deposits are slightly inclined bodies from 1 to 5 feet thick that conform to the bedding of the Upper Jurassic strata. The two horizons most favorable to replacement are the Pony Express limestone or Iron Clad contact of the miners and the Bright Diamond limestone contact of the miners and enclosing shale beds from 10 to 15 feet above the basal quartzite in the sandstone member of the Morrison. Some gold-bearing sulphide replacement deposits occur also in the top part of the quartzite, but these are not typical of the contact-metamorphic deposits. The limy shales interbedded with and above these zones contain considerable quantities of the contact-metamorphic silicates, and the Dolores formation below contains deposits of lodestone (magnetite and hematite) with a minor percentage of sulphides.

The principal silicate minerals that have been recognized are andradite, hornblende (cummingtonite?), actinolite, epidote, thuringite, stilpnomelanite, and chlorite. Magnetite and hematite are commonly associated with the contact silicates, and apatite, rutile, and titanite are widely distributed as minor accessory minerals. In the closely associated sulphide deposits pyrite is by far the dominant mineral, but chalcopyrite, sphalerite, and galena are present locally, the latter two especially in the upper or Bright Diamond contact. Siderite, calcite, sericite, chlorite, and quartz are gangue minerals present with the sulphides. The minerals were deposited in at least several fairly well defined stages. The earliest was the formation of the lime and iron silicates, andradite, hornblende, and actinolite. This stage was closed with the introduction of the iron oxides. Just before the sulphide stage or very early in it fissuring was renewed, and some additional hematite, together with epidote and thuringite, was deposited. The sulphides followed in the normal order of the gold belt, namely, pyrite, chalcopyrite, sphalerite, and galena. The final stage was the introduction of native gold, which, as mentioned above, was controlled by further fissuring of the beds.

The gold ore channel in the Wanakah mine extends northeastward diagonally across the northern edge of the sulphide replacement body (fig. 33). The northwest boundary of the shoot follows closely the edge of the sulphide ore where it grades into barren beds, but the southeast boundary of the shoot is formed by an indefinite assay wall in the sulphide replacement body. The outlines of the lower channel along the Pony Express beds are shown in figure 33. The upper channel, about 120 feet above the lower one, is essentially along the same line. Along the south side of the gold-bearing channel, particularly at the west, the gold ore is closely associated with contact silicates, but at the northeast and towards the apparent source of the gold-bearing solutions the higher-temperature contact-silicate minerals disappear. At this position the principal products of rock alteration are chlorite or thuringite, quartz, sericite, siderite, and calcite, minerals found likewise in the more distant gold-bearing sulphide ore channels outside the zone of contact metamorphism. The highest concentrations of gold are related to minor fractures or faults parallel or diagonal to the trend of the main channel, and at the extreme northeast end of the channel, where high-grade ore has been found along the southwest side of the northwest-trending fault fissure, locally known as the Iron dike. The massive pyrite bodies lying south of the channel contain very little gold, commonly no more than 0.05 ounce to the ton; however, the enriched ores of the channel according to early records, averaged about 0.5 ounce to the ton in gold, and ore containing from 3 to 5 ounces to the ton was found in a pocket along the Iron dike.

The distribution of gold in comparison with that of the contact silicate and sulphide replacement bodies is roughly indicated in figure 33, which shows an outline of the stoped ground that corresponds essentially to that of higher-grade ore. The figure, however, does not show the full extent of the low-grade pyritic bodies, which have replaced parts of the limestone beds for more than a thousand feet southeast of the Jonathan dike. The occurrence of a rich pocket of gold ore just along and west of the Iron dike is believed to indicate the position at which the gold-bearing solutions broke through this semipermeable barrier. At the northeast end of the American Nettie channel in the Dakota (?) quartzite, a similar pocket was encountered near the Jonathan dike, so that the gold-bearing solutions appear to have had some original source east or northeast of these barriers. Along the line of the Wanakah channel, explorations northeast of the Iron dike or fault revealed more sparingly mineralized ground in which either the sulphides were below commercial grade or ore of better grade was not present in minable quantities. Hence it appears likely that the solutions bearing the gold and a portion of the sulphides came up near or alongside the local barriers and along the north flank of the intrusive zone (pl. 53). On the other hand, the solutions bearing the bulk of the substances introduced during the earlier stages of contact metamorphism appear to have originated more locally southeast of the replacement deposits and along the edge of the central intrusive bodies. The indicated shift in possible sources of the solutions corresponds in direction to that of the more pronounced regional shift between the gold and silver belts of mineralization in the northern division as a whole (see p. 207).

DEPOSITS ASSOCIATED WITH FLEXURES OF NORTHEAST TREND AND RELATED FISSURES AND DIKES

The deposits associated with flexures of northeast trend lie mainly along the bedding of the sedimentary rocks and in relatively small crosscutting veins nearby. The ores belong to the pyritic base-metal group and contain gold and silver tellurides and native gold. The channels of the most productive and highest-grade ore are in the Dakota (?) sandstone that has been locally altered to quartzite, but lower-grade pyritic ores are found in the underlying zone of favorable beds described above. The deposits in the upper, or Dakota zone, lie on the east side of the Uncompahgre Valley from 2,000 to 4,000 feet north of the intrusive center. The flexures that apparently control the positions of the deposits are minor folds or terracelike warps superimposed upon the general north-northeast dip of the strata in this part of the district (pl. 54, *A*). Parts of the ore channels have linear trends that seem to be controlled by relatively minor fissures or joint systems, for in places a channel cuts diagonally across some of the larger dikes and fissures in its course. In other places the ore is found in the favorable sedimentary rocks near the walls of these dikes or ends against the dikes. On the other hand certain fissures, some of them occupied by dikes, formed conduits along which the ore-forming solutions migrated from one stratigraphic horizon to another. In the Dakota (?) quartzite, which is more than 100 feet thick, the ore is found at several favorable horizons, commonly just below shale partings. Because of the relatively large vertical range of the deposits in this formation and the local complexity of the structural controls, small pockets of high-grade ore have escaped detection during many years of prospecting. Some of these have been found and mined within the last few years, although the high-grade ore along the main channels is exhausted.

There are only two known ore channels in the northern division of the district that are controlled by structural features of this kind—that of the Wanakah group in the lower ore zone, already described, and that of the American Nettie, O. & N., and Jonathan groups mainly in the Dakota (?) quartzite (pl. 54, *A*, and fig. 33). The main ore channel of the American Nettie (pl. 53, No. 2) essentially parallels that of the Wanakah mine and probably is related to the same zone of flexing, though the two are separated about 800 feet stratigraphically and from 500 to 600 feet horizontally.

The gangue of the pyritic ore is similar to that associated with pyritic deposits in the contact-metamorphic zone, except for the absence of the contact silicates. The principal minerals are sericite, quartz, chlorite, and carbonates, but there is in addition some barite. The ore minerals include sphalerite, chalcopyrite, galena, tennantite, tellurides of gold and silver, and native gold. The tellurides and native gold, which represent the latest stage of mineralization, are characteristic of this group.

The ore-forming period was introduced by the intrusion of clastic dikes, which was followed by sericitization, chloritization, and carbonatization of the sedimentary rocks and igneous dikes. Hydrothermal leaching of the sandstone beds, which occurred locally, was especially strong west of the Jonathan dike (pl. 54). The highest-grade ore appears to be definitely related to channels along which hydrothermal leaching took place and where at the same time the surrounding sandstone was converted into quartzite. Both cave filling and replacement were thus involved in the formation of the deposits. Fissure and replacement veins occur locally in close association with the bedding deposits, but the largest ore bodies lie in the upper or middle part of the massive quartzite. In the American Nettie channel the caves and bedding replacement deposits commonly occur along a linear group of small fractures in the quartzite, produced evidently by the moderate bending or flexing of relatively brittle beds. The main ore channels lie west of the northeastward-trending Jonathan dike, the walls of which acted as a semipermeable barrier to lateral migration of the ore-forming solutions. Intersections of this dike with fissures or other dikes of east and southeast trend appear to have afforded conduits for the passage of the solutions from lower to higher horizons. Thus in places cross fissures within the dike, which is from 15 to 20 feet thick, were mineralized below the horizon of the main deposits in the quartzite. Where mineralized in this manner, the dike is highly pyritized, silicified, and sericitized, and the ore appears to be largely of replacement origin. The higher-grade ore within the dike is not known to extend more than 100 feet below the horizon of the quartzite into the uppermost Morrison beds, but lower-grade pyrite and altered rock continue downward an unknown distance. Such bodies may indicate the positions of feeding channels from below. East of the Jonathan dike the American Nettie channel has been very much less productive as the sulphide bodies are more scattered, of smaller size, and for the most part of lower grade.

West of the Jonathan dike the highly productive central part of the American Nettie channel was bounded on either side by small caves only partly filled with ore or lined with barren quartz crystals. At the outcrop and for some distance into the deposit the original sulphide ore was thoroughly oxidized and reduced to a clayey mass in the bottoms of the caves that contained iron oxides, hydrous sulphates of iron and copper, and native gold. The proportion of original sulphide increased down the pitch of the shoot, and just west of the Jonathan dike an extremely rich pocket of sulphide and telluride ore was encountered. This contained masses of native gold and gold and silver tellurides, mostly hessite, which were associated with pyrite, chalcopyrite, sphalerite, galena, tetradymite, benjaminite (?), and tetrahedrite. The occurrence of this large pocket was similar structurally to that of the smaller one of the Wanakah channel described above, as it lay just west of a partly permeable barrier (fig. 33). This pocket apparently resulted from an abrupt change in pressure on the ore-bearing solutions where they entered the permeable quartzite west of the dike, although it also appears likely that comparatively large pre-ore caves existed in the quartzite at this position. As stated above, the quartzite was leached hydrothermally mainly before the sulphide and telluride stages of mineralization. Ore formed by replacement and recently mined from a deposit near the edge of this pocket contained from 2 to 4 ounces of gold and 2 to 25 ounces of silver to the ton. Ore mined in 1898, that may have represented the central cave filling, had a value of as much as $3,000 per car of 10 tons. According to the average ratio of gold and silver in the ore, this value represents about 12 ounces of gold and 60 ounces of silver to the ton. In general, however, the proportion of silver probably increases somewhat in the highest-grade telluride- and tetrahedrite-bearing ore.

DEPOSITS ASSOCIATED WITH FISSURES AND DIKES OF EAST TO NORTHEAST TREND

These deposits include veins and small associated bedding deposits that contain gold-bearing ores and silver-lead-zinc ores. The combined production of the larger silver-lead veins forms a large part of the total output of the district.

Most of the gold-bearing veins lie within the intrusive zone and a belt 3,000 to 4,000 feet in width to the north of it. Many of these veins replace the wall rocks, but some of the richest ore was formed partly by the filling of fissures. The walls of the granodiorite porphyry dikes or of the clastic dikes, which are favorable positions for the veins, are mineralized in all formations from the Hermosa to the Dakota(?) sandstone. The ore shoots, however, lie mainly in massive permeable beds that have favored open fracturing and replacement. They are small compared with the vertical and lateral extent of the fissures. Alternations of sandstones and shales tend to deflect the strikes and dips of the fissures, and, in conjunction with the slight faulting, these irregularities control the location of some shoots. In the Memphis and some other deposits the mineralized fissures are parallel to the dikes only a few feet away from their walls, as though induration of the sandstones by heat and emanations from the dike had favored refissuring or replacement at this position rather than along the immediate wall of the dike. The mineral composition of the gold veins of this group is relatively simple. The principal sulphides are pyrite and chalcopyrite, with minor amounts of hematite, sphalerite, galena, and native gold. The gangue minerals are quartz, sericite, thuringite or chlorite, and calcite. Locally the walls of the higher-temperature replacement veins are recrystallized to aggregates of quartz, orthoclase, thuringite, epidote, apatite, and titanium minerals. Representative deposits are the Great Western and the Memphis (pl. 53, Nos. 3 and 4), in the Hermosa and Cutler formations, respectively.

Almost all of the silver-bearing veins have nearly east-west strikes and are found north of the gold belt. The more productive of them lie from 1 to 4 miles north of the intrusive axis, and their productive ore shoots lie between half a mile and 2 miles east of the Uncompahgre axis. In the productive belt only clastic dikes are found along the veins, but farther west in the nonproductive belt both igneous and clastic dikes are present. The igneous rocks are of latitic to dacitic composition. The veins are most productive within the Upper Jurassic formations and in the Dakota(?) sandstone, and the width of vein matter is noticeably less in the Cutler formation beneath the base of the Triassic. This is in part due to the relatively shaly character of the Cutler formation, and in part to the highly permeable limestone breccia at the base of the Morrison formation, which acted as the main lower channel of circulation (pl. 54, *C*). The ore-forming solutions, which apparently originated from a source near the intrusive axis and 2 to 3 miles or more east of the Uncompahgre axis, moved upward and westward in paths nearly conformable to the easterly tilt of the beds. The east limit of possibly productive ground along the veins has not been reached, but in this direction the ores show an impoverishment in silver and lead and an increase in iron and zinc. This change in composition takes place much farther east of the Uncompahgre axis in some veins than in others.

The silver veins of the northern division may be separated into two groups. The southern group comprises those veins lying along and south of Dexter Creek. In this group the more productive ore shoots are found within a belt that trends northeastward parallel to the intrusive axis, though the individual veins trend nearly due east. The best ground is found both in the upper zone of favorable beds in and below the Dakota(?) sandstone and in the lower favorable zone near the base of the Upper Jurassic (pls. 53, Nos. 5–8, and 54, *B*). In the northern group (pl. 53, Nos. 11–13) the productive belt lies farther west, and nearly all production has come from the lower favorable zone. Along the north side of Dexter Creek the two groups are separated by a westward-trending belt of intrusive dikes and plugs composed of fine-grained, porphyritic latite or dacite with associated clastic-dike material. Fissures along the line of this intrusive belt are much less productive than those to either the north or the south. The southern group, which includes the Bachelor, Pony Express, Calliope, El Mahdi, Old Maid, and other veins, has been by far the most productive. The solutions perhaps rose along a course parallel to the northwest side of the intrusive zone, and thence traveled westward along the fissures and more permeable bedding channels. Under such conditions the comparatively weak mineralization in the Dakota(?) or upper favorable zone in the northern group might indicate that the solutions failed to gain direct access to these higher beds and hence that the zone of intrusion plunges deeper northeastward.

In the southern group of veins a structural feature of particular interest is the approximate coincidence of the ore shoots along the Pony Express, Bachelor, and Calliope veins with a reversal in the normal northeast dip of the country rock (pl. 53, Nos. 5–8). This reversal of dip is strongest along the line of the Pony Express fissure at the extreme west where the beds dip locally 15° to 20° southward (pl. 54, *B* and *C*). In the easternmost workings of the Bachelor vein the strongest reversal crosses to the north side of the vein and extends across the line of the Calliope ore shoot about 1,200 feet north of the Bachelor. Here the beds locally dip as much as 30° south or southeast but for short stretches only. Thus the main zone of flexing strikes more to the northeast than the veins and is similar structurally to the northeastward-trending flexure along the ore channels of the gold belt. It is possibly caused likewise by subsidence towards the mountain front or the intrusive axis. Because of the additional fracturing of the beds along the line of the flexure and its possible influence on the strikes and dips of the veins, the flexure may be a factor in the localization of ore shoots in the several veins. If so, its northeasterly extension across veins beyond the Calliope vein should be of interest in further prospecting.

In the northern group of veins no such pronounced flexures exist, but several thousand feet east of the outcrops of the productive lower beds these veins are said to have become progressively impoverished. Certain of the ore shoots lie either to one side or the other of cross breaks essentially parallel to the Uncompahgre axis. Similar cross breaks also intersect the Neodesha and Pony Express veins of the southern group about a mile east of the Uncompahgre Valley. As only a few of the cross breaks contain ore and as they nearly parallel the Uncompahgre axis of uplift, they are interpreted as shallow tensional breaks along the crest of the arch and hence are not believed to extend deep enough to tap primary sources of mineralization. This zone of cross breaks extends northward from the intrusive axis to Cutler Creek and beyond, but only at the south close to the intrusive axis, where the igneous activity was shallow, do any of them contain igneous dikes; also, more of them are mineralized there than elsewhere. Individual fissures in this zone are not continuous for long distances, and they appear to be arranged en echelon. Though some of the fissures of this trend are premineral they were choked by gouge because of slight faulting and are not commercially mineralized, but others as far north as Dexter Creek are locally mineralized (pl. 53, No. 10). Several of these fissures show evidence of post-ore origin or reopening, as they contain only quartz or crystals of scalenohedral calcite, which were formed after the ore; indeed, some of this vein filling may belong to the late Tertiary epoch of mineralization.

The position of an individual ore shoot in the east-west veins is dependent upon several factors, among which the character of the enclosing rocks, the dip and strike of the fissure, and certain deflections of the fissure locally known as rolls are the most important. The more massive sandstone beds such as those of the Dakota(?) and certain beds in the upper Jurassic formations maintain the open fissures, whereas the interbedded shales tend to choke or tighten them. The alterations of sandstone and shale in the Morrison formation have the effect of deflecting the fissures from the vertical so that at certain favorable horizons the fissures are diverted laterally from 10 to 40 feet or more where they pass from a massive bed into shale or limy shale beds. Along these rolls the ore spreads out in flats between the diverted parts of the vein, and some of the flats are continuous for long distances along the strike of the fissure as in the Bachelor mine. Where the beds are locally flexed, as along the strike of the Pony Express vein, the rolls are wide and the permeability of the Pony Express limestone breccia favors the formation of bedding deposits that extend beyond the limits of the vertical parts of the veins (pl. 54, *C*). Ore in the deposits in the breccia is commonly of lower grade than that in the vertical fissures, owing to the dispersion of the mineralizing solutions in the bed and to the replacement of the rocks by gangue minerals and sulphides during the early stages of mineralization; but where the bituminous limy shales at the base of the Pony Express limestone breccia are intersected by silver-bearing veins, very high grade silver ores may be precipitated in the shale along the roll of the fissure. The deflection of the fissure, moreover, tends to result in alterations of dip in the generally vertical course of the fissure, so that wherever there is slight faulting along the fissure the changes in dip may result in favorable openings. Most of the fissures are remarkably straight, and most changes in strike are not sufficiently pronounced to affect the distribution of ore appreciably. There is a suggestion along the Bachelor and Calliope veins, however, that slight curves in the strike to the right coincide with more favorably mineralized stretches. These changes in strike may be related to intersection with the northeastward-trending flexure of Dexter Creek.

SUGGESTIONS FOR PROSPECTING

The narrow gold-bearing veins and the contact-metamorphic deposits of this division need few suggestions for prospecting. The ore shoots are small and the productivity of the group as a whole is not likely to be much extended by extensive prospecting. Further prospecting on the gold-bearing veins should be confined mainly to the coarser-grained and more massive sandstone beds for most favorable results. As yet explorations in the intrusive zone of this division have not yielded evidence of large low-grade stockworks or bodies of disseminated ore. One of the longer exploratory tunnels in the intrusive area, the Mayflower, has failed to disclose either disseminated deposits or veins of appreciable size, but it has not cut the main intrusive body. As has been mentioned on page 213, disseminated copper deposits have been found in the intrusive stocks of the La Plata Mountains and may exist at somewhat greater depth in the Uncompahgre center. At best, the chances of finding large bodies of low-grade disseminated ore are not good, but the possible occurrence of disseminated chalcopyrite in porphyritic rocks should receive some consideration. The pyrite disseminated in rocks within and near the intrusive zone is not likely to contain sufficient gold or copper to make ore.

The gold-ore channels of the American Nettie and Wanakah mines just north of the intrusive zone were productive mainly in the belt that lies between the Jonathan dike and the Uncompahgre axis. This belt has been rather thoroughly explored in the lower favorable beds by the workings of the Wanakah group and Seaburg tunnels and in the Dakota (?) quartzite, or upper favorable zone, by the workings of the Jonathan, American Nettie, and O. & N. groups. There remains to be considered certain parts of the ground east of the Jonathan dike and ground below the upper workings, which, as mentioned before, are thought to be less favorable because of the high pressure and temperature that probably existed there during mineralization. West of the dike the general direction of movement of the ore-forming solutions seems to be clearly indicated by the trends of the ore channels, but east of the dike there is less evidence on this feature, as some of the easternmost workings are inaccessible and only relatively scattered and small bodies of ore have been found. With respect to the American Nettie channel it is possible that the solutions rose into the quartzite by way of steep channels formed by northwestward-trending breaks that cross the Jonathan dike along and north of the Nettie Nos. 1 and 2 dikes (fig. 33). Here, impounded by the overlying shale beds east of the dike, the solutions spread outward until a large breach was encountered in the dike wall near the root of the main ore shoot. Hence the solutions may have come from the lower permeable zones in the Pony Express beds where they were trapped in the pocket formed by the intersecting dikes and forced to migrate upward to the Dakota

(?) quartzite. Another possibility is that the solutions gained access directly to the quartzite from the southeast along numerous minor fractures that intersected the intrusive zone. This second possibility is favored by the fact that a considerable thickness of relatively impermeable shale lies between the lower and upper ore zones, though it is probable that a portion of the solutions made their way upward through these shales along and within dikes, especially within and near the Jonathan dike at cross-fissures mentioned on pages 224 and 231.

The Seaburg tunnel workings, directly beneath the American Nettie channel, failed to expose large bodies of ore west of the Jonathan dike but encountered ground that had been leached and locally mineralized by hot solutions along and near the Nettie No. 1 dike, which strikes S. 60° E. (fig. 33). In view of these showings, the amount of work already accomplished, and the first-mentioned possibility that the solutions rose from depth along the dike, an extension of the Seaburg tunnel to explore the ground along both walls of the Jonathan dike as well as within the dike on cross-breaks appears justifiable. Some unfavorable factors other than the uncertainties mentioned above should be appreciated. Owing to the increased distance from the Uncompahgre break and to the barrier effect of the Jonathan dike, pressure east of the dike would have been higher during mineralization and consequently leaching by hot solutions would probably have been a more subordinate factor in preparing the ground for mineralization; furthermore the Pony Express breccia along the eastern inclines of the Seaburg tunnel shows a pronounced decrease in thickness and permeability so that if this change continues east of the dike the conditions for mineralization were still less favorable. The breccia, however, may increase in thickness northeastward, so that exploration in that direction is more worthy of consideration, especially as it would also bring the workings more directly beneath the root of the main channel of the upper zone (fig. 33).

Because of these unfavorable factors, exploration east of the Jonathan dike, if attempted, should be extended northeastward from a point near the intersections of the Jonathan dike with the Nettie No. 1 porphyry dike and Nettie No. 2 (clastic) dike. If the Pony Express breccia does not increase in thickness or permeability there is little justification for extending drifts much beyond the northeast end of the main ore shoot above. If, on the other hand, the breccia does increase in thickness in that direction, the better-grade ore shoots are likely to be found within the zone where such change occurs, as the greatest changes in pressure on the ore-forming solutions are likely to have occurred there.

Possibly also a narrow favorable zone may exist in leached beds along the west side of the Jonathan dike. A drift northward parallel to the dike along this side would determine shortly the possibility that sulphide pockets there might contain higher-grade ore than the small ones already found several hundred feet west of the dike. Where the breccia remains thin and tight, such pockets are likely to be small at the best; but, as in the American Nettie and Wanakah channels, the grade of ore is likely to be better at positions near the side of a local barrier that faces towards the Uncompahgre break.

In the upper workings below the quartzite the more favorable places for prospecting in depth would be those near or within the Jonathan dike at cross-fissures or cross-dikes (fig. 33). If the ore-forming solutions came up from below along such channels, the ore is likely to be confined within narrow, steep shoots. It is not possible to predict the depth to which small ore shoots of this type could be profitably mined (see p. 224). Where the dike walls are shale the ore is perhaps more likely to be confined within the dike, but where the walls are sandstone some ore might lie in shattered or fissured sandstone near the dike and cross-fissures.

The extension of development eastward on the silver veins of the southern group in this division of the district involves mainly engineering problems, particularly because of separation of the better ore shoots into upper and lower zones with less productive ground between them (pl. 54, *B*). Thus, in both the upper and the lower workings of the Bachelor Consolidated mine, and probably in the Calliope mine, the most favorable stratigraphic zones dip below the main working tunnels in the easternmost workings. Extension of the lower Bachelor (Syracuse) tunnel eastward to the place where it should intersect the Dakota (?) sandstone on the down dip would require a mile or more of development, and the relatively unfavorable ground between the upper and lower productive zones through which a drift must pass increases the risk of getting an inadequate return on the cost of exploration. Hence the geologic conditions seem to require that development should be based on an income from current production that would equal or exceed the cost of exploration rather than on the uncertainty of tunneling through poorly mineralized ground with the hope of eventually reaching favorable ground and an ore body sufficient to return a net profit.

Beneath the Calliope and other veins, lying within 1,000 or 1,200 feet north of the Bachelor, the lower or Pony Express zone has not been prospected by any of the development tunnels. The most direct way of reaching this ground is by a crosscut northeast from the lower Bachelor (Syracuse) tunnel. There is reason to believe that the ground may be mineralized, but the grade of ore is likely to be low, and the better mineralized ground may lie farther east than that along the Pony Express vein. Hence prospecting this ground should also be regarded as relatively hazardous, until it can be proved that the known ore deposits of low to moderate grade in this same zone along the Pony Express and Bachelor veins can be mined at a profit. Recent mining and milling operations, employing selective flotation on ore from this zone, yielded about 0.006 ounce of gold, 11.3 ounces of silver, 1.9 percent of lead, 0.08 percent of copper, and 0.1 percent of zinc per ton of ore mined. In the easternmost workings on the lower ore zone the ore in place assays about equal proportions of lead and zinc, with a combined lead and zinc content of 7 to 14 percent.

Other veins, such as the Little Eva, (pl. 53, No. 9) which lie 1,700 to 1,800 feet north of the Calliope, may also belong to the southern group. These have not proved productive in the upper or Dakota ore zone, and they are not exposed in the lower ore zone. If it could be shown that the Dexter Creek flexure had been the sole or main factor in the localizing of ore shoots, exploration along these veins as far eastward as their intersections with the projected flexure would be warranted. However, because of other possible factors, such as distance from the Uncompahgre axis and the absence of knowledge on the trend of the concealed flexure farther east, the exploration of these veins to a distance of several thousand feet east of their outcrops involves undue risk. On the other hand, should eastward development on the larger veins to the south prove feasible at some time in the future, crosscutting to these more northerly veins in both the lower and upper ore zones might be risked.

With the exception of the Senorita, silver mines of the northern group have been explored several thousand feet east of the outcrops of the lower favorable beds, and reports indicate a gradual impoverishment of ore eastward. These northern veins differ from those of the southern group in that the lower ore horizon, embracing the lower La Plata sandstone and Pony Express beds, is the only one appreciably mineralized. The Senorita mine (pl. 53, No. 13) has received the least development, but favorable metal prices should warrant extension of the workings farther east. As in all the mines of this group, the small vertical range of the favorably mineralized zone adds to the cost of mining, but, as the easterly dip of the formation is less here than in the southern group, development can be continued for some distance from one main working tunnel before reaching the place where the mineralized zone passes below tunnel level.

All the outcropping mineralized fissures of the northern group have been prospected or mined, but there may be a blind ore shoot along the eastern part of the dike that lies from 1,200 to 1,400 feet south of the Newsboy vein and dike (pl. 53, No. 11). The main supporting evidence for this speculation is that, although the exposed part of this dike is barren at the surface, ore is present to the east along one of the northwestward-trending fissures in the Dakota(?) sandstone (Black Silver and Champion, pl. 53, No. 10), about in line with the dike. If the two intersect below in the Pony Express or lower ore zone, structural conditions would be favorable for an ore shoot. Although no large bodies of ore have been found along it, the northwestward-trending fissure contains vein material consisting of pyrite, sphalerite, galena, tetrahedrite, polybasite(?), and pyrargyrite. If the inference is correct that these northwestward-trending fissures are shallow tensional breaks that fail to tap primary sources of mineralization, the presence of even small ore bodies at this position suggests that they have been formed by solutions that escaped from some east-west channel beneath the Dakota(?) sandstone. As the strongest channels of the northern group of veins lie in the Pony Express limestone breccia, there may be a concealed channel in these beds along the line of the dike in question. A part of the work necessary to test this ground has been accomplished in the Ely tunnel (pl. 53, No. 10a), which is north of Dexter Creek on the Pony Express limestone. The breast of the tunnel, about 900 feet N. 14° E. from the portal, appears to be within a few hundred feet of the eastward extension of the dike or its fissure. The tunnel should first be extended this distance to determine if the fissure or dike actually extends this far eastward. If not, further prospecting would hardly be justified. The presence of strong fissuring or silicification along the line of the dike may be considered favorable. Drifting 600 to 700 feet eastward from the intersection of the extended tunnel and the dike, or its fissure, would be required to cross the mineralized northwestward-trending fissure and explore the ground east of it.

WESTERN DIVISION

GENERAL FEATURES

Many of the larger mines along the gold-bearing fissure veins of the western division are located in a narrow zone near the intrusive axis along the west side of the Uncompahgre Canyon. Most of the veins strike nearly east-west, but some follow the more northeasterly trend of the granodiorite porphyry dikes. The country rock includes the Cutler formation and the overlying Mesozoic strata. The ore consists mostly of pyrite and chalcopyrite, with minor amounts of other base-metal sulphides. Quartz and sericite are the principal gangue minerals, but locally a little barite is present. Some veins contain much specular hematite, partly associated with and partly independent of sulphides. The ores have replaced the more permeable sandstone beds near fissures, but some of the better-grade ore appears to have been deposited partly in openings.

In the Mesozoic beds are some bedding-replacement deposits along the basal Upper Jurassic formations, either in the Pony Express limestone breccia or in the more massive sandstones. These have been less productive than those in the northern division east of the Uncompahgre break.

Although most of the deposits in this division lie near the intrusive axis, some lie a mile or two to the north or west. Those to the west consist of gold-bearing fissure deposits in the Dakota(?) sandstone, and those to the north, along and north of Corbett Creek (pl. 53, Nos. 20, 21), consist in part of similar gold, silver, and lead deposits in the Dakota(?) sandstone and in part of bedding deposits in the Pony Express limestone, which are essentially western extensions of the silver-lead-zinc channels of the northern division. Most of the bedding deposits lie close to the crest of the arch along the Uncompahgre axis and for practical purposes may be considered as belonging to the northern rather than to the western division. The total production from all these outlying deposits of the western division has been comparatively small.

DEPOSITS ASSOCIATED WITH FISSURES AND DIKES OF EAST TO NORTHEAST TREND

Essentially all of the deposits associated with eastward-trending fissures and dikes in the southern part of the western division belong to the pyritic gold-bearing class (pl. 53). The fissure veins and bedding deposits of this class that lie immediately west of the Uncompahgre break are second in production of gold in the district, but as might be expected from their relation to the two major axes of structural control, they have not been productive very far west of the Uncompahgre break, and their total gold production is very much less than that of the northern division. Mineralizing solutions from deep sources along the intrusive zone apparently rose steeply along the fissures and tended to seek an egress towards the surface along the line of the Uncompahgre break. Toward the north where the Uncompahgre break grades into a gentle arch the solutions spread westward from the northern division into the Corbett Creek area, but the mineralization became increasingly feeble. Also along the line of the intrusive zone some mineralization took place in such favorable beds as the Dakota(?) sandstone as far west as Oak Creek. Because of its permeability this sandstone acted as a receiver for such solutions as escaped up through the lower formations to the base of the highly impermeable capping of Mancos shale. Most of the ore shoots, however, except those lying close to the Uncompahgre break, have been of little economic importance. They imply that the volume of mineralizing solutions that escaped along fissures distant from the Uncompahgre break was small.

The ores are mainly of the pyritic replacement type, but contain chalcopyrite, sphalerite, and galena locally. Near and within the intrusive zone hematite is also locally developed. The principal gangue minerals are quartz, sericite, chlorite or thuringite, calcite, and barite, with manganocalcite locally. The gold appears to be closely associated with ore that contains fair amounts of chalcopyrite. The mineral composition of the ores is thus similar to that of the gold deposits of the northern division, except that tellurides if present have not been recognized. Where the fissures and dikes of easterly trend intersect the favorable beds in the basal Upper Jurassic strata west of the Uncompahgre break, bedding deposits similar to those east of the break have been formed locally, such as that in the Rock of Ages (pl. 53, No. 16). Bedding deposits in quartzite of the Morrison formation show evidence of leaching and cavity formation similar to that in the American Nettie mine, but the caves are much smaller and decrease westward in size and number, indicating that the solutions moved eastward toward the Uncompahgre break. Along the fissures that have been developed west of the valley, the workings are mostly less than 1,000 feet in length, and, in such mines as are accessible, indications of slight impoverishment are shown in the westernmost workings. The largest developments on the veins are in the Cutler formation, whose massive sandstones or arkosic sandstones appear to have been favorable rocks for the formation of small ore shoots. In the interbedded shales the fissures are more commonly tight. As noted in connection with the similar veins of the northern division, alternations of the sandstones and shales have caused deflections of the fissures, so that changes in strike and dip, as well as in the nature of the rocks, have apparently influenced the formation of ore shoots. As most of the veins are narrow and the ore shoots are small, they have been developed largely by intermittent leasing operations. Few of the deposits have supported large-scale operations for any length of time.

SUGGESTIONS FOR PROSPECTING

Although a few relatively large ore shoots have been found in all the thoroughly developed mines of this division, structural conditions in general have not been favorable for the formation of large shoots comparable with those of the northern division, and this condition should be realized in any plans for prospecting or further development. On such veins as the Plutus (pl. 53, No. 17), which are only partly developed, exploration could be extended deeper as well as higher along the slopes of the valley; however, it does not appear that the known ore can be extracted profitably from the present workings, and it seems unlikely that further work will disclose ore of much better grade, or much larger shoots.

Where the veins and dikes intersect the favorable beds in the lower Mesozoic formations, above and below the Pony Express limestone breccia, the present workings in most of the fissure and bedding deposits appear to have exhausted the larger ore shoots. Extension of workings westward would not be likely to yield important new discoveries but would probably show a continued decrease in the size and number of shoots.

The same statements apply to deposits in the upper part of the Morrison formation and in the Dakota(?) sandstone along westerly extensions of the Rock of Ages and other fissures that lie north of the Morning Star (pl. 53, No. 18). Some minor production has been made as far west as the Stenographer (pl. 53, No. 19) in the Dakota(?) sandstone on Oak Creek, but these deposits as a whole have been only intermittently productive. Possibly the fissures along which they formed may have been enriched at or near intersections with some of the northwestward-trending breaks that parallel the Uncompahgre axis. As on the east side of the valley, it seems probable that the Dakota(?) sandstone may once have contained larger and richer gold deposits, but this formation has been eroded much farther back from the line of the valley than the lower mineralized beds, so that any large deposits of this division that were formed close to the Uncompahgre break have been destroyed by erosion.

SOUTHERN DIVISION

GENERAL FEATURES

Except for small pyritic deposits close to the south margin of the intrusive zone the southern division contains chiefly fissure and bedding deposits of silver-lead-zinc ores. Most of these deposits lie southwest of the town of Ouray in the limestone beds close to or south of the Ouray fault. The Mesozoic beds have been eroded from this part of the division, except a narrow strip from a few hundred to 2,000 feet in width along the south side of the intrusive axis. The Molas, Hermosa, and Cutler formations overlie the lower limestones along the sides of Canyon Creek near its junction with the Uncompahgre River. As the Molas formation and the basal parts of the Hermosa are dominantly shaly, most of the silver-lead deposits along the bedding of the Leadville limestone lie just beneath these impermeable shaly beds. The production from the division has come mainly from one bedding channel and from several smaller combined bedding and fissure deposits. The division's production of silver-bearing ores of the Uncompahgre epoch of mineralization, which in large part came from the Mineral Farm mine, has probably been much less than a million dollars.

The silver-bearing ores are similar in mineral composition to those of the northern division. They include baritic or siliceous lead and zinc sulphide ore, with chalcopyrite, tetrahedrite, pearceite, and ruby silver (pyrargyrite). The gold content of the ores so far mined has been low. These deposits are distinguished from the nearby late Tertiary silver-lead veins of Hayden Mountain by the typical association of pearceite with tetrahedrite and by the ankeritic carbonate associated with the ores in limestone.

For purposes of description the southern division is conveniently divided along the line of the Ouray fault. The area south of the fault is the more important commercially; that north of the fault includes a few pyritic deposits close to the intrusive zone and some silver-bearing veins in the limestone just north of the fault, but the part of this area that lies near and beneath the town of Ouray is unfavorable to mining development because of structural conditions or the presence of hot springs.

AREA SOUTH OF THE OURAY FAULT

Deposits associated with flexures and faults of general easterly trend.—The principal secondary features of structural control in the area south of the Ouray fault, and in the entire southern division, are faults and associated fissures or flexures that trend eastward parallel to the strike lines of the pre-Cambrian formations. The pre-Cambrian rocks consist of steeply dipping to vertical bands of massive quartzite 600 to 800 feet thick alternative with relatively incompetent shale bands 500 to 600 feet thick. The great differences in competency of these bands and the probable existence of very old lines of weakness along their contacts have strongly influenced younger lines of deformation. These conditions are illustrated in plates 53, section A–A′, and 54, *E* and *F*. The Ouray fault, which is at least as old as the late Paleozoic, parallels the pre-Cambrian rocks that trend N. 75°–80° W. and extends along a layer of slate to the south of which the faults lie along a faulted synclinal trough of slate beds. Faulting was renewed during the successive periods of mountain uplift, including the period of intrusive activity of the district. Although most of the master fault zones within the slate layers were not mineralized strongly because fissuring was parallel to the steeply inclined bedding, the Paleozoic beds lying discordantly above the slate were flexed or slightly faulted, and the fracture channels in them became feeders to the relatively few mineral deposits found in the favorable limestone beds. Some of the stronger faults extend up into the Hermosa formation, and locally, where this formation is thin, also into the overlying volcanic rocks; but the weaker fissures and flexures die out in the shaly beds at the base of the Pennsylvanian strata. Those places where minor faults or fissures extend up into the volcanic rocks afford evidence that renewal of movements along the fault lines continued into late Tertiary time.

In the area south of the Ouray fault the mineralizing solutions originated evidently at the west along the intrusive zone and made their way up along the dip of the formation towards the main valley and the Uncompahgre break. The main channels of mineralization were the fissure zones in the south wall of the Ouray fault and certain minor flexures associated with the eastward-trending faults. The sources of the mineralizing solutions south of the Ouray fault were apparently about 2½ miles southwest of the central intrusive body of the district, about the same distance but in the opposite direction from this center as the probable sources of the silver-lead veins of the southern group in the northern division. The ores of the two divisions are somewhat similar mineralogically.

Hydrothermal leaching of the rocks accompanied the earlier stages of mineralization and in the Mineral Farm deposit appears to have preceded and partly accompanied the silicification of the limestone and shale (pl. 54, *D*). The leaching of the Leadville limestone along fracture channels just beneath the shale of the Molas formation produced caves and cave breccias in which most of the ore is found. The forms and attitudes of individual ore shoots are controlled in part by fissures of northwesterly and southwesterly trends, but the main trend of the ore channel appears to parallel that of the fault in the underlying pre-Cambrian formations (fig. 34 and pl. 53), which is N. 75° W. This fault lies close to the contact between the bands of quartzite and slate though flexures in the overlying limestone beds extend 800 or 900 feet south of the contact (pl. 54, *E*, and fig. 34). About 3,000 feet southeast of the Mineral Farm mine a branch of the fault-flexure in the pre-Cambrian beds follows the south edge of the synclinal fold (pl. 54, *E*). Limestone beds along the southern branch have been silicified and pyritized but contain no minerals that are restricted to deposits of the Uncompahgre period of mineralization. For this reason and because renewed movement appears to have taken place along the fault fissure in late Tertiary time, these mineral deposits cannot be referred definitely to either period of mineralization; however, as the flexure strikes about S. 70° W. its extension would intersect the intrusive zone 6 miles or more southwest of the intrusive center, and it appears probable that the flexure may not have tapped the sources of mineralizing solutions of the early period and that the quartz and pyrite present are of late Tertiary age.

Deposits associated with fissures.—Between the flexures just considered and the Ouray fault are numerous small fissure and bedding deposits. These deposits (pl. 53, No. 25, and others) are mainly fissure veins, but locally the ore extends into favorable layers of the adjoining sedimentary rocks. Solution channels have been leached in the limestone near or along the fissures. Although high-grade silver ore has been found in some of these, the quantity has been small.

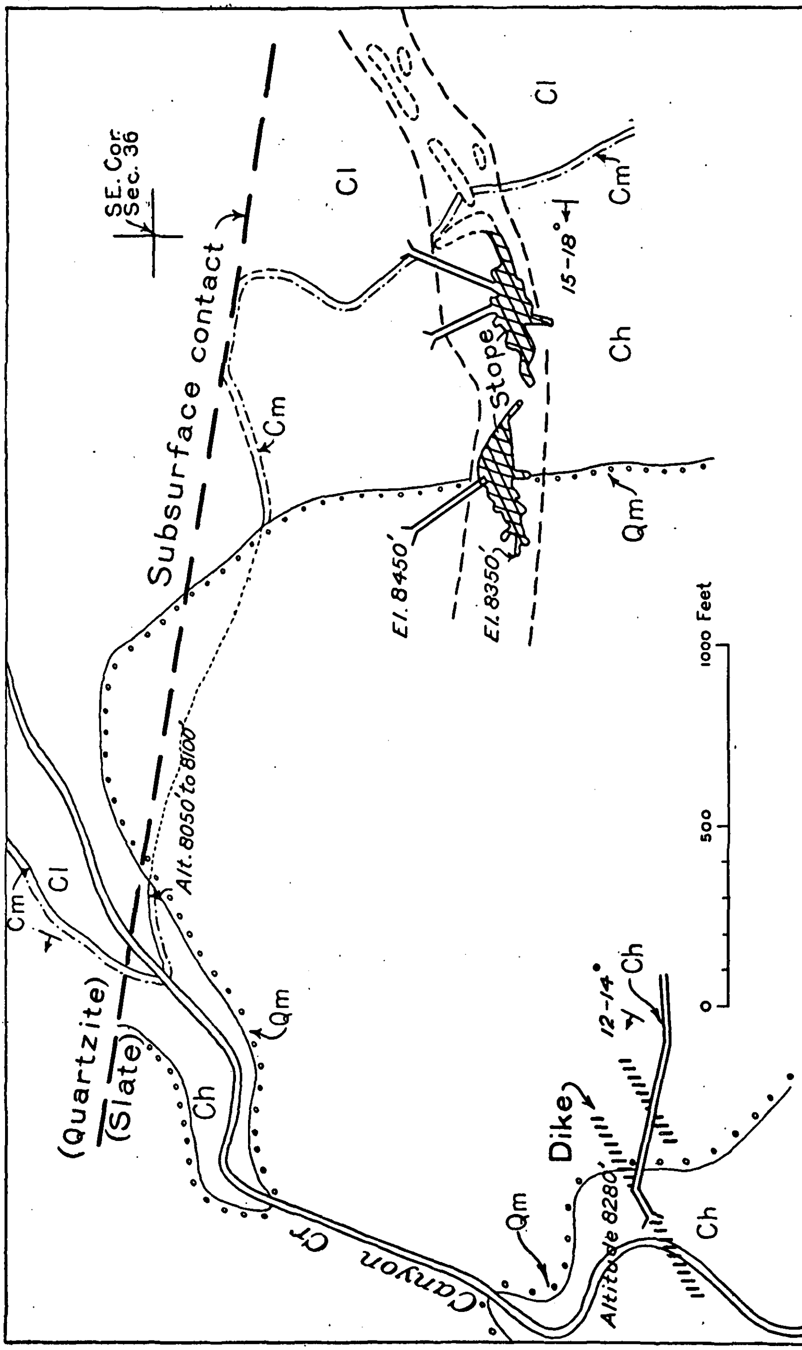

FIGURE 34.—Plan of the Mineral Farm ore channel. Position of developed ground is shown relative to the subsurface contact of the pre-Cambrian quartzite and slate and to dikes at Contact (Legal Tender) tunnel. Cl, Leadville limestone; Cm, base of Molas formation; Ch, Hermosa formation; Qm, border of morainal and landslide area.

AREA NORTH OF THE OURAY FAULT

Most of the triangular area bounded by the Ouray fault, the intrusive zone, and the Uncompahgre break, is underlain by the lower Paleozoic limestones, but they are largely covered by valley fill and, in the west half, by the Molas and Hermosa formations. The most productive deposit of the area was probably the Trout and Fisherman vein (pl. 53, No. 24), which lies in the Leadville limestone and Molas formation near the wall of the Ouray fault. The fissures of this area have a northerly trend and are probably related to tension fractures that parallel the Uncompahgre break. The sulphides of these veins, including ruby silver, were deposited for the most part in solution channels leached in the limestone near or along the fissures.

The ore-forming solutions presumably reached the fissures along fracture channels that plunge westward along the Ouray fault. Just north of the Ouray fault is a sharp fold that trends about N. 65° W., but, although the limestone beds between this and the fault are locally leached and recrystallized, they do not contain productive bedding deposits.

SUGGESTIONS FOR PROSPECTING

As just noted, the northern part of the southern division contains several hot-spring channels. The springs are of much greater economic and social value than any underlying ore deposits, and diamond drilling or otherwise exploring deep ground in this area would be likely to divert or waste the supply of water. Temperatures would also be too high for mine developments, so that the conditions thus preclude economical prospecting in the northern part of the southern division.

South of the Ouray fault the most promising prospects evidently lie along the extension in depth of the mineralized channels already found. Of these the Mineral Farm channel is the strongest and has been developed for about 1,000 feet down the 15° dip of the beds from the portal of the workings, and also for about 600 feet east of the portal on the outcrop of the limestone (fig. 34). The ore in the eastern or shallowest shoot contained considerable tetrahedrite and some pearceite and was higher in grade than that in the western or deeper shoot, where the proportions of zinc and lead were higher. This relatively sudden change in the mineral composition is due perhaps to the more open channel that existed nearer to the line of the Uncompahgre break and the Ouray fault, and to less choking of the channel by shale debris that slumped into it from the overlying Molas formation; in fact, the deeper part of the upper or western shoot was found to be choked with shale breccia formed by caving of the roof. The eastern shoot was inaccessible. There is a possibility that with decrease in silicification, and with a possible increase in the corrosive powers of the leaching solutions in depth, the ratio of sulphide minerals to gangue may increase; furthermore the mineral stages and zoning suggests that the ore may change below the zinc zone into a higher-grade copper zone, possibly containing some gold, and finally into low-grade pyrite. Even though the deposit has not as yet paid for its development, conditions appear to warrant further prospecting of the downward extension of the channel. Disregarding the directions of diagonal and en echelon fractures within the channel, the main trend is believed to parallel the structure in the underlying pre-Cambrian beds.

The most conservative method of prospecting would be to open the western deeper workings and drive an incline in a direction of about N. 75° W. along the indicated trend until the true direction of the channel could be established. If deeper shoots are found, a crosscut to the channel could be made for further development or transportation purposes from the south side of Canyon Creek near the Molas-Leadville contact at an altitude of about 8,100 feet (fig. 34). However, it is very hazardous to prospect for such channels by crosscuts as they are commonly erratic in course and may change in stratigraphic position as well as horizontal direction.

It should be mentioned that some prospecting has been done southwest of the deposit in the belief that this is the general direction of the channel and that the Legal Tender dike (pl. 53, No. 26, and fig. 34) is structurally related to the deposit. The work done was not sufficiently deep to prove or disprove this theory, but, as there is no dike in the limestone near the deposit and as the Legal Tender dike is only feebly fissured and pyritized, there is little evidence favoring the dike fissure as the feeding channel.

The area along the northwest side of Canyon Creek between the Ouray fault and the subsurface contact between the quartzite and slate may also deserve further prospecting, as the upper ore horizon at the base of the Molas formation has not been thoroughly tested there. This horizon is partly concealed beneath talus and morainal debris on the hillslope north of Canyon Creek. Fissure channels such as are exposed in and near the Columbine mine (pl. 53, No. 25) illustrate the possibilities in this area.

The silicified fault flexure (pls. 53, No. 23, and 54, *E*), which crosses the Forest Belle lode claim southeast of the Mineral Farm mine, has not proved to be commercially mineralized, and, as noted above, the quartz and pyrite along it may be of late Tertiary age. Until the Mineral Farm channel has been proved to extend to greater depth and to contain commercial ore bodies, further prospecting to the south of this is hardly warranted. On the other hand, should the Mineral Farm channel become better mineralized in depth or be found to coalesce with other small channels, further prospecting in depth of the ground both south and north of the channel might be justified.

EASTERN DIVISION

GENERAL FEATURES

The eastern division contains small deposits of contact-metamorphic origin along the south margin of the intrusive zone and pyritic gold-bearing deposits that extend for a distance of about 4,000 feet south of the intrusive zone. The northern part of the area between the latitude of Ouray and the intrusive zone is underlain by both Paleozoic and Mesozoic formations, except where the latter have been eroded along the Uncompahgre Canyon. In the southern part the Mesozoic beds and parts of the Paleozoic beds as low as the Hermosa formation have been eroded, and an area east of Ouray nearly a square mile in extent is covered by glacial deposits.

Although the gold deposits in this division extend about as far from the intrusive zone as do those of the northern division, all the deposits explored have been much smaller and their total production is very much less. As in the western division, there are no commercial lead-silver deposits related to the Uncompahgre epoch of mineralization. Most of the known silver-lead veins east and southeast of Ouray belong definitely to the late Tertiary epoch.

The pyritic ores along the south side of the intrusive axis are related to fissures and dikes of either east-west or north to northwest trend. In their stratigraphic positions and mineral content they resemble deposits in the northern division and range from low-grade contact-metamorphic deposits in the limestones of the Hermosa formation and basal Upper Jurassic strata to higher-grade gold deposits in the Dakota (?) quartzite.

DEPOSITS ASSOCIATED WITH INTRUSIVE CONTACTS

As in the northern division, certain favorable beds close to the edge of the intrusive zone have been replaced by contact-metamorphic ores. Most of those of the eastern division lie just south of the faults that limit the intrusive zone. The deposits of the Skyrocket group (pl. 53, No. 27), which lie in the Pony Express limestone have received the most prospecting. In the vicinity of the Skyrocket workings the beds are cut by a small plug of quartz diorite, by granodiorite porphyry dikes, and by numerous small fissures. There are also small sills near the base of the Morrison formation. The mineralizing solutions, guided by these structural features, have highly altered the beds, and locally highly pyritic ores have replaced the more favorable strata. As most of the ore contains only from 0.02 to 0.08 ounce of gold and less than an ounce of silver to the ton the deposits have not been extensively developed. Stratigraphically lower in the Hermosa formation, some of the thin limestone beds also have been replaced by pyritic ores. These are represented by such deposits as that of the Two Kids in the cliffs just north and east of Ouray. They have not proved to be of commercial value.

DEPOSITS ASSOCIATED WITH FISSURES AND DIKES

Veinlike and bedding channel deposits closely associated with fissures and dikes of west to northwest trend or with fracture zones of parallel trends are the most productive of this division. These have been most productive in the Dakota (?) sandstone, which has been altered to quartzite south of the intrusive zone (pl. 53, Nos. 28 and 29). Along the northward- and northwestward-trending fissures the quartzite is irregularly warped and slightly faulted. The fissures of these trends acted as feeding channels for solutions that entered the quartzite along the south boundary of the intrusive zone. The solutions were in part diverted to fissures of westerly trend along which some of the larger deposits were formed by replacement of beds or by the filling of solution cavities.

SUGGESTIONS FOR PROSPECTING

The eastern division is less favorably situated than the northern for the formation of large ore bodies, as there are no direct circulation channels between the intrusive axis and the Uncompahgre break. The ore-forming solutions appear to have traveled south or southeast a short distance and then westward towards the Uncompahgre Valley; hence prospecting far towards the east in this division is not likely to lead to the discovery of larger ore bodies, because it would be increasingly remote from the source of solutions as well as from the general course followed by them. Another unfavorable factor is that slightly more than a mile east of the Uncompahgre Valley the Dakota (?) quartzite is absent, as it was eroded during the Telluride epoch. The Telluride erosion surface where it truncates the quartzite may be seen on the slope north of the Amphitheatre a little more than a mile east of Ouray.

As indicated diagrammatically on plate 53, solutions gaining access to the quartzite appear to have moved southward or southeastward along dikes, fissures, or faults, until cross fractures of westward trend were reached. The largest and better-grade deposits were found in the Valley View and adjacent properties (pl. 53, No. 29), 3,000 feet or more south of the intrusive zone, along bedding channels and fissures that trend about east. If these channels are explored farther east additional deposits may be found as far as the place where the quartzite has been eroded, but they are likely to diminish in size. Just as in the northern division of the district, the highest grade of ore found along channels in the quartzite is likely to lie on that side of a barrier dike that faces the Uncompahgre Valley or break (see p. 229). Hence if northwestward-trending dikes are found, the better-grade ore may be expected to lie just west of them rather than on the east side. Similarly with respect to east-west dikes, the better ore should normally lie on the south side. If any deposits in the quartzite were exposed during the Telluride epoch of erosion, they may have been oxidized and later covered by the San Juan tuffs. If, therefore, the contact between the sandstone and tuff is reached by exploration eastward it should be followed northeastward in order to intersect any deposits truncated by this surface.

If the general conclusions reached regarding structural control of ore deposition are essentially correct (p. 217), there is little likelihood that large deposits of lead-silver ore of the Uncompahgre epoch exist in the eastern division. Ore of this class would normally lie several miles to the east or northeast of the intrusive center under cover of the late Tertiary volcanic formations (pl. 53). For deposits to have formed at this position there should have been strong fissures or other structural channels extending south or southeast from the intrusive axis toward the edge of the Paleozoic uplift. The only known fissures of this trend, however, are those essentially parallel to the Uncompahgre axis, and, as stated before, they are believed to represent relatively shallow tensional breaks that probably failed to tap the deep sources of mineralization. If strong and deep breaks of this trend do exist by any chance they are effectively concealed by the volcanic cover. The most favorable beds for the deposition of lead-silver ore are the limestone at the base of the Paleozoic section. As these beds crop out where they are upturned along the Paleozoic uplift in the Amphitheatre east of Ouray, they can be prospected towards the northeast along the strike of the flexure. The known structural conditions, however, are not favorable, and, as the beds must be prospected for a long distance towards the northeast, such an undertaking would be extremely speculative.

Lead-silver ores in veins of late Tertiary age, which cut limestone in the area at the head of the Amphitheatre, are discussed in the following section of this report and have no bearing on the possibilities of the older deposits considered above.

ORE DEPOSITS OF LATE TERTIARY AGE

GENERAL FEATURES

The ore deposits of late Tertiary age found in and near the Uncompahgre district are related to two centers of mineralization. The principal center lies to the south in the Silverton quadrangle, and the other, which has received little attention, lies to the east in the Cow Creek area (fig. 32). Descriptions of the controlling structural conditions and mineral deposits of the Silverton center and of the general geology but not the mineral deposits of the Cow Creek area have been published.[12]

[12] Burbank, W. S., Vein systems of Arrastre Basin and regional geologic structure in the Silverton and Telluride quadrangles, Colo.: Colo. Sci. Soc. Proc., vol. 13, No. 5, pp. 135–214, 1933. Ransome, F. L., A report on the economic geology of the Silverton quadrangle., Colo.: U. S. Geol. Survey Bull. 182, 1901. Cross, Whitman, and Howe, Ernest, U. S. Geol. Survey Geol. Atlas Ouray folio (No. 153), 1907.

As the influence of the Silverton center extends into the Uncompahgre district, a review of the general features of the districts south and southwest of Ouray are given in the following paragraphs to serve as a basis for the description and interpretation of the late Tertiary deposits within and near the Uncompahgre district.

The principal known ore deposits of late Tertiary age are fissure veins formed in volcanic rather than sedimentary rock and are related to structural features of deep-seated volcanic origin. Veins associated with the Silverton center radiate from a large volcanic caldera or down-faulted shield-shaped block about 8 miles in diameter. The outline of this block and the distribution of associated vein systems are shown in figure 32. The total area of mineralization covers several hundred square miles and includes many of the most productive districts of the San Juan Mountains.

The form and mineral composition of the deposits are in part dependent on their position relative to this down-faulted block or, more directly, to centers of igneous activity and mineralization along its margins. Small intrusive bodies and local centers of volcanic eruption are relatively common in the marginal areas, and in the Red Mountain district chimney deposits containing sulphide ore lie along the intersections of marginal faults and subsidiary fractures with volcanic pipes. The ores and related altered rocks of this and other districts along the margins of the block are typical of processes related to shallow volcanic sources. Large areas of rock have been affected by fumarolic alteration, and the outstanding associated ore deposits are high-grade massive sulphide bodies, whose precious-metal contents diminish rather abruptly at moderate depths. At moderate distances away from the down-faulted block the intersecting of the fissures becomes less pronounced, the ore bodies are almost entirely fissure veins of greater length and depth, alteration has been confined to the immediate walls of veins, and the vein minerals are typical of those formed at relatively moderate and low temperatures.

The mineral output of the districts south and southwest of Ouray has come mainly from the San Juan tuff, an andesitic tuff-breccia, which forms the thick basal member of the volcanic series. In general the younger rhyolitic and latitic members of the volcanic series do not contain strong fissures. However, such a generalization is found to have some significant exceptions because the local strength of rupturing forces, the presence or absence of dikes along vein walls, and changes in strike and dip of the fissures are locally more weighty factors than the nature of the country rock. The possibilities of production from the different sedimentary and metamorphic rocks of the basement vary greatly with local conditions. The particular conditions existing just south of the Uncompahgre district are described on pp. 259–261.

Geologic factors involved in the productivity of late Tertiary veins in sedimentary rocks differ in some respects from those applied to older deposits related to the Uncompahgre center of mineralization. The chemical reactivity and permeability of certain limestone and sandstone beds, which were of critical importance in the formation of bedding-replacement deposits during the earlier mineralization, became less important, as the later vein deposits were formed mainly by the filling of relatively open channels in the fissures. Furthermore the ore-forming solutions of late Tertiary age tended to migrate in these channels almost directly upward from deep sources towards the surface, either because the impermeable cap beds that confined ore channels of the earlier mineralization epoch were eroded during the Telluride epoch or because those preserved were breached by the strong fissuring of late Tertiary age. The attitudes of the sedimentary beds, therefore, commonly do not conform to that of the late Tertiary mineralizing channels, and, the more favorable beds, unless of great thickness, enclose a relatively small fraction of the channel as a whole. An exception to this condition is illustrated just south of Ouray by the quartzite beds of the Uncompahgre formation, which are not only of considerable thickness but are also steeply inclined.

SECTORS AND MINERAL ZONES OF THE SILVERTON CENTER

Outside the Silverton caldera, numerous mineralized sectors are distinguishable, within each of which the kinds of ore and the productivity of deposits differ in accordance with structural factors or a mineralogic zoning. These sectors may be defined by their relative positions at the sides or corners of the down-faulted block and according to prevailing directions of fissuring. The greater productivity of some sectors over others is attributable in part to critical geologic conditions. The more productive sectors include one that extends northwestward from the main center towards Telluride and from an outlying intrusive center near Sneffels (fig. 32, No. 5), one that extends southeastward near Silverton, and several, including the Eureka Gulch, Mineral Point, and Poughkeepsie Gulch districts, that extend northward. An outlying productive sector extends due west through Ophir towards the Mount Wilson intrusive center. The Hayden Mountain sector (fig. 32, No. 6), which lies outside the northwest corner of the down-faulted block, though between sectors of relatively high productivity, has not been productive. The possible reasons for its small output will be considered in the light of the local geology (pp. 253-259), as the sector directly adjoins the Uncompahgre district (pl. 53).

Deposits within the caldera with a few exceptions have been productive on only a small scale and have no bearing on the deposits near the Uncompahgre district. Those along the margins and outside may be divided for descriptive purposes into four zones: the marginal zone and the inner, intermediate, and outer zones of the surrounding area. They all possess certain structural or mineralogic differences. Deposits along the margins, as represented by those of the Red Mountain district, have been formed in highly fissured and faulted ground that contains numerous small, shallow, intrusive bodies and has been subjected to intense fumarolic alteration. Both vein and vertical-pipe deposits are common, but the mineralized pipes have yielded the major output. They grade structurally into deposits of the inner zone of the surrounding area. This inner zone may be defined as a strip within which some of the faults that bound the caldera, or the subsidiary faults and fractures related to them, form a well-defined structural network. This shattered zone is rarely more than a mile in width. The discontinuity of many fissures, the complexity of the fault movements, and the local influence of cross-faults on the main radial vein systems are all factors that either decrease the chances for ore bodies of commercial size or increase the difficulties of exploration. The ore shoots tend to have greater vertical than lateral dimensions. Base-metal ores predominate, though locally gold-bearing ores are found. In the sector west of Red Mountain the Treasury Tunnel mines, the Barstow, the Mountain King, and the Beaver and Belfast are representative mines and prospects of this zone.

An intermediate zone may be defined as extending outside the inner zone for distances ranging from 3 to 5 miles or more. Within this zone cross breaks related to the down-faulted block are absent or of minor importance, and the ore shoots in the main fissures have greater lateral continuity than those of the inner zone. The ores are complex, ranging in content from base-metal to precious-metal kinds. In the Telluride-Sneffels sector the bulk of the highly productive mines belong to this zone and include the Camp Bird, the Tomboy mines, the Smuggler Union, the Virginius, and others.

An outer zone may be defined in which the distinguishing features are a persistence of only the stronger veins and an essential absence of base-metal ores. In the northwest sector near Telluride this zone extends 7 or 8 miles from the margins of the caldera. The ores are mainly silver-gold in a quartz-carbonate gangue, but minor shoots of the more massive sulphide ores are also present. The Humboldt vein of the Smuggler Union mine and the Liberty Belle vein are representative deposits.

In the different sectors the widths of individual zones differ in accordance with local conditions surrounding the central down-faulted block, and in some sectors the zones appear to be imperfectly developed or even to be absent. The mineral zoning commonly shows minor irregularities, owing in part to variations in the strength and continuity of veins containing different kinds of ore and in part to the fact that many of the veins are compound and contain more than one class of ore.

MINERAL STAGES OF THE COMPOUND VEINS

The compounding of veins is an important factor in the structural control of ore deposition and appears to be closely related to zoning. The compound veins are formed of two or more separate veins or by separate stages of mineralization, so that the veins either lie side by side in the same fissure zone or the stages have been superimposed one upon the other. The effects have resulted primarily from reopening or renewed brecciation along an intermittently active zone of fissuring. The compound character of veins in the San Juan region has been recognized or emphasized by several geologists who have worked in this region and is recognized and used in practice by the prospector and mine operator. As a result of his work in the late 90's Purington said [13]

> Some of the occurrences noted above appear to indicate a succession of movements, with a second and even a third deposition of ore along the reopened fissures. * * * Especially the metallic sulphides of the Telluride veins appear to offer analogies in this regard, as two and sometimes three successive bands containing galena, iron pyrite, zinc blende, etc., may be seen in the same vein, the different bands appearing to offer physical characteristics by which they differ one from another.

This appears to be the first published recognition or suggestion that many of the common sulphides are repeated in the different stages or episodes of vein formation in this district. Spurr [14] regarded the Camp Bird vein as composed of three main veins. During the many years of silver mining in the early history of the San Juan region this vein was not mined, for the gold-bearing quartz, which lay to one side of the low-grade silver-bearing base metal vein was not assayed. During later operations in the mine the gold-quartz ore was selectively mined in certain parts of the shoots. Hulin [15] has recently emphasized the importance of these successive stages in the formation of veins, especially as applied to the structural control of ore deposition. He cites the Sunnyside vein, which lies in the northeast sector of the Silverton center, as an example in which he recognizes three major stages of fissuring and vein growth. Because there existed divergent views among geologists as to the importance or possible correlations of these different stages from one place to another, and particularly as a consequence of Spurr's work on the Camp Bird vein, the writer has given special attention to the areal and depth

[13] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: U. S. Geol. Survey 18th Ann. Rept., pt. 3, p. 799, 1898.

[14] Spurr, J. E., The Camp Bird compound vein dike: Econ. Geology, vol. 20, pp. 115-152, 1925.

[15] Hulin, C. D., Structural control of ore deposition: Econ. Geology, vol. 24, pp. 15-49, 1929.

distribution of the different stages represented by the compound veins. A number of the stages are definitely recognizable over essentially entire sectors of the Silverton center and indicate that the compounding effects are evidently related to structural disturbances of widespread influence. Because of the repetitions of some of the common sulphides in the different stages, as first recognized by Purington, compounding of the veins must be taken into account during the microscopic examination of ores and their gangues, especially if the sequence of ore minerals is to be determined by microscopic methods, as the examination of random specimens collected without regard to possible repetitions leads to incorrect conclusions.

Mineralization in the northwest or Red Mountain-Telluride-Sneffels sector of the Silverton province took place in three or four main stages, including one that seems to be confined to the innermost zones. Some of these stages may be locally difficult to distinguish on the basis of mineral composition alone and are clearly identifiable only where the structural relations are clear. A number of the minerals, as quartz, pyrite, and some of the carbonates, are common to several if not all stages, but are represented in different proportions in each. Other minerals, as rhodonite, rhodochrosite, barite, and fluorspar, are diagnostic of only one or two stages. The common base-metal sulphides sphalerite, chalcopyrite, and galena decrease markedly in succeeding stages after their first introduction in the base-metal stage.

A special phase of mineralization that is essentially confined to the margins of the caldera is represented by the siliceous, kaolinitic, and alunitic alterations of the Red Mountain district. This represents the effect of fumarolic emanations from comparatively shallow centers of igneous activity and in sequence but not in mineralogy corresponds to the early stages of rock alteration of the inner zone of the adjoining sector. Special conditions of comparatively low pressures and moderately large temperature ranges prevailed in this marginal area, but further discussion of these need not be pursued for the purposes of this review. The principal feature of the marginal zone that bears most directly on the mineralogy of the outer zones is the so-called "telescoped" character of the associated ore deposits, which at very moderate depths show a pronounced change in mineral composition.

In the northwest sector two or three stages of mineralization are commonly recognizable in many veins (fig. 35), though less commonly are all fully represented at any one place. Also in places where the several stages have been superimposed because of brecciation, replacement, and infiltration of later solutions into earlier deposits, the results may prevent local recognition of the separate stages as distinct entities. At very few places, however, is all evidence of refissuring lacking, and even those are along short intervals of veins that are clearly compound elsewhere.

The earliest stage, which was most active in the inner zone of the sector, is represented by the alteration of the wall rocks along fissures to sericite, pyrite, ankerite, and other less diagnostic minerals. It was accompanied by the formation of highly pyritic veins in parts of some fissures. This class of ore is usually of minor economic importance, but within and along the margin of the caldera some of the pyritic veins have been enriched by the later introduction of

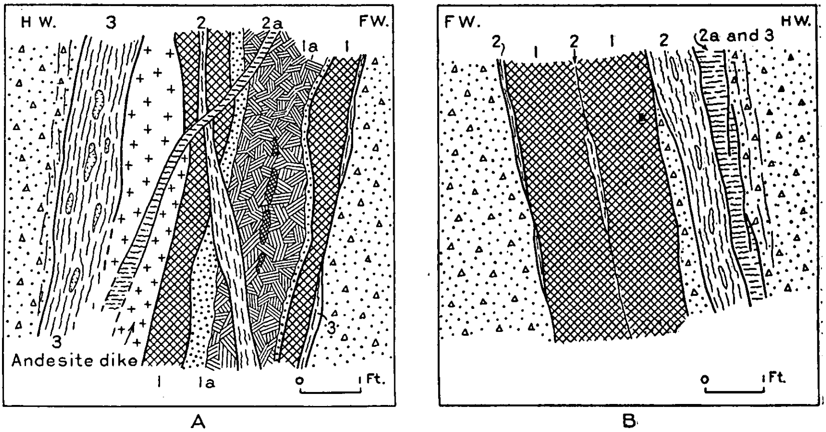

FIGURE 35.—Typical structure of late Tertiary compound veins in the intermediate zone of the Sneffels district. Both hanging wall (HW.) and footwall (FW.) of veins are San Juan tuff.

A. Sketch of back of stope, Highland Chief vein. 1, Base-metal vein with border of quartz containing pyrite, sphalerite, and galena, grading inward to massive mixed sulphide; 1a, quartz with pyrite and sphalerite forming narrow border, with inner part of vein chiefly barite and massive galena; 2, quartz with rhodochrosite and narrow crinkly bands of sulphides, mainly pyrite and sphalerite; 2a, gray and white ribbony or banded quartz with pyrite; 3, white chalcedonic quartz with pyrite, and crystal-lined vugs.

B. Sketch of a breast, Cumberland vein, Revenue tunnel workings. 1, Base metal ore, mainly the massive sulphides, pyrite, sphalerite, and galena (silver-bearing), with minor gangue of quartz, ankerite, barite, sericite, and calcite; 2, quartz and rhodochrosite vein with narrow crinkly bands of sulphides of pyrite and sphalerite, with some chalcopyrite, and galena (rhodochrosite and galena mainly in center of vein); 2a and 3, granular quartz and sericite (containing small specks of pearceite), argentite (?), and some pyrite (also gray banded quartz with narrow streaks of fine pyrite, some of which is gold-bearing, and late barren quartz with vugs belonging to stage 3).

free gold. Some of the gold is found in crystal-lined cavities of the massive pyrite together with small crystals of the common base-metal sulphides.

The first important stage of the inner zone is represented by complex ores of zinc, lead, and copper in a quartz gangue. Their sulphide contents are relatively high, but their precious-metal contents are low. Base-metal ores of this class extend outward into the intermediate zone in many veins and locally, as in parts of the Camp Bird vein, are associated with massive rhodonite. In the outer part of the intermediate zone the base-metal ore becomes less prominent, and the sulphides are associated with a more abundant gangue of quartz, barite, or carbonate, such as rhodochrosite. These changes are accompanied by an increase in argentiferous galena and tetrahedrite, so that the ore becomes essentially a lead-silver ore. The timing of the tetrahedrite-bearing sulphide stage of this zone with respect to the typical base-metal ore of the inner areas is not exactly established, but it is believed to represent probably a substage of the base-metal mineralization. Thus some veins of intermediate position contain the low-grade early sulphides pyrite, sphalerite, and galena in a quartz gangue whereas the later sulphides, consisting predominantly of galena, were preceded by a reopening of the vein walls and the deposition of barite as a gangue mineral (fig. 35, A).

The second main stage in all zones is represented by quartz veins, which in the inner zone and parts of the intermediate zone contain minor amounts of chalcopyrite and other base-metal sulphides. In the Camp Bird and several other veins in the inner part of the zone, specularite may also be present in ore of this stage, but except locally this mineral is neither abundant nor characteristic. The introduction of specularite during this stage may in some way be related to the concentration of copper, for commonly chalcopyrite rather than pyrite is the dominant early sulphide of this stage. In the central part of the intermediate zone the second or quartz stage is characterized by rhodochrosite in small proportion, and in such vein matter sphalerite and chalcopyrite, together with some galena, constitute the characteristic sulphides. Some gold and silver were introduced with minor sulphides late in this stage. The higher-grade gold-bearing quartz was deposited after a renewal of fissuring and appears to represent a substage or separate major stage of mineralization. Some of the gold-bearing quartz is accompanied by adularia, clay minerals, and calcite or fluorite. In the outer zone the quartz veins contain only small or negligible amounts of common sulphides but more conspicuous amounts of tetrahedrite, stephanite or pearceite, and pyrargyrite and late free gold. Locally the silver-bearing and gold-bearing parts of the quartz were deposited during separate substages, gold being the later, and in this respect compare with the main quartz stages of the Camp Bird mine. In the outer zone calcite may be an important constituent of the gangue in the silver-gold ores.

The latest or third major stage is represented by barren or low-grade quartz, locally accompanied by additional fluorite in the inner or intermediate zones. Pyrite in minor amount is commonly the only recognizable sulphide that accompanies this quartz. Fluorite veins, locally forming small shoots of commercial fluorspar, were evidently formed during this stage, as most of the larger quartz veins have local pockets of fluorite.

Carbonates occur not only as crustifications in all stages but are locally important constituents of the productive quartz stage of mineralization. In general the carbonates exhibit a zonal distribution, with ankerite confined to altered rocks of the inner zone, rhodochrosite and manganiferous calcite to the intermediate zone, and with dolomite and calcite represented most abundantly in the intermediate and outer zones though not confined to this position.

STRUCTURAL CONTROL OF ORE DEPOSITION

The local control of ore deposition and distribution of ore shoots of higher and lower grades in any mineral zone appears related primarily to the timing of local fissure opening with respect to the successive stages of mineralization. Parts of a fissure zone opened only during the base-metal stage contain little gold and, except in the outer parts of the intermediate zone, little silver; however, because of the widespread influence of the stronger stages of fissuring, many of the more persistent veins of the intermediate zone contain minerals of all stages at one position or another. Where repetitions of movements of like kind have occurred the deposits of the different stages are likely to be coextensive. In the Camp Bird vein, where the successive movements were in part of a like kind, the gold-quartz vein matter is for the most part coextensive with the base-metal vein. In some sectors where the growth of fissure zones appears to have advanced outward from the structural center with successive stages of fissuring, the part of a zone that is farthest from the center may contain a relatively greater bulk of the late stage minerals. Thus in some veins late barren quartz and carbonate are the only vein filling in the outermost zone, though nearer the structural center these minerals overlap the deposits of an earlier stage. This change in composition is particularly applicable to some veins in the area immediately adjacent to the Uncompahgre district and is considered at some length later.

Replacement processes were doubtless important in the formation of the veins,[16] as both wall rocks and shattered material within the fissure walls have been replaced by ore or gangue, and ore minerals of one stage have been replaced by later ones of the same stage or by those of later stages. The selective precipitation of gold or silver minerals by massive sulphide ore was possibly a large factor locally in the formation of ore shoots, but, on the whole, replacement processes were apparently less effective as controlling factors of ore deposition than the structural disturbances that provided new channels for the infiltration of solutions.

[16] Moehlman, R. S., Ore deposition south of Ouray, Colorado: Econ. Geology, vol. 31, pp. 489-502, 1936.

MINERAL ZONING IN DEPTH

Changes in grade of ore and the zoning of the minerals in depth is most pronounced along and near the margin of the down-faulted block, whereas in the intermediate and outer zones changes in depth are very much less conspicuous. Ore found in the chimney deposits of Red Mountain shows the most abrupt changes with depth from argentiferous galena near the surface to exceptionally high grade silver-copper ores at a depth of several hundred feet and to low-grade pyritic ore within a thousand feet. The gold-bearing quartz-adularia veins, as in the Camp Bird mine, on the inner edge of the intermediate zone also show definite impoverishment in depth, but not as abruptly as the Red Mountain deposits. In the outer parts of the intermediate zone high-grade gold shoots have been mined without appreciable impoverishment down to the basement rocks beneath the volcanic formations.

At greater depth, structural changes involving the length and width of high-grade shoots rather than decreases in precious-metal content seem to be responsible for the most abrupt diminution in quantity and grade of ore. In general where the width of the ore shoot decreases the grade also falls, but there appear to be examples of strong fissures that continued in depth, though the grade of ore diminished, especially where the vein passed into the sedimentary beds. Lack of competency of the beds to support clean-cut wide fissures and consequent constriction of the solution channels in the fissured zone appears to account for these unfavorable veins. The more massive sedimentary rocks, including the thicker sandstones, quartzites, limestones, and less bouldery facies of the conglomerates, where likely to be cut by persistent fissures, should show only gradual and relatively small effects on the continuity of ore channels. The shales and weak shaly sandstones may be expected to cause more abrupt changes in channel form and hence in the grade of ore. The most favorable conditions for deep exploration on ore channels will be found where volcanic rock rests directly upon the more massive sedimentary rocks, that is, where intervening thick bodies of shale or other incompetent beds are not present.

HAYDEN MOUNTAIN SECTOR

The Hayden Mountain sector of the Silverton province of mineralization adjoins the Uncompahgre district on the south and southwest (fig. 32, No. 6, and pl. 53). This sector is defined by its position near the northwest corner of the down-faulted central block and by its fissures and sheeted zones that strike N. 10°–30° W. and for the most part dip steeply northeastward. Veins are found in the fissures that trend N. 15° W. or along the sheeted zones of like trend, and also in others of northeasterly or easterly trend that were perhaps formed by renewal of movements along nearly parallel zones of weakness in the basement rocks. The sector differs structurally from certain others in the absence of an outlying intrusive center such as that represented by stocks of Mount Sneffels (fig. 32) and Stony Mountain in the Telluride-Sneffels sector, those of the Ophir sector, and those of the Mount Wilson group.[17] It is noteworthy that a number of the more productive sectors have such outlying intrusive stocks and that the arrangement of their vein systems is controlled by that of preexisting dike rocks, even though some of the better veins may not follow the walls of the dikes.[18] In contrast, the less productive Hayden Mountain sector contains only a few late Tertiary dikes of appreciable continuity, and it may be inferred that forces producing the local fracture pattern were not initially strong enough to tap the very deep igneous sources. This evident weakness of the forces that produced initial as well as subsequent fissuring may be attributed to certain rather well defined features in the structural setting of the sector. Thus the position of the sector at the northwest apex of the triangular central block is perhaps one of the more obvious reasons for the weakness of fissuring.[19] It is reasonable to suppose that forces resulting from flexing of the crust would not be effectively transmitted from the center in apical directions or that such forces as were effective would be shortly dispersed by their fanwise divergence from the narrow apex (fig. 32). Once an initial weakness of fracturing was locally established, whatever the cause, the upsurging of molten igneous material would be hindered; furthermore later forces that caused refissuring during the vein-forming period would be similarly weak within the sector. In these respects the Hayden Mountain sector has a unique structural setting and must be considered on its own merits as a mining district, irrespective of adjoining sectors.

Because of the prevailing small size of veins and the low grade of ore found thus far, the Hayden Mountain area has received only minor development work; on the other hand, owing to the proximity of the northern part of the sector to the Uncompahgre ore deposits in sedimentary formations of the Uncompahgre district, there has existed a justifiable belief that exploration in this sector has for the most part tested only the younger Tertiary formations and has failed to prove the absence of commercial ore bodies in the underlying rocks. To some extent justification for this belief is now offset by the fact, only recently recognized, that the deposits of the Uncompahgre center are older than those of the Silverton province of mineralization and their distribution is controlled by structural features of earlier and different

[17] Burbank, W. S., Vein systems of Arrastra Basin and regional geologic structure in the Silverton and Telluride quadrangles, Colorado: Colo. Sci. Soc. Proc., vol. 13, No. 5, pp. 171–173, 1933.

[18] Idem, pp. 182–185, 189, and 195–196.

[19] Idem, p. 181.

origin. The expectancy of finding ore deposits related to the Uncompahgre center is very small in that part of the Hayden Mountain sector south of latitude 38°, as it is so far from the structural features that controlled the distribution of these deposits (pp. 213–218). The only consistent plan of prospecting, therefore, is to follow the few stronger late Tertiary veins downward with the hope that they may be productive not only in the volcanic rocks but in the underlying sedimentary rocks also.

The late Tertiary ore deposits of this sector are found not only in the mountain mass called Hayden Mountain but also to the north across Canyon Creek and include most of the veins in the volcanic and sedimentary rocks that form the southeast slope of Whitehouse Mountain (pl. 53). This area has not been mapped during the present resurvey, but a few of the veins on the lower slopes near Canyon Creek have been mapped and examined.

The geologic structure and formations along north-south directions through Hayden Mountain are shown in plate 53, section A–A′, and in plate 54, *F*, which is taken about 1 mile west of section A–A′, and nearly parallel to it. These illustrate several geologic features of particular significance, bearing on the possible distribution of ore shoots in the late Tertiary veins. The first of these is the character and structure of the rocks composing the pre-Cambrian Uncompahgre formation, which underlies both the Paleozoic formations and the San Juan tuff. The principal structural feature in the pre-Cambrian beds is a compressed synclinal fold, the slate core of which plunges and widens westward, as shown by comparison of the two sections mentioned above. South from this synclinal axis the beds are composed of several alternating wide bands of quartzite and slate that dip steeply to the north or northwest. Where the fissuring forces have been sufficiently strong to rupture the quartzite beds in this formation they are favorable host rocks of the veins. Also, in some of the narrower slate bands strong fissures maintain a fair width, especially where they strike across the trend of the slate, though the veins are narrower than in the quartzite. Veins exposed along the Uncompahgre Canyon and as far as the vicinity of Bear Creek (pl. 53) were mineralized during two stages, an early stage of base metals with quartz and rhodochrosite gangue and a later stage of quartz that is commonly barren or shows only traces of gold. In several representative veins the barren quartz extends much farther northward than does the base-metal ore, indicating evidently that the fissures were intermittently reopened and extended during successive stages of activity. In their northernmost parts some of the veins end in tight brecciated zones in slate and others fail to penetrate adjacent quartzite bands, evidently because the rupturing force died out northward. So far as now known, only a few of the late Tertiary veins penetrate northward across the main syncline in the slate. One of these, which contains base-metal ore, lies on the east side of the Uncompahgre Valley where the syncline is shallower and more highly compressed. West of the Uncompahgre Canyon several veins extend across the syncline, but their northerly extensions across Canyon Creek consist of barren or very low grade quartz with pockets of calcite or fluorspar, or of barren calcite only. Narrow seams of galena are found locally alongside or near the stronger fissures showing that the first stage of opening formed merely a sheeted zone, in the cracks of which the latest base-metal sulphide was deposited. The openings in which the quartz was deposited form continuations of the stronger fissures and extend several miles farther north across Canyon Creek, but, as these parts of the fissures were evidently opened after the period of valuable ore formation, they are of no worth as sources of ore.

An additional factor in the distribution of favorable zones is the wedge of Paleozoic sedimentary rocks that lies between the pre-Cambrian basement and the San Juan tuff (pls. 53, sec. A–A′, and 54, *F*). The beds in this wedge dip westward and northwestward and are beveled by the Telluride erosion surface beneath the San Juan tuff, thinning out eastward and southward along the northward-trending boundary line of the Paleozoic rocks shown on plate 53. The Paleozoic rocks consist mainly of the Hermosa formation whose lower part includes several hundred feet of shaly beds, which are unfavorable to the persistence of well-defined veins; however, this formation is underlain by the Ouray and Leadville limestones, which total 150 to 300 feet in thickness and form an environment that should be favorable to ore deposition.

It appears from the different structural factors mentioned above and from the general weakness of fissuring in the northeastern part of the Hayden Mountain sector that there is a very restricted belt within which all the geologic conditions combine to favor a reasonable continuity of ore shoots in length and depth. This belt lies west of the Uncompahgre River and mostly south of latitude 38° and is scarcely more than a mile wide. Within this area the wedge of Paleozoic rocks is thin, the basement rocks are predominantly quartzite, and, as shown by surface exposures of the veins, more than one stage of mineralization is commonly represented. Representative veins include those of the Sutton group, the Combright and Daniel Bonanza groups, and some farther south, such as the Dunmore property (pl. 53, Nos. 37, 38, 39). Veins of the New Mineral Farm group (pl. 53, Nos. 40, 41), somewhat farther west, are on the western fringe of the more favorable zone, but, as the openings are along the valley of Canyon Creek just above the wider and deeper parts of the slate syncline (pl. 54, *F*), extensive exploration towards the south is required to penetrate more favorable ground. None of the veins mentioned has yet supported a fair-sized profitable enterprise, although small operations in some of them have been remunerative. Only silver and gold ores have been shipped. Some veins contain base-metal ores, but little or no attempt has been made to mine them on a commercial scale.

The value of veins in this part of the sector is best indicated by the extent, mineral composition, and grade of the few deposits that have received the most development. The only distinct stages of mineralization either widely or well exposed in this sector are a base-metal sulphide stage and late barren quartz, fluorite, or carbonate stages. An early pyritic ore, formed either by replacement or by filling and found in parts of many veins, has no value except where it has been modified by a later introduction of chalcopyrite and gold. In many of the sheeted or weakly fissured zones of the sector this early pyrite and the late barren quartz are about the only indications of mineralization. Although some exploratory work has shown that such zones may locally contain ore shoots of other mineral stages, only the strongest zones appear to warrant attention. The main stage of mineralization, which was especially active in the eastern part of the sector along the Uncompahgre Canyon, is represented by chalcopyrite, sphalerite, and galena in a gangue of quartz and rhodochrosite. These minerals are accompanied by very little silver and gold. The less widely distributed higher-grade silver-bearing ores contain tetrahedrite in conspicuous amount associated with either quartz or barite gangue, and possibly represent a late episode of the base-metal stage. In other places quartz with a little chalcopyrite follows the base-metal sulphide or the rhodochrosite stage, but, though it might be supposed to represent a gold-quartz stage, there is no conclusive evidence that it does. The final stage, represented by barren quartz with a little pyrite, was introduced by a widespread renewal of fissuring, and the quartz was locally followed by fluorite or calcite. Except for the shoots of fluorspar the vein matter of this later stage appears to be valueless.

The most extensively mined veins in the northeastern part of the sector belong to the Sutton group. Concentrates produced in the Sutton flotation mill from about 4,400 tons of crude ore contained about 0.02 ounce of gold, about 6 ounces of silver to the ton of crude ore treated, and less than 0.5 percent of copper and lead. The mill recovery is not known, and the zinc was not saved. It is said that in the upper and older workings of the mine the grade of ore was higher, because it contained either more gold or more silver-bearing tetrahedrite; but the streak of silver ore was narrow. Small selected shipments from the mine contained as much as an ounce of gold and more than 50 ounces of silver to the ton. The heavier base-metal ores of the Combright group have a content, shown by sampling, of about 0.02 ounce of gold, 3 ounces of silver, 3 percent of lead, 4 percent of zinc, and 0.5 percent or less of copper. As shown either by mining development or by surface cuts the ore shoots of these properties have a length of at least 400 or 500 feet and a width of 1 to 5 feet.

Veins farther west in the central part of the Hayden Mountain sector, represented by the Thistledown (pl. 53, No. 42), show some differences in mineral composition. The sulphide ores show an increase in the relative proportion of galena with a decrease in the proportion of manganiferous carbonate, and the later barren quartz or fluorite commonly predominates in bulk over the earlier sulphides. The Thistledown, with a development of about 2,500 feet of drifting, is said to have exposed only a narrow shoot of galena that was 150 feet long and contained 6 to 7 ounces of silver to the ton. The sulphide vein ranges in width from a few inches to a foot. Lenticular shoots of fluorite occur along the wall of the vein. The Hayden vein of this group was operated primarily for its lenticular shoots of fluorspar, which were several feet thick. Where the vein was wide the fluorspar was very pure, but quartz was also present along most of the vein. An attempt was made to commercialize the fluorspar vein during the World War, but operations were not successful, owing conceivably to difficulties in selecting spar free from quartz in the narrower parts of the fissure.

In the westernmost parts of the Hayden Mountain sector the veins become somewhat stronger again in spite of an increase in thickness of the underlying wedge of Paleozoic rocks to 2,500 feet or more. Their strike is N. 20°–35° W., approaching the northwest strike of the Sneffels sector. The principal sulphide minerals are pyrite, chalcopyrite, galena, and sphalerite, which occur chiefly in a quartz gangue. Free gold has been found in these veins, but apparently the gold shoots are not at all coextensive with the main masses of quartz, as the reported finds occurred in small relatively rich pockets. The late-stage quartz is abundant locally, but fluorite is less conspicuous or absent. Although small shipments of ore have been relatively high in gold and silver content, the production of the remaining ore has been too small to warrant estimates of grade though the average grade is believed to be low. Some of the stronger veins cross Canyon Creek and extend along the slopes of Whitehouse Mountain (pl. 53, No. 44). The Gem City and Angel Mining Co.'s properties, which also lie on the slope of Whitehouse Mountain, contain gold-bearing veins. The writer is not familiar with these properties, but a small shipment from the Angel group shows the gold to be associated with the chalcopyrite in a siliceous gangue.

Some general conclusions regarding the Hayden Mountain sector may be briefly summarized. Those parts of the sector adjacent to the Uncompahgre district belong to the intermediate and outer zones. The average fissuring is comparatively weak; the strongest stages of fissuring coincide with the early stage of base-metal ore deposition and with the latest stage of barren gangue or fluorite deposition. The extreme eastern and western parts are the more strongly fissured and mineralized areas. The fluorspar veins of the central part are apparently not of sufficient average width to form commercial deposits under ordinary market conditions. Geologic conditions in the eastern part are the most favorable for the extension of explorations on some of the stronger veins into the basement formations, though there is little likelihood of marked improvement in the ore bodies except along a restricted zone where the Ouray and Leadville limestones form the bulk of the Paleozoic wedge. In the westernmost part of the sector conditions appear unfavorable for deep explorations beneath the base of the thin Jurassic sandstones and limestones, which immediately underlie the Telluride conglomerate (pp. 211, 212). Final conclusions on the more southern parts of the sector and on the extreme north-central parts, adjoining Whitehouse Mountain, will be reserved for more comprehensive reports on the late Tertiary mineralization of the region.

SECTOR EAST OF THE UNCOMPAHGRE CANYON

The sector of the Silverton province that lies east of the Uncompahgre Canyon appears to represent a marginal part of the Bear Creek-Poughkeepsie Gulch sector (fig. 32). As the geologic mapping of this sector has not been completed the relations of the local deposits to the structure of the sector as a whole and to the zonal distribution of the ores cannot be treated in this report. It may be noted, however, that the veins along the Uncompahgre Canyon and on both sides of it have some mineralogical features in common, so that a separation of veins in the northeastern part of the Hayden sector from those east of the canyon is rather arbitrary. Thus the relatively conspicuous rhodochrosite in veins of the northeast part of the Hayden sector suggests a close affinity with the veins east of the canyon; on the other hand, veins in the extreme western parts of the Hayden sector appear more closely allied to veins of the Sneffels sector. Until the geologic work is completed in all sectors, the affinities of deposits in overlapping zones of the different sectors cannot be determined.

In the sector east of the canyon, the principal veins are found in the walls of the Amphitheatre east and southeast of Ouray (pl. 53, Nos. 31–35). Most of them strike north to N. 30° W. and dip steeply to both the east and west. The geologic conditions in general are much like those in the eastern part of the Hayden sector. South of the northeastward-trending boundary of the Paleozoic formations, shown on plate 53, the volcanic rocks rest directly on the pre-Cambrian formations. North of this boundary is a northward-dipping wedge of Paleozoic and Mesozoic strata between the volcanic and pre-Cambrian rocks. The thickening of this wedge northward appears to have affected the strength of late Tertiary fissuring, as the younger fissures are only weakly mineralized north of the Amphitheatre. East of the Uncompahgre River as far north as Dexter Creek there is a feeble system of late Tertiary fissures of northerly trend, but the vein filling in them is mostly barren quartz or barite with a few widely scattered small pockets of galena. Also in the Blowout, which marks the center of mineralization during the Uncompahgre epoch, a few barite and quartz veins cut through both the older pyritized formations and the San Juan tuff, which overlies the altered rocks unconformably. Here as elsewhere overlapping veins of the two ages are distinguished with some difficulty unless structural relations are apparent. Criteria for distinguishing certain barren gangues of the two epochs have not been found. If other data are lacking the relation of the veins to the structure pattern is probably the most useful criterion. In addition the older veins appear to be characterized by ankeritic carbonates, whereas the younger veins more commonly contain rhodochrosite. West of the main canyon and north of Canyon Creek, the filling of the set of fissures that trend N. 30° W. is mainly barren scalenohedral calcite (dog-tooth spar) or quartz, evidently of the late Tertiary epoch because of its continuation in the Hayden sector, though some fissures of this set originated during the earlier epoch of mineralization as shown by relations of the older dikes to them.

The Portland vein (pl. 53, No. 31) is representative of the veins east of Ouray in the Amphitheatre. The deposit consists of a complex base-metal and precious-metal ore in fissures that cut the San Juan tuff and the immediately underlying Paleozoic limestones. Laterally for short distances near the contact the ore has replaced basal layers of the tuff and underlying brecciated limestone. Because the tuff here is locally calcareous and contains thin lenses or beds of limestone, it is more replaceable than elsewhere. The workings of this mine are in a favorable zone of the sector, where limestones predominate in the Paleozoic wedge. Though a shaft has been sunk to a depth of 100 feet in the limestone, most of the small production of the mine has come from shallower stopes. The ore minerals are pyrite, sphalerite, galena, and chalcopyrite, in a gangue of silicified limestone, quartz, barite, and rhodochrosite or manganiferous carbonate. There is a later generation of comby quartz and pyrite with kaolin that may possibly represent gold-bearing vein matter. A still later and more abundant drusy quartz together with coarse calcite represents the last barren stage of mineralization. In shallower parts of the mine, the vein matter is oxidized and contains black oxide of manganese. Shipments of this class of ore, which evidently composed the main production credited to the mine, contained from ⅛ to 1 ounce of gold, and from 20 to 90 ounces of silver to the ton. The steep, fissured cliffs of San Juan tuff that rise abruptly several thousand feet above the mine apparently served as a catchment area for surface waters, which descended through the primary shoot of ore at the base of the slope and brought about the local oxidation and enrichment. Small shipments of lower-grade, less oxidized or unoxidized ore contained from 0.02 to 0.20 ounce of gold and 16 ounces of silver to the ton and about 3.5 percent of lead with some copper. Apparently the lowest-grade zincy ore has been sorted out and piled on the dump. The ore shoot exposed is about 400 feet long and is evidently confined to a small vertical range near the contact of the andesitic tuff and the limestone. Drifting has been extended about 400 feet beyond this shoot to the southeast, but other shoots have not been discovered. Other nearby veins such as the Denver and Oak Street, which consist mainly of quartz, are said to have produced a little gold.

Owing to the fact that the late barren quartz and carbonate extend farthest north in the veins of the Amphitheatre, as they do in those of the Hayden sector, the most favorable direction for prospecting these veins is towards the south; however, in this direction the Paleozoic limestone may be expected to wedge out, so that the more favorable rocks likely to be encountered are the San Juan tuff and the underlying pre-Cambrian quartzite. Few of the veins have the topographic setting of the Portland that favored local enrichment, and developments southward should encounter only primary unoxidized ores. At least beyond the extension of the Ouray fault, about 2,500 feet south of the Amphitheatre (pl. 53), the basement rock is probably mainly quartzite. Bands of slate in the quartzite trend directly across the strike of the veins and therefore should not appreciably affect the stronger fissures. The main syncline of slate west of the canyon pitches about 30° west and narrows abruptly eastward, so that it should not be an appreciable factor in the structural setting south of the Amphitheatre.

VEINS AND DIKES OF THE COW CREEK CENTER

The late Tertiary Cow Creek center lies 4 or 5 miles to the northeast of the Uncompahgre district, but several of the longer dikes from this center extend to the east border of the district (pl. 53, Nos. 34, 45, 47). The southernmost dike exposed in the walls of the Amphitheatre east of Ouray (pl. 53, No. 35) is the only one appreciably mineralized. Pockets of a complex base-metal ore with some gold content are said to occur along the dike walls. As this dike lies only a short distance north of and roughly parallel to the Paleozoic boundary (pl. 53), it lies within a zone in which the Paleozoic wedge may not exceed 400 or 500 feet in thickness. Strong ore shoots, therefore, if proved for appreciable length, may reasonably be prospected in depth; however, as the Paleozoic beds west of the Amphitheatre plunge rather steeply to the north, this structure may continue for some distance northeastward, so that the depth to the pre-Cambrian basement may conceivably be greater than 500 feet from the lowest outcrop of the dike. On the other hand, if the plunge of the beds decreases northeastward, the depth to the basement may be less in this direction. The actual condition at the head of the Amphitheatre is obscured by glacial debris.

The northernmost dike (pl. 53, No. 45), locally known as the Calliope, lies about 500 feet north of the Calliope vein and trends nearly east. Although the walls of this dike in the San Juan tuff are locally fissured, mineralization has been comparatively feeble. The dike parallels the Calliope vein, which belongs to the Uncompahgre epoch of mineralization, and the two have been considered closely related; but their parallelism is accidental or controlled by a local tendency for fissuring in the basement rocks in this direction. The Calliope dike is very much younger than the Calliope vein.

The Sunday vein (pl. 53, No. 46) cuts the San Juan tuff about 3 miles east of the Uncompahgre Valley in the Dexter Creek drainage area. This vein is probably related to the Cow Creek center. The vein fissures strike N. 25°-30° E. and run diagonal to the easterly trend of the main dikes in this area. The San Juan tuff along the Sunday fissure zone is highly silicified and is either locally replaced by sericite or beidellite (?) for widths of as much as 5 feet or cut by numerous small quartz stringers over a wider zone. The sulphide content of the altered rock and vein matter is low and the mineral composition simple. Pyrite in small crystals and sphalerite in minor amounts constitute the principal sulphides disseminated through the silicified rock. Proustite and native gold are the only other minerals recognized microscopically. The ore assays from a few tenths to half an ounce of gold and as much as 9 ounces of silver to the ton. The copper, lead, and zinc content of the ore is negligible, and smelter tests showed only about 4 percent of iron. Development work on the vein is insufficient to determine the extent of ore shoots, but further prospecting of this or other veins of its kind appears justifiable in view of the comparatively simple character of the ore and the possibility that fairly large bodies may be proved. Inaccessibility of the area surrounding the Cow Creek center is a factor in the rather meager development work that has been done.

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